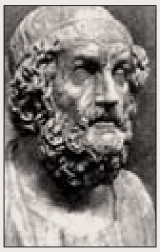
GNSS Trilogy: Our Story Thus Far

GLEN GIBBONS EDITOR, *INSIDE GNSS*

"Tell me, O muse, of that ingenious hero who traveled far and wide after he had sacked the famous town of Troy. . . ."



Oops! Wait a minute! Hold your horses there, Homer; it's not *that* Odyssey. We're talking about the GNSS odyssey.

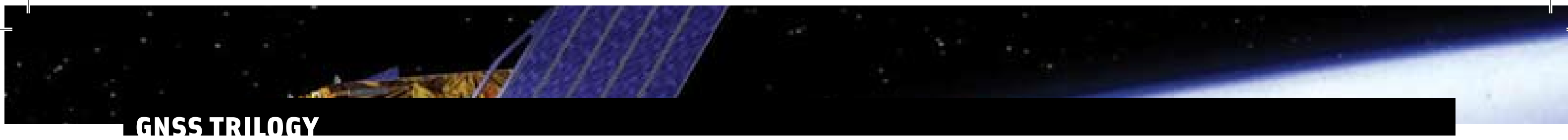
More than 30 years in the making, not a mere decade. And its heroes didn't simply drift idly about the wine-dark Mediterranean enjoying the rosy-fingered dawn like Odysseus and his buddies. The GNSS crew — GPS, GLONASS, and now Galileo — has traveled from California to Colorado to Brussels, Moscow, India, Kazakhstan, Beijing, Tokyo, and beyond!

Oh, sure, Circe and Polyphemus and the ghost of Agamemnon made for some rough customers, but try launch failures, dissolution of a nation, the labyrinths of Brussels and Washington, and that most frightful ogre: the Office of Management and Budget.

No, it's not The Lord of the Rings or even the first three installments of Harry Potter's adventures, but the GNSS trilogy has produced a fascinating story line and introduced a kind of magic to the real world. It has created a vast popular utility as profound in its own right as the Internet or mobile phones — with the ability to discover connections among people, places, and things that were heretofore impossible and nearly unimaginable.

But getting there hasn't been easy. Read on…

Russian Federal Space Agency/LockheedMartin/ESA



Will Success Spoil GPS?

The more that the Global Positioning System has exceeded the expectations of its creators, the more challenges it has faced.

Like some behemoth rocket ship launched in the 1970s, the Global Positioning System sails on through an expanding universe of users and applications, seemingly imperturbable, successful beyond the expectations of its creators, an enormous momentum carrying it into the third millennium.

To all appearances, GPS is prospering more than ever: a second full signal (L2C) is becoming available to civil and commercial users, a denser ground monitoring system being built out, improved accuracies squeezed out of the algorithms and operational practices at the Master Control Station in Schriever Air Force Base, prices dropping on products with more features and functions than ever, hundreds of millions of receivers in use around the world. A follow-on generation (Block IIF) of satellites with a third civil signal (at the so-called L5 frequency) is being built by Boeing for launch beginning in 2007.

NASA

Since its first satellite launch 28 years ago, GPS has blazed a trail for satellite-based positioning, navigation, and timing. Thanks to GPS, global navigation satellite systems have gone from being a technological unknown to becoming a widely recognized utility. GPS, a model and inspiration to its imitators across the oceans.

Or is it?

In fact, for some years now GPS has been a victim of its own success. Performing better than advertised, the system has suffered from budgetary pilfering for other defense programs and risks getting lost in the shifting maze of diffuse dual-use management responsibilities.

"History has shown that the Air Force has had chronic difficulty in adequately funding GPS, even in the absence of the more expensive GPS III satellites," observes a high-level Defense Science Board (DSB) task force report on GPS issued late last year. "If the Air Force continues to use its GPS investments as a funding source to offset other space/aircraft programs, then GPS service continuity will remain in jeopardy even without the more costly GPS III." (See article on page 42.)

Meanwhile, an Air Force Space Command projection puts the worst-case probability of the GPS constellation falling below its fully operational capability (FOC) of 24 space vehicles sometime between 2007 and 2012 as 20–40 percent. Indeed, the task force argues for a 30-satellite constellation to ensure robust coverage in "challenged environments."

The timelines for the last three GPS satellite development and launch programs — Block IIR, IIR-M, and III — all slid to the right, as they describe schedule delays these days.

Intermittently starved for fuel, with sporadic guidance from the helm, will new resources reach the system before its speed inevitably begins to slow, threatening its being overtaken by other GNSS vehicles?

Okay, that's the bad news.

The good news is that no one connected to the program wants to let one of the world's leading U.S.-branded utilities slip into the shadow of the other GNSSes under development. And steps are under way to ensure that doesn't happen.

New Game Plan

A long-awaited next-generation program, GPS III, spent well more than hundred million dollars on conceptual studies and several years jogging in place before receiving a renewed go-ahead from the Department of Defense (DoD). The Fiscal Year 2006 (FY06) federal budget allocated $87 million for GPS III. The FY07 budget will be finalized soon in Washington, and current indications are that GPS Block III will receive at least $237 million, according to the GPS Joint Program Office (JPO). Of course, GPS III funds have been zeroed out before.

Current plans call for GPS JPO decision this summer that chooses among proposals submitted for separate space vehicle (SV) and operational control (OCX) segment contracts. Once acquisition strategies are formally approved in Washington, release of the GPS Block III SV request for proposals (RFP) are expected to be released by mid-February and later in the spring for the OCX RFP, according to JPO.

"Minor adjustments are being implemented in the program planning to reflect an incremental development and delivery approach for both acquisitions that will provide increased GPS capability sooner and more frequently over the life of the program," the JPO told *Inside GNSS*. Nonetheless, an upgrade in the control segment to accommodate the new generations of satellites is behind schedule, which means that the capability to operationally control those signals will not be available until 2009 at the earliest, according to the DSB task force.

Modernizing Technology

In terms of its fundamental design, the Global Positioning System is nearly 35 years old. More recent spacecraft designs using modern electronics, new rubidium clocks, better satellite management techniques, and navigation message enhancements have improved performance. But the design of the key resource for manufacturers and users, the GPS signals-in-space, is essentially the same as when the first satellite was launched in 1978: a C/A-code on L1 (centered at 1575.42 MHz) and P/Y-code military signals at L1 and L2 (1227.60 MHz)

Over the next five years, however, this situation will change dramatically.

Beginning with SVN53/PRN17, the first modernized Block IIR (IIR-M) satellite built by Lockheed Martin and launched last September 25, GPS has gained a new open civil signal at L2 (centered at 1227.6 MHz). A third civil signal, L5 (centered at 1176.45 MHz) will arrive with the Block IIF satellites now scheduled to begin launching in 2007.

The good news is that no one connected to the program wants to let one of the world's leading U.S.-branded utilities slip into the shadow of the other GNSSes under development.

Both IIR-M and IIF satellites will offer new military M-code signals at L1 and L2 with "flex power" capability of transmitting stronger signals as needed. The L5 civil signal will be broadcast both in phase and in quadrature, with the quadrature signal being broadcast without a data message. Air Force Space Command expects to have a full complement of satellites transmitting L2C and M-code signals by 2013; for L5, fully operational capability is expected by 2014.

Generally, the new signals will be characterized by longer code sequences broadcast at a higher data rate and with slightly more power. Beginning with the IIR-M satellites, the Air Force will be able to increase and decrease power levels on P-code and M-code signals to defeat low-level enemy jamming — a capability known as "flex power."

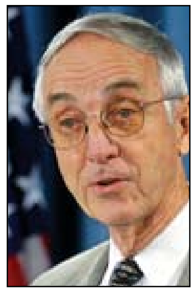
These new signal features will support improved ranging accuracy, faster acquisition, lower code-noise floor, better isolation between codes, reduced multipath, and better cross-correlation properties. In short, the new signals will be more robust and more available.

Looking farther ahead, another civil signal at L1 is planned to arrive with the GPS III program. Under a GNSS agreement signed with the European Union in June 2004, this will be a binary offset carrier (BOC 1,1) signal similar or identical to that of the Galileo open signal. This is expected to simplify the combined use of GPS and Galileo signals. Nominal first launch date for a GPS III spacecraft is currently 2013.

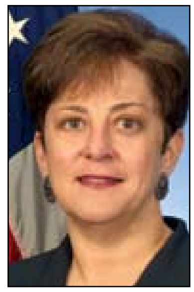
Modernization will also take place in the ground control segment. Six GPS monitoring stations operated by the National Geospatial-Intelligence Agency (formerly the National Imagery and Mapping Agency) have been folded into the existing five Air Force GPS monitoring stations (which includes the Master Control Station at Shriever AFB, Colorado.) This will eliminate blank spots in coverage and support Air Force plans to monitor the integrity (or health) of civil signals as well as military signals.

New Political Structure

Under a presidential national security policy directive (NSPD) released in December 2004, a National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee and Coordination Office have taken over from the Interagency GPS Executive Board (IGEB). Mike Shaw, a long-time GPS hand on both sides of the civil/military interface, stepped in toward the end of 2005 as the first director of the PNT coordination office.



GORDON ENGLAND



MARIA CINO

Establishment of the PNT committee — now cochaired by deputy secretaries of defense and transportation, Gordon England and Maria Cino, respectively — kicked GPS leadership up a notch from that of the IGEB. Other members include representatives at the equivalent level from the departments of state, commerce, and homeland security, the Joint Chiefs of Staff and the National Aeronautics and Space Administration.

The committee had met once shortly after its formation under President Bush's NSPD, but a January 26 gathering marks its first with the current leadership. In addition to getting acquainted with one another and the PNT topic in general, the agenda covered such issues as the DSB task force report, modernization and funding of GPS, and the new UN International Committee on GNSS (see article on page 61).

Without a director and coordination board in place, the executive committee was unable to get on with many of the tasks assigned it by the presidential directive, including writing a five-year plan for U.S. space-based PNT and appointing an advisory board of outside experts. With Shaw on board, the coordination board now has seven staff members detailed from agencies represented on the executive committee.

A charter for the advisory board has been drafted and awaits approval by the committee, as does a draft of an international PNT strategy prepared by the State Department under the direction of Ralph Braibanti, who heads that agency's space and advanced technology staff.

GLONASS: The Once and Future GNSS

The end of the Soviet Union almost spelled the end of GLONASS. But 15 years later, a new leadership, new mission, and new resources are bringing the Russian system back on line.

Once widely written off as another victim of the economic and political disarray following the collapse of the USSR, Russia's GLObal NAvigation Satellite System (GLONASS) has arguably demonstrated the most stability of the world's three GNSS programs in recent years.

GLONASS followed the Global Positioning System into space with its first satellite launch on October 12, 1982, 4½ years behind the first GPS satellite went up. After reaching a high point in 1996 with more than two dozen operating satellites in orbit, GLONASS dwindled over the next five years to a nadir of seven operational satellites.

Strapped for cash and expecting a greater role in Europe's Galileo project, Russia allowed paying commercial payloads from foreign customers to get in line ahead of GLONASS at its launch facilities. A dispute with newly independent Kazakhstan over maintenance, operation, and funding of the Baikonur launch facility further complicated the picture. Meanwhile, the relatively short design life of the spacecraft (three years compared to 7½ years for GPS) contributed to a rapid decline in operational satellites.

In 2001, a new Russian government under President Vladimir Putin reassessed its commitment to space-based positioning, navigation, and timing (PNT), and refashioned its development timeline to more sustainable dimensions. An August 21, 2001, decision committed the government to a 2002-2011 program to rebuild and modernize GLONASS.

A schedule of annual launches since then has doubled the constellation to 13 operational satellites. As a result, since 2001 the gap in worldwide navigation with GLONASS declined from 14 to 2 hours as of November with coverage 98 percent of the time over Russia, according to Sergey Revnivykh, an official with Roscosmos' Satellite Navigation Department at the Mission Control Center of the Central Research Institute of Machine Building.

Picking Up the Pace

On December 25, Russia placed three more spacecraft into orbit and brought the system within striking distance of an 18-satellite constellation, which should be in place late next year with all satellites in service by early 2008. Under the current plan, the frequency of launches would increase over the next two years to provide a 24-satellite constellation by 2010–11.

The day after the December 25 launch, however, Putin expressed support for accelerating the GLONASS effort. According to the Russian Information Agency Novosti, Putin told government members, "The GLONASS system should be created before 2008, as it was originally planned. We have the possibility. Let us see what can be done in 2006-2007."

RIA Novosti subsequently quoted Anatoly Perminov, head the Russian Federal Space Agency, as saying a proposal for earlier completion of the system would go to Putin before January 15, 2006.

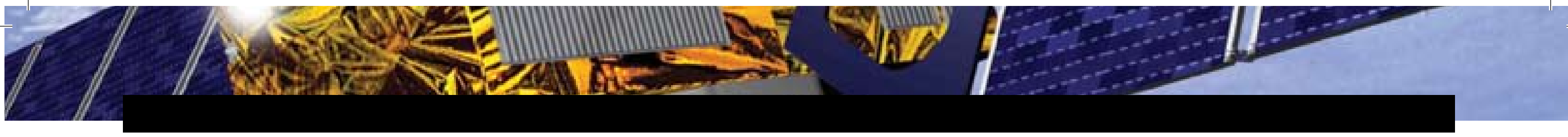
Modernized GLONASS spacecraft (GLONASS-M) with a 7-year design life have flown on the launches since 2003. Two more went up with the most recent launch. Not well known is the fact that these include a second open civil signal at L2.

The availability of a second full open signal provides little practical benefit, however, because of the lack of user equipment outside the GLONASS control segment that can process the GLONASS L2 civil signal. New 72-channel chips recently announced by Javad Navigation Systems (the GeNiuSS) and Topcon Positioning Systems (Paradgim – G3) employ a common technical design that can process the GLONASS L2 signals, both C/A-code and P-code, as well as the new Galileo signals. Topcon has launched a new line of surveying equipment based on the technology, with the first product to be released as the NET-G3 receiver for reference station installations.

Technology, Policy, and Budgets

Unlike the Global Positioning System and Galileo, in which each satellite broadcasts a distinct code on the same frequency, GLONASS broadcasts the same code on different frequencies. At the L1 frequency, for example, the GLONASS open signal is spread between 1598.0625 MHz to 1607.0625, in sub-bands with signal peaks separated by 0.5625 MHz. This RF strategy requires broader swaths of increasingly rare radio spectrum and, at one point, brought the Russian system under pressure from radioastronomers and satellite communication systems that wanted to operate at the upper end of its RF allocation.

An agreement in the late 1990s committed Russia to an "antipodal" signal strategy that halved the number of bands on which satellites transmit their signals by assigning the same frequency to spacecraft orbiting on opposite sides of the Earth. This ensured that GLONASS receivers would not see conflicting signals on the same frequency, while allowing the



bandwidth that it required to be compressed toward the lower portion of its allocation.

A 1999 presidential decree formally established GLONASS as a dual-use (civil and military) system, as is GPS. An Interagency Coordination Board comprised of civil and military agencies provides inputs from user communities, similar to the U.S. Interagency GPS Executive Board and its successor, the Space-Based PNT Executive Committee. The Russian Ministry of Defense (MoD) maintains and controls the system's ground and space assets, although Roscosmos – the Russian Space Agency – acts as the program coordinator.

GLONASS receives funding directly from the Russian federal budget through line items in the MoD and Roscosmos agency allocations. Until recently, however, getting the funds through the civil agency remained problematical, according to Russian sources. The run-up in oil prices over the past couple of years has benefited Russia substantially. The nation produces and sells on the world market large quantities from its central Asian petroleum fields. President Putin has primarily used the funds to pay down indebtedness to the International Monetary Fund. Military programs, however, have received higher levels of support, which has translated into more stable funding for GLONASS, too.

At his urging, a proposal for earlier completion of the GLONASS system has gone to Russian President Vladimir Putin

Closing the Performance Gap

Shorter satellite survival on orbit has exacerbated the difficulty of sustaining the GLONASS constellation. All of the current operational spacecraft have been launched since 2000, and the mean mission duration (actual operational lifespan) is 4.5 years – about half that of GPS satellites.

Moreover, GLONASS performance has lagged behind GPS. A March 2005 study by the Swiss Institute of Science Research and Engineering, cited in a Tokyo symposium in November, reported that the accuracy of GPS ephemerides (the orbital locations of satellites broadcast as part of the navigation message) averaged about one meter compared to postprocessed tracking data from monitoring stations. In contrast, GLONASS ephemerides averaged about seven to eight meters.

In part, that reflects the more difficult challenge of tuning multiple signal/frequency combinations and accounting for the different propagation effects of carrier waves with slightly varying lengths. But the quality of on-board atomic clocks and system timekeeping, as well as weaknesses in the satellite navigation payload software and ground monitoring network, also contributed to the problem.

Now Russia is implementing an accuracy improvement program with modernization of satellites and ground infrastructure. Beginning with the GLONASS-M, manufacturered by Reshetnev Applied Mechanics Research and Production Association (NPO-PM) in Krasnoyarsk, on-board clock stability over 24 hours has improved from $5x10^{-13}$to $1x10^{-13}$. An improved dynamic model in the satellite navigation software will produce a lower level of unpredicted accelerations.

GLONASS-M spacecraft use previously reserved bytes in the navigation message to provide additional information, including the divergence of GPS and GLONASS time scales, navigation frame authenticity (validity) flags, and age of data information. Moreover, improved filters have been installed to reduce out-of-band emissions.

On the ground, GLONASS will also gain 3 stations from military tracking facilities and 9 to 12 from the Roscosmos network, much as the United States has done by incorporating National Geospatial-Intelligence Agency monitoring sites into the GPS tracking network. Both the United States and Russia are evaluating the utility and security of adding facilities from the International GNSS Service, an extensive network coordinated by NASA's Jet Propulsion Laboratory in California.

New system clocks with high stability and improved systemwide synchronization will further improve GLONASS timing. Definition of the GLONASS coordinate system will tie it to the International Terrestrial Reference System, an international standard. As a result of these modernization efforts, Russian officials predict that GLONASS performance will equal that of GPS by 2008.

A new generation of satellites — GLONASS-K — is planned for launch beginning in 2008. These satellites will have a 10-year design life and carry a third civil signal at L3 frequency band, with a couple of frequency schemes under consideration in the 1198 to 1208 MHz band. Current plans for GLONASS-K include providing GNSS integrity information in the third civil signal and global differential ephemeris and time corrections to enable sub-meter real-time accuracy for mobile users.

Renewed Initiative

The recent progress in rebuilding and modernizing GLONASS appears to have bolstered the confidence of Russian officials in promoting the system internally and internationally. Russian state policy enacted last June mandates that, beginning in 2006, federal GNSS users employ only GLONASS or combined GLONASS/GPS receivers on Russian territory for aerospace and transport vehicles as well as for geodesy and cadastral surveying. And even before Putin's recent remarks, Russia had re-engaged in several initiatives

The most recent round of talks with the United States led to a joint statement in December 2004 confirming that direct user fees would not be imposed on civil GLONASS or GPS services and committed the two nations to ensuring the compatibility and interoperability of the two systems, implementing search and rescue functions using GNSS positioning, and cooperating on GNSS issues at international organizations.

On December 6, Russia and India signed an intergovernmental pact on the protection of classified military technologies during long-term cooperation under an agreement reached a year earlier for the joint development and peaceful use of GLONASS. This includes cooperation in GNSS ground infrastructure development and launch of GLONASS-M satellites on India's Geosynchronous Satellite Launch Vehicle (GSLV). The GSLV design incorporates Russian rocket engine technology.

Finally, consultations with the European Union continue on a prospective Galileo/GLONASS agreement, with a technical working group scheduled to submit a a proposal in April on signal compatibility and interoperability at the GLONASS L3 and Galileo E5b bands. Russian rockets will help launch Galileo satellites, including a Soyuz-Fregat used in the successful first launch of GIOVE-A on December 28 (See article on page 16.), and laser retro-reflectors produced by NIIPP, the Russian Scientific-Research Institute of Precision Instrument-Making, will measure the altitude of both GIOVE spacecraft to within centimeters.

The Perils (and Pearls) of Galileo

Getting Galileo approved and on its way to being built required the unruly fusion of 27 countries, two multinational organizations, repeated confrontations among their political and industrial leaders, international asides and interventions, and hair-raising brinkmanship. Will this novel hybrid ever bloom?

Successful launch of the first Galileo satellite on December 28 marks the culmination of a process that began almost exactly 13 years earlier.

On January 19 the European Space Agency and Galileo Industries GmbH, the European company steering a consortium of more than 100 subcontractors, signed a €950 million (US$1.15 billion) contract that will pave the way for the operational deployment of Galileo. The contract calls for a mini-constellation of four satellites backed by an extensive network of tracking and control stations that will validate the design of the Galileo space and ground infrastructure. Four satellites are the minimum required to generate three-dimensional positioning and precise timing over the selected showcase sites.

In December 1992, however, Galileo was just a glimmer in a few visionaries' eyes. That was the month that two European Commission (EC) directorates-general — those for transport and science, research, and development – decided to fund a modest study of satellite navigation options for Europe. The intervening years produced a kind of programmatic version of "The Perils of Pauline," the cliffhanger serial movie in which each installment ends with the title character – a perpetual damsel in distress – placed in a situation that threatens her imminent demise, only to be rescued at the beginning of the next episode.

Galileo's most recent "peril" revolved around a dispute between Germany and other members of the European Union (EU) over the allocation of contracts and responsibilities that they would have during the deployment phase of the system. A December 5 agreement on sharing Galileo operational and control centers among five nations rescued Galileo from the months-long impasse.

The next (but probably not final) act of the "Perils of Galileo" remains to be played out: the signing of an agreement


ESA

Preparing the adapter between Soyuz and Giove-A

with a consortium of companies that will complete the development of the space and ground segments and operate the system for the next 20 years. Current estimates place that milestone in the latter half of 2006, reflecting delays that have dogged the program since its inception and finally pushed its timeline for completion to 2010 – two years beyond the date long proposed by the EC and its Galileo partner, the European Space Agency (ESA).

Nonetheless, the launch of GIOVE-A, the experimental Galileo spacecraft built by Surrey Satellite Technology Ltd., marks a major—and probably irrevocable—step forward for the European GNSS. The start of transmissions from GIOVE-A and a second testbed satellite, GIOVE-B, manufactured by Galileo Industries, will allow the system to lay claim to use of the radio frequencies allocated at World Radio Conferences in 2000 and reaffirmed in 2003.

They will also allow ESA to evaluate on-orbit performance of several new satellite components and technologies and, significantly, also enable GNSS receiver developers to work with real signals in space. For example, GIOVE-B will be launched in the first half of 2006 and will have a passive hydrogen-maser clock as an additional payload, the first such clock ever flown into space. Current spaceborne clocks are cesium and rubidium frequency standards. Galileo satellites will also have rubidium clocks on board.

Political Merry-Go-Round

Several aspects of the €3.8 billion (US$4.6 billion) Galileo program distinguish it from its U.S. and Russian counterparts, GPS and GLONASS: full civilian control, a so-called public-private partnership (PPP) in its deployment and operation, international participation, and a multitude of services, including some that will be fee-based with guaranteed delivery of service. Indeed, the political challenges have long eclipsed the technical ones.

Fusing the interests of 15 (later 25) EU member-states, three additional non-EU ESA participants, and their leading industrial factors into a single enterprise has required a sustained exercise in what's sometimes called "concertation." Galileo represents the first Europe-wide infrastructure project and, consequently, challenged the EU and ESA to achieve a new level of political capability — within themselves and between one another. After the original 1992 satnav study, it took nearly seven years before Galileo even got its name in a February 1999 EC document, "Involving Europe in a New Generation of Satellite Navigation Services."

"Let's put all the players in one room and lock them in until they come out with something."

Until then the program had been known rather generically as GNSS 2, distinguishing it from GNSS 1, the European Geostationary Navigation Overlay Service (EGNOS), a satellite-based augmentation of GPS and GLONASS. In May 1999 the ESA Ministerial Council approved the GalileoSat program; in June 1999 the EU Transport Council endorsed a first resolution on Galileo.

A November 22, 2000, EC communication to the European Parliament and European Council laid out the financing, organization, R&D, and implementation plan. In November 2001 the ESA Ministerial Council approved the development of Galileo (Phase-C/D, with a budget of €550 million). In May 2002 the Council authorized a joint undertaking, an institutional entity envisioned under Article 171 of the European Community Treaty but only implemented once previously, which allows the EU to collaborate in a single enterprise with non-EU bodies.

ESA and the EC (on behalf of the EU) comprised the initial membership of the Galileo Joint Undertaking (GJU), which has as its primary task the completion of a concession contract. Subsequently, non-EU governmental organizations representing China and Israel signed on with the GJU. Other nations, including Ukraine and India, are expected to join soon. The concessionaire will complete deployment of the Galileo satellites and ground infrastructure and operate the system over the next 20 years, monitored by a Galileo Supervisory Authority.

Final action to deploy the system only came with European Council action on December 10, 2004. Along the way, however, the growing EU-ESA cooperation on Galileo led to a broader initiative on a common European space policy. Late in 2003 the two institutions issued a White Paper on Space and signed a "framework agreement" for cooperation in space activities. Under the agreement, "the EC and ESA will launch and fund joint projects, participate in each other's schemes, create common management agencies, carry out studies and jointly organize conferences and training of scientists, exchange and share experts, equipment and materials, and access to facilities."

The overall cost of the Galileo system was first estimated at €3.4 billion, with a public investment for the development and validation phase of €1.1 billion divided between the EC and ESA. This phase was re-evaluated in 2005 at €1.5 billion.

The Art of the Deal

Currently, a "grand coalition" of leading European aerospace, telecommunications, and banking interests is negotiating with the GJU in a formerly competitive process that saw the merger of the two leading consortia in March 2005. Last month's agreement on Galileo's operational and administrative direction saw Eurely — a grouping led by Alcatel, Finmeccanica, and Vinci Networks — and the iNavSat consortium headed by the European Aeronautic Defense and Space Company (EADS), Thales, and Inmarsat, joined by a new consortium of Munich, Germany–based companies. The latter group, TeleOp, includes the commercial arm of the German Space Agency (DLR), the LfA Förderbank Bayern, and subsidiaries of EADS and T-Systems.

But the agreement didn't come easily. Multi-sided talks by representatives of eight companies and five governments (France, Germany, United Kingdom, Italy, and Spain) would reach tentative accords at one level or with one group of negotiators but then fall apart when brought to another forum. Coloring the dialog were national ambitions to be seen as leading the Galileo program and the sensitivity to geographic return — the practice of spreading contracts and revenues among program participants in a proportion close to the contributions made by the various nations.

"Finally, we realized we can't keep on fighting over these assets without getting an agreement," Martin Ripple, director of Galileo Program for EADS Space Services, told Inside GNSS. "So, EADS said let's put the all industrial players in one room and get the five governmental players into the same room. And lock them in until they come out with something."

What they came out of the room with was a plan that reallocated key components of Galileo operations among the five leading space nations in Europe. The headquarters of the Galileo concessionaire will be located in Toulouse, France, with administrative and market development responsibilities. Inmarsat will have overall management leadership of the operations company based in the United Kingdom and responsible for global network operations, including performance monitoring and operations security. The two control centers (for constellation and mission) will be located in Germany (near Munich in Bavaria) and Italy (Fucino space center in Abruzzo region) along with two performance evaluation centers supporting the concessionaire headquarters. Spain will host backup control centers as well as facilities related to Galileo safety-critical applications.

"It's a major step toward a concession contract," says Ripple.

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The Same, Only Different

On the technical side of the program, Galileo has entered the in-orbit validation (IOV) and development phase using the two GIOVE experimental satellites to test out ESA's spacecraft design and ground control. The IOV phase will conclude with the deployment of four operational satellites in 2008. According to the current schedule, an additional 26 satellites will then be launched over the following two years with full operational capability (FOC) declared in 2010.

Galileo operational satellites will transmit signals in a variety of bands clustered around the 1176-1207 MHz spectrum near the GPS L2 frequency, 1775.42 MHz centered at the GPS L1 frequency, and 1278.75 MHz. The latter band lies at some distance from the GPS L2 signals at 1227.6 MHz, but would fall within one of the bands that Russia is considering for the third civil GLONASS signal that will begin broadcasting with launch of its new satellites in 2008.

Galileo signal structures include a combination of biphase shift keying (BPSK) and binary offset carrier (BOC) designs. (Current GPS signals are BPSK variations, but future signals will also be BOC-based.) Recently, the Galileo Signal Task Force has proposed the addition of a composite binary coded symbols (CBCS) design that superposes BOC and a binary coded symbol waveform with the same chipping rate.

Galileo will offer five services: a free open service; a fee-based, encrypted commercial service offering higher accuracy and service guarantees; a safety of life service the includes signal authentication and integrity alerts (targeting, for example, commercial aviation); a search and rescue service operating in near-real time with a return communications link possible; and an encrypted governmental service known as the "public regulated service" or PRS, which will be used by public safety agencies and, conceivably, military forces. Certification for safety of life services is scheduled to occur within a year after FOC.

This final point and the liability issues that it raises probably is the largest complication for the final negotiations in the concession contract. Sizing and sharing the risk associated with service guarantees introduces an problematical element to the Galileo project not faced by its GPS and GLONASS counterparts. As one participant in the deliberations has posed the dilemma: What do you do if a hiker in the Rocky Mountains gets lost and sues Galileo in front of a U.S. judge? Once signed, the concession agreement will lead to the phasing out of the GJU and the advent of the Galileo Supervisory Authority's role. The concession contract also represents the turning point of the public-private partnership that marks Galileo as a different kind of beast from publicly funded GPS and GLONASS. The framework for negotiating the concession contract assumes a two-thirds contribution from the private sector for the €2.2 billion deployment phase and all of the €220 million annual expense of operating and maintaining Galileo.

Given the past history of the European GNSS initiative persevering and escaping perils — including self-created ones, the Galileo project will probably manage to solve the PPP riddle and get on with the (comparatively) simple task of building and operating a system. IG