Flying EGNOS: The GNSS-1 Testbed

As satellite positioning, timing, and navigation applications proliferate throughout the world, so too does the need for improvements to system performance. The European Geostationary Navigation Overlay Service (EGNOS) will not only enhance GPS and GLONASS, but also likely serve as a building block for Europe's own Global Navigation Satellite System — Galileo. The EGNOS System Testbed is already serving as an essential tool in preparing Europe for implementing these new systems.

Long before plans to create its own satellite navigation system started taking shape, Europe recognised the pivotal role this technology would play in positioning, navigation, and timing communities throughout the world. It also realised, however, that the existing constellations — the United States's Global Positioning System (GPS) and Russia's GLONASS — did not offer sufficient performance for all users.

Therefore, in 1994, to augment GPS and GLONASS and thereby meet the navigation and timing requirements of various users in Europe and neighbouring regions, work began on EGNOS — the European Geostationary Navigation Overlay Service (EGNOS). The project has involved many organisations and companies and has provided a tremendous boost to scientific and industrial activities involving satellite navigation in Europe.

The development and operational implementation of EGNOS relies heavily on various support systems, in particular the EGNOS System Testbed (ESTB). Most recently, trials organised by EUROCONTROL (the trans-European agency in charge of air traffic control) used the ESTB to test the ability of satellite-based augmentation systems (SBAS) to enable Category I (Cat-I) precision approaches. Some of this article's authors participated in those trials, with others contributing to the multitude of steps that have brought us this far.

On the following pages, we will take you through some of that journey, showing how we arrived at this point and where we intend to go from here. Although every participant in the EGNOS project may have a different set of individual goals, we are all aiming for the same outcome — achieving EGNOS advanced operational capability (AOC) in 2003 and, ultimately, expanding that system into Galileo, Europe's contribution to the next-generation Global Navigation Satellite System, GNSS-2.

BUILDING EGNOS

The EGNOS project has been defined and promoted by the European Tripartite Group,

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The U.K. Defence Evaluation Research Agency uses this BAC 1-11 Series 200 airplane during trials of the EGNOS System Testbed. Although the former passenger aircraft may seem outdated and no longer holds many seats, its onboard equipment makes it one of the most technologically advanced aircraft in the sky.

All photos courtesy of the authors

which is composed of the European Union - represented by the European Commission (EC), EUROCONTROL, and the European Space Agency (ESA).

To support EGNOS efforts, the European Commission is responsible for institutional and policy matters, coordinating the implementation of a trans-European navigation and positioning network, and identifying multimodal user requirements. The EC is also currently funding the navigation transponders on the Inmarsat-III satellites. EUROCONTROL, for its part, is in charge of defining the specific mission requirements for civil aviation, operational validation of GNSS-1 for aviation, and providing support for safety regulation.

ESA is responsible for the EGNOS AOC system development, deployment, and qualification and has, to that purpose, awarded a contract to a European consortium led by Alcatel Space Industries with the participation of European and Canadian industries. ESA is also developing the ESTB to provide a pre-operational EGNOS signal-in-space and thereby facilitate progress toward AOC.

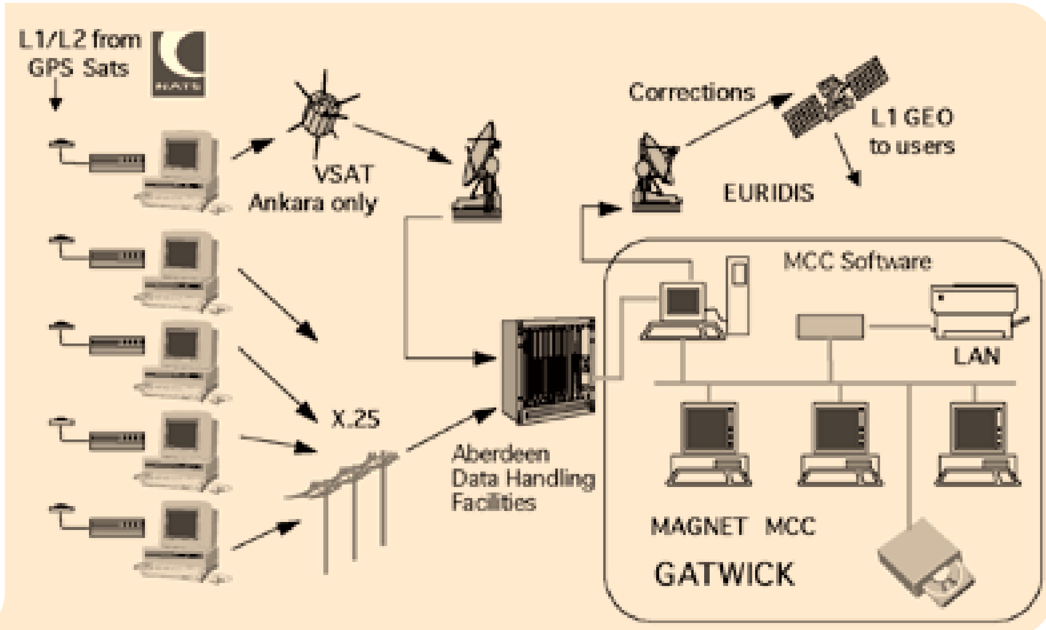
Specific ESTB objectives include not only supporting EGNOS system development and verification but also demonstrating EGNOS to its potential user communities, preparing for its future operational introduction, and demonstrating the service's expansion capabilities outside Europe.

The preliminary system development phase of EGNOS was completed in November 1998, followed immediately by the implementation phase in December 1998. The culmination of these efforts will be attaining AOC, which, for the aviation community means providing a primary navigation service in the area of the 38 states belonging to the European Civil Aviation Conference (ECAC) for all phases of flight down to Cat-I precision approach. In other words, EGNOS will provide to the user a horizontal and vertical accuracy over the landmasses of ECAC of better than 4-6 metres 95 percent of the time, with an availability objective of 99 percent, while meeting the continuity and integrity requirements for Cat-I. Although civil aviation needs drive these requirements, they also meet most other user requirements as well.

Before EGNOS AOC arrives, though, the ESTB will allow potential EGNOS users to prepare for the integration of GNSS technology into real-life applications such as transport services and time transfer. It will also be possible to perform real-time operational demonstrations of those applications.

In particular, a set of early trials sessions have been planned, some within the framework of the ESA Early System Design Verification experiments and others under the umbrella of the GNSS-1 Operational Validation activities coordinated by EUROCONTROL. Most of these experiments are carried out in close cooperation with

Figure 1. The MAGNET ground segment employs receivers and computers to preprocess the GPS range measurements, which are then transmitted to the Master Control Centre (MCC) using an X.25 leased phone line or very small aperture terminal (VSAT) satellite link. The MCC processes the signal to generate the correction data, which are broadcast as a navigation message through the Euridis link and on to users.



European Air Navigation Service providers. In the near future, the fielding of additional reference stations will allow satellite navigation trials outside Europe using the current ESTB configuration as a backbone.

PUTTING IT ALL TOGETHER

The ESTB will progressively evolve to become more representative of the future EGNOS system. It will also provide flexibility in its configuration to facilitate the test and analysis of specific aspects of the EGNOS system and operations.

For this reason, the ESTB comprises various building blocks that, when combined, constitute successive configurations, or generations, of the ESTB. The first two of these have been successfully assembled and used: a geostationary ranging element called Euridis and a differential ground station network and processing centre called MAGNET. Together these two elements form the ESTB Version-0.

Building Block I. Euridis serves both as the mechanism for broadcasting the wide-area differential corrections generated by successive generations of the ESTB to its users and as an additional ranging source to the Inmarsat AOR-E (Atlantic Ocean Region–East) geostationary satellite. Euridis became operational in early 1999 and has now been integrated in the ESTB, providing all the information necessary to allow experimental users to employ range measurements from AOR-E in their navigation solution.

The Euridis ground segment consists of three monitor stations in Hartebeeshoek, South Africa; Kourou, French Guyana; and Aussaguel, France. The data collected from these stations are sent to the Euridis Mission Control Centre (MCC) in Toulouse, France, where the orbit of the AOR-E satellite and the related user data messages are determined. These messages are sent to the Inmarsat uplink station in Aussaguel, which transmits them to AOR-E to be broadcast to the user. The uplink station also controls the timing of the ranging signal.

Building Block II. MAGNET (Multimodal Applications of GNSS in European Transport) is the ESTB-V0 element that generates the wide-area differential corrections. Its development commenced in January 1996 and led to the system being fielded for the first time in July 1998. Its primary aim was to support early civil aviation trials of satellite-based augmentation system (SBAS) technology and to ensure Europe's contribution to the development of international civil aviation standards documents.

MAGNET allows user receivers to correct for satellite clock errors (including the effects of selective availability) and ionospheric delays. Orbital errors are included in the satellite clock corrections, with satellite health and use/don't-use parameters also generated to prevent users from employing unhealthy satellite signals.

The MAGNET ground segment (see Figure 1) consists of five ranging and integrity monitoring stations (RIMS) located in Rotterdam, the Netherlands; Ankara, Turkey; Aberdeen, Scotland; Cadiz, Spain; and Bronnoysund, Norway. The RIMS contain an L1/L2 GPS receiver, an atomic frequency standard, and a personal computer. The RIMS computer under-

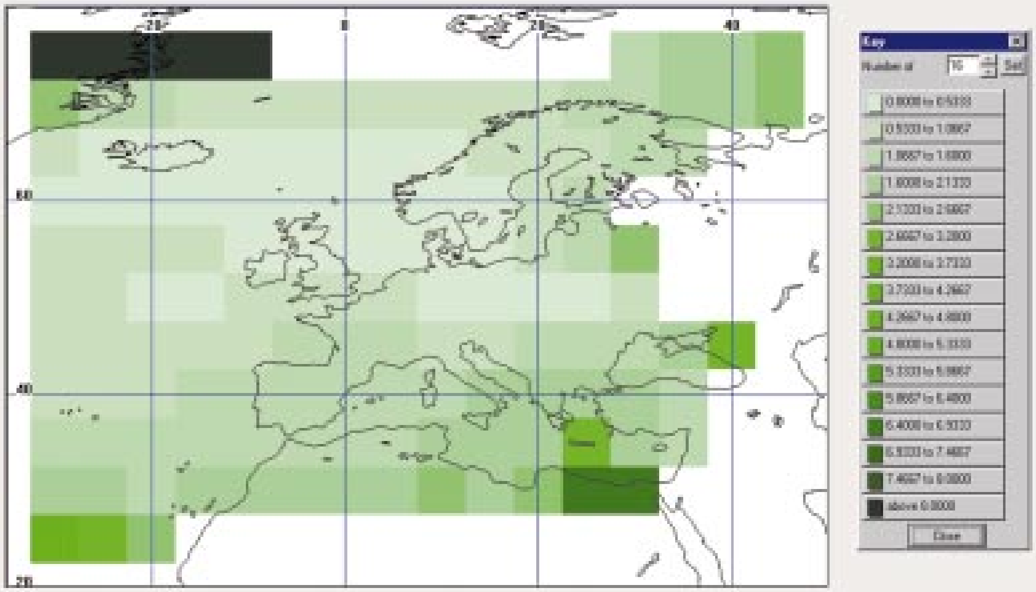


Figure 2. The MAGNET MCC uses all incoming data to develop a model of the ionospheric delay and delay error at the GPS L1 frequency over the region within view of the RIMS network. This screen capture shows the output of one such model.

takes preprocessing of the received satellite signals to remove the effect of tropospheric delay errors, carrier-phase cycle slips, ionospheric delay errors, and noise.

Data from the RIMS are transmitted once every second over a leased telephone line or a VSAT (very small aperture terminal) satellite-link through the Racal SkyFix control centre in Aberdeen, Scotland, to the MAGNET MCC located at the National Air Traffic Services (NATS) Ltd. Services Management Centre near Gatwick airport in England.

MAGNET MCC Operations. The MAGNET MCC then executes a number of functions to generate the user navigation messages. The incoming preprocessed data from the reference stations form the input for the ionospheric modelling function and the clock correction function, which allows accurate estimation of all the clocks in the MAGNET and GPS systems, including those in the satellites and the RIMSs. Based on this, the system generates fast and slow corrections for each GPS satellite.

The ionospheric modelling function estimates the ionospheric delay and delay error at the GPS L1 frequency over the region within view of the RIMS network (see Figure 2). The estimated delay and delay error are broadcast to users as vertical ionospheric delays for specific locations on a predefined grid covering the core European area. Users can use this ionospheric model to establish the ionospheric delay for each received satellite signal at their location.

An independent monitor implemented at Gatwick allows the operators to observe the accuracy performance of the signal in space and facilitates collection of user level data for later analysis. MAGNET also provides directly to the operators status information relating to the RIMS stations and the number and location of satellites being tracked. The operators monitor the data and, if necessary, take corrective maintenance action. By and large, though, MAGNET will automatically seek to resolve any problems that may occur.

From MAGNET to Euridis. After logging and processing the received data from the RIMSs, the MAGNET MCC outputs the 250-bits-per-second RTCA DO-229 compliant navigation message by way of an ISDN digital telephone connection. This travels to the Euridis MCC in Toulouse, which sends it to the Inmarsat satellite uplink station in Aussaguel.

TESTING SBAS TECHNOLOGY

Together MAGNET and Euridis have formed the first system to provide a complete SBAS signal-in-space in Europe. This ESTB Version-0 has thus far been successfully used on a number of occasions to support various trials of SBAS technology.

A Flying Lab. For some of these SBAS technology trials, NATS has contracted the U.K. Defence Evaluation and Research Agency (DERA) to carry out a series of precision approaches using guidance derived from the ESTB-V0 combined with GPS. DERA conducted these flight trials on XX105, a BAC 1-11 Series 200 aircraft that DERA operates as a test platform (see the “A Modern Old Bird” sidebar).

The experimental airborne user platform (UP) employed during the ESTB trials consists of a modified 10-channel GPS receiver connected to a standard L1/L2 GPS antenna. The receiver has been modified so that two of the channels can be used to track the SBAS signals broadcast by the geostationary (GEO) satellite.

The receiver sends pseudoranges, ephemerides, and the raw ESTB messages by way of a serial link to the PC. Software decodes the ESTB signals, applies the corrections to the GPS ranges measured onboard the aircraft, and carries out the position calculations to determine the augmented aircraft position. The software follows the requirements laid down in RTCA DO-229 Minimum Operational Performance Standards (MOPS) for Global Positioning System/Wide Area Augmentation System (WAAS) Airborne Equipment.

Guidance Generation. A configuration file on the PC contains the definition of the required approach path, including the latitude, longitude, and ellipsoid height of the runway threshold; the latitude, longitude, and ellipsoid height of a second point at the far end of the runway; the threshold crossing height; and the required glidepath angle. Using this information and the aircraft position, the UP is able to determine the deviation of the aircraft from the approach path.

These deviations are displayed to the pilot as beam bars on the electronic primary flight display on the lefthand-side of the cockpit (see Figure 6). The pilot in the left hand seat flies the aircraft manually down the approach path following the ESTB derived guidance, with the guidance appearing exactly as it would if he were following an ILS.

By entering the current phase of flight, the UP is able to anticipate whether or not the position solution's accuracy is within tolerance for this phase of flight. If the accuracy requirements are not met, then warning flags drop in on the pilot's

A Modern Old Bird

The BAC 1-11 is a twin-engined, short–medium range airliner. This particular aircraft first flew on 6 July 1964 as G-ASJD, one of the original BAC 1-11 development aircraft. After seeing airline service with British United Airways and British Caledonian, it was purchased by the Royal Aircraft Establishment (now DERA) in 1971 and converted into a flying laboratory.

Internal Overhaul. The aircraft has been heavily modified since its days in airline use. Most of the passenger seats have been removed and replaced with equipment racks. The cabin is fitted with a wide variety of satellite navigation systems and other equipment. This includes datalinks, computer stations, microwave and instrument landing systems (MLS and ILS), satellite communications, and a traffic alert and collision avoidance system.

DERA has developed the autopilot and flight management system especially for this particular aircraft. A dedicated recording system logs data from all the devices on the aircraft's ARINC 429 databus.

The cockpit has also been heavily modified. On the captain's side, many of the original analogue instruments have been replaced by two colour CRT (cathode-ray tube) displays consisting of a navigation display and a primary flight display (PFD) showing standard flight instruments such as the attitude indicator, altitude, airspeed, rate of climb, and so forth.

All instruments on the right-hand side of the cockpit are conventional, certified units that a safety pilot uses to monitor the aircraft. During the experimental ESTB approaches, the safety pilot follows an analogue ILS and can take over control of the aircraft if a problem were to occur. This operating method, and the fact that the aircraft is military registered, makes it possible to install and flight-test experimental equipment without having to satisfy the full range of civil certification requirements.

Although the BAC 1-11 is an early second-generation jet transport and its airframe can seem somewhat crude when one compares it with the latest technology, this 35-year-old airliner is still, technologically, one of the most modern aircraft in the sky.

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Circle 4

The GPS receiver on the BAC 1-11, which can track the ESTB signal broadcast by the GEO satellite, sends pseudoranges, ephemerides, and raw ESTB messages to this PC. Software then decodes the data and computes the aircraft's corrected position.

display to indicate that one cannot rely on the satellite navigation system.

Truth System. To assess the accuracy of the ESTB position a post-processed, carrier-phase GPS solution is used. On board the aircraft, a dual-frequency, geodetic receiver is connected to the same antenna as the UP. A similar receiver is placed at a ground-based, surveyed site in the flight region, and data are logged on both receivers. After a flight, this information is post-processed to provide an aircraft truth track that is accurate to better than one metre.

TRIAL BY FLIGHT

Flights to shake down the ground and onboard equipment started in August 1998. Since then, the plane has carried out some 15 flights and 45 approaches using the ESTB-V0 signals. Invited guests from the aviation industry and satellite navigation community have been present on many of these flights and have been able to observe the performance of the ESTB-V0 from the cockpit. Arriving at that point, though, was not as simple as it might sound.

A Challenge to Conquer. The initial timeline to procure, install, test, and demonstrate the airborne elements was very tight indeed, with a hard deadline to demonstrate at the U.K.'s Farnborough Airshow in September 1998. Naturally, some teething troubles had to be ironed out of the system, such as when one engineer realised he had to debug his software at a 40-degree bank, with only 10 minutes between approaches.

In addition, problems with aircraft availability meant that acceptance testing of the airborne equipment could not be completed in flight. Adapting quickly to the situation, participants lashed an antenna to a van's roof with an old piece of rope, installed the receiver in the back of the van, and then called out "left a bit, right a bit" to guide the driver up and down the Boscombe Down runway. The system was flight proved just 30 minutes before the first demonstration.

In the Air. DERA carried out the first ESTB demonstrations on 7–10 September 1998, during the 1998 Farnborough Airshow. On those four evenings, they flew 12 approaches to runway 23 at the U.K.'s Boscombe Down airfield. All of the approaches were to Cat-I minima, namely a 200-foot decision height. One flight even took place during true Cat-I meteorological conditions, with the pilot unable to see the runway until he reached the decision point. Naturally, the copilot was very closely monitoring the ILS during this approach!

These initial trials were very successful and led to a further set of demonstrations at Keflavik Airport, Iceland, in October 1998. They were held in conjunction with the U.S. Federal Aviation

Administration (FAA) and the Icelandic Civil Aviation Authority (ICAA), and an ESTB RIMS was set up in Iceland for the duration of the trials.

These flights studied the interoperability between the ESTB and the FAA National Satellite Testbed (NSTB) as well as the effectiveness of the augmentation systems at the edge of coverage for both the geostationary satellite footprint and the ground monitor network. It also provided an opportunity to again demonstrate the system performance to invited guests from the aviation industry.

The BAC 1-11, FAA's Boeing 727, and the ICAA King Air 200 were all able to demonstrate Cat-I approaches using GPS signals augmented by either the ESTB or NSTB using the same receiver. In addition, the results showed no major differences between the two testbeds. Despite the fact that in Iceland, at 65 degrees north latitude, the geostationary satellites appear to be very close to the horizon, either the ESTB or NSTB were available continuously throughout each approach in all four runway directions in Keflavik, indicating the benefit of dual GEO coverage.

Paris in 1999. The next flights were at Maastricht, the Netherlands, in February 1999, followed shortly thereafter by EUROCONTROL-organised trials near Paris in June 1999.

This latter event marked the first time that Euridis was used in SBAS-trials in Europe. Incorporating the GEO ranging into the position solution, the aircraft conducted six approaches using the full ESTB-V0 system. Figure 3 shows the vertical profile for the approaches to Melun airport, with Figures 4 and 5 showing the ensemble of localiser and glideslope deviations generated by the ESTB.

Figure 6 and Figure 7 show in more detail the accuracy performance of ESTB during one of these approaches, which was flown to 200 feet before the aircraft commenced an overshoot.

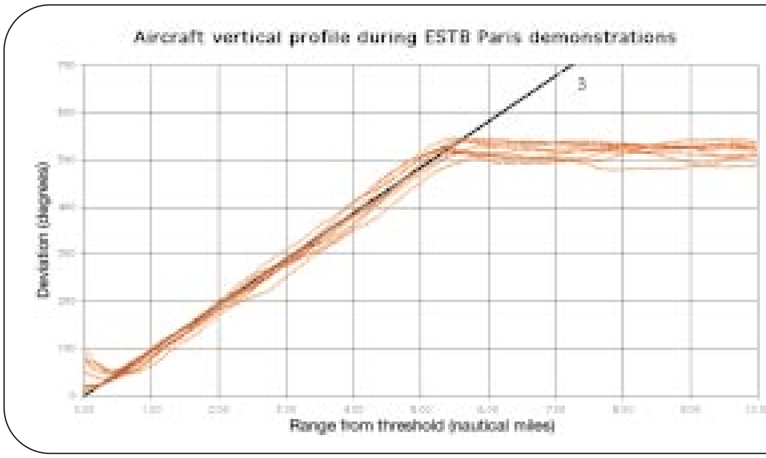

Figure 3. The circuit height for the Paris demonstrations was 1,800 feet (550 metres). As seen in this plot, the aircraft intercepted the glideslope at a range of 5.5 nautical miles before beginning a 3-degree approach, terminating in an overshoot at 200 feet at a range of 0.5 nautical mile.

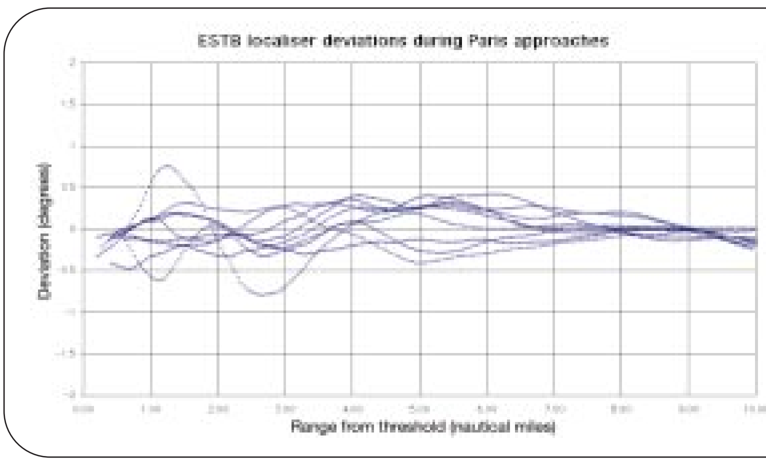

Figure 4. This plot demonstrates the pilot's ability to follow the ESTB localiser guidance to within 0.5 degree during the approaches.

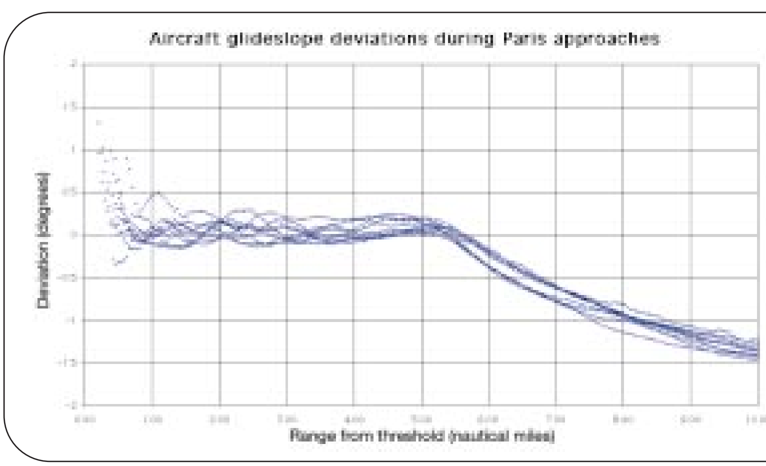

Figure 5. This graph shows that prior to the overshoot at 0.5 nautical mile from the runway, the pilot is able to keep the aircraft within 0.3 degree of the approach path.

The graphs compare the ESTB system accuracy with the postprocessed GPS truth track and are plotted as a function of range from the runway threshold, starting at around 10 nautical miles. This entire approach lasted approximately five minutes.

For the same approach, Figures 8 and 9 compare the ESTB generated glidepath guidance and the ILS. These signals are divided into a lateral component called the localiser deviation and a vertical component called the glidepath devia-

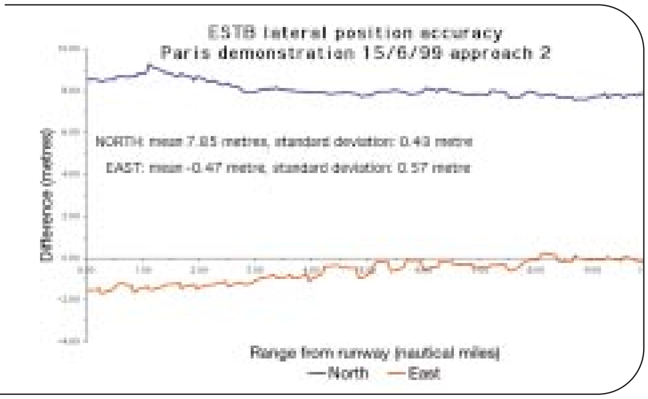

Figure 6. This plot compares the ESTB derived position and the aircraft truth track for one of the Paris approaches. The results are presented in East and North axes and are well inside the 16-metre lateral accuracy requirements for Cat-I approaches.

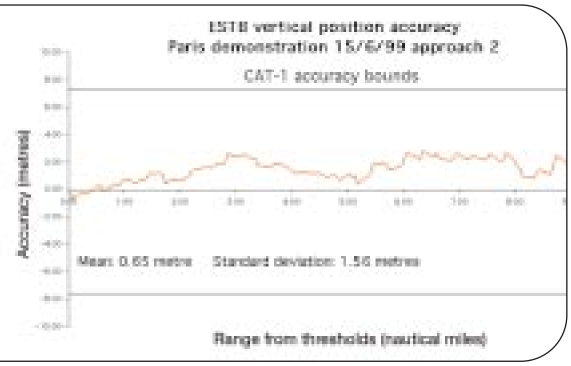

Figure 7. This graph compares the ESTB position and the truth track in the vertical direction. The Cat-I vertical accuracy requirement is 7.7 metres, and again the ESTB solution is within this accuracy.

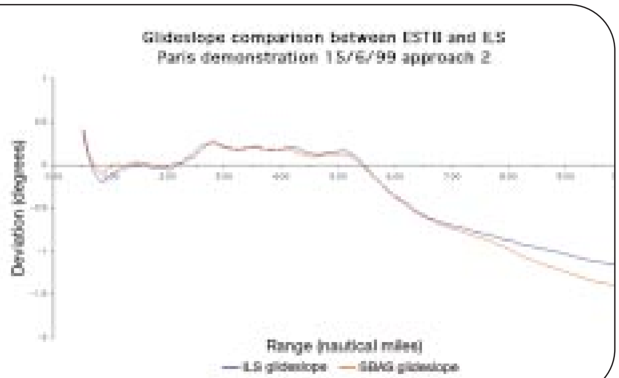

Figure 8. This plot compares the ESTB derived approach guidance with the ILS on the airfield. There is a close correlation between the two systems. In general, results have shown that the ESTB guidance is smoother and less prone to noise than ILS guidance.

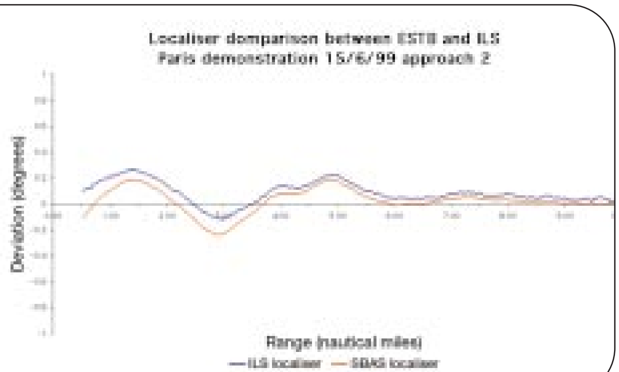

Figure 9. Comparison between the lateral guidance from ESTB and the ILS on the Paris Airfield. Again there is a good correlation between the two systems.

tion. These plots show a very good correlation between the two signals and demonstrate that the ESTB guidance is generally much smoother than this ILS, which is a Cat-I system.

The fact that these traces are not exactly zero on the way down the approach path is an indication of the flight technical error, a measurement of the ability of the pilot to accurately position the aircraft on the glideslope, which in turn depends on the pilot's performance, the aircraft's handling characteristics, the human-machine interface, and the weather conditions on the day of the flight.

Automatic Flight. To date, pilots have been very impressed with the guidance from the ESTB system. To them, it looks very much like the ILS guidance to which they are accustomed, with the added benefit of a much more stable signal from the ESTB than is available from an ILS.

Thus far, though, ESTB flight trials have involved manual flight with the pilot following guidance information from the SBAS system displayed on the ILS beam-bars. Future trials will explore SBAS automatic flight. The user platform has recently been upgraded to include aircraft standard ARINC-429 digital outputs, which has made it possible to connect the SBAS equipment to the BAC 1-11's autopilot and flight management system. This allows the aircraft to automatically fly using the ESTB system from take-off, through en route, and down to a 200-foot decision height on final approach.

Initial trials of SBAS-coupled approaches are planned to take place at DERA Boscombe Down, in southern England, during November of this year, after which, in early 2000, work is expected to begin on the use of GNSS for curved and missed approaches.

ESTB EXPLORES NEW GROUND

With regard to the testbed itself, at the end of 1999, ESTB Version-1 will become operational. This new configuration will constitute a major step in the ESTB life cycle, because it will be the first version to integrate prototypes of the future EGNOS operational processing elements and algorithms.

Developed in the frame of an ESA contract, the ESTB-V1 will be expanded with new reference stations, processing centres, and access stations as represented in Figure 10. In addition to the five reference station locations from the MAGNET system, the ESTB-V1 will operate eight new stations that will contain prototype EGNOS algorithms and also support data collection of GLONASS signals.

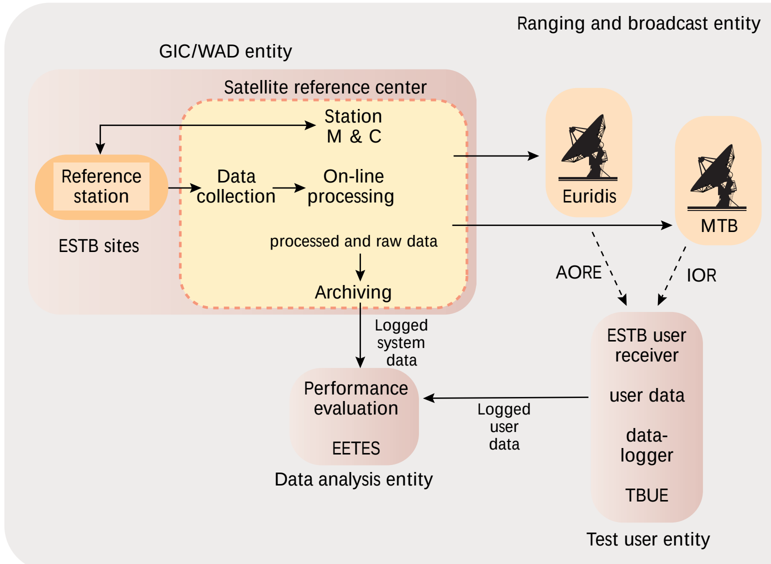

Figure 10. ESTB V1 will operate eight new reference stations, which are now being equipped with GPS/GLONASS receivers, as well as additional processing centres and access stations. This diagram shows the general configuration of the future ESTB V1 ground segment.

Reference Sites and Systems. For this purpose, the stations will contain two receivers: a GPS/GEO unit configured with 10 L1/L2 GPS channels and one L1-GEO channel, and a GPS/GLONASS receiver with 12 L1-GPS channels and 12 L1-GLONASS channels. The new stations are located in Norway (which has two), Iceland, the United Kingdom, the Netherlands, France, Spain, and Turkey. The ESTB-V1 will be completed by two other stations — located in Fucino and Matera, Italy — belonging to another early test-bed version called the Mediterranean Testbed (MTB).

Two processing centres — in Hönefoss, Norway, and Toulouse, France — share the tasks of collecting, archiving, and processing data; generating ranging, integrity, and wide-area differential messages; and monitoring and control of the ESTB.

Two navigation land earth stations (NLES) provide the signal uplink to the Inmarsat-III navigation transponders: one in Aussaguel transmitting to the Inmarsat AOR-E satellite and another located in Fucino transmitting to the Inmarsat IOR (Indian Ocean Region). Only the NLES in Aussaguel is currently equipped to support the so-called "long loop" necessary for the GEO ranging service. Both NLES, however, can be used for the transmission of the differential messages.

Finally, a real time ESTB communication network connects all the various elements of the system using a mix of ISDN links and terrestrial frame relay lines.

Even Better in Y2K. In parallel to the rollout of ESTB-V1, a number of further improvements have already been planned for the year 2000. The first one will be introducing new building blocks to allow for EGNOS trials outside of Europe. Today, the various SBAS systems being developed around the world (the FAA's WAAS, Japan's Multifunctional Transport Satellite-based Satellite Augmentation System, and EGNOS) are optimised to provide a service over their own regions, but, by their nature, the service can easily be expanded to other regions. This could lead to a genuine seamless global SBAS service for users.

Expansion Outside Europe. For this reason, transportable reference stations are being developed for international trials under the European Commission's International Test Bed initiative. In addition, a new message type is being introduced in the ESTB to reflect a very recent RTCA MOPS change on this subject (Message Type 27). A valid ESTB signal-in-space outside Europe is expected in the first half of 2000.

As a result, if they are within the coverage of the ESTB space segment, countries in South America, Africa, the Middle and Far East, the Commonwealth of Independent States (CIS), and even as far away as Australia will be able to perform trials for aeronautical, maritime, and land-mobile applications using the navigation signal generated by the EGNOS System Test Bed.

In the first half of year 2000, additional reference stations will be installed in various parts of Europe. This will provide a network with a density of operational reference stations, which is more representative of the EGNOS network helping the future EGNOS service providers to prepare for the introduction of the operational service.

Finally, a number of other future improvements are currently being discussed, in particular, evolution of EGNOS algorithms within the EGNOS development cycle and also changes in the RTCA MOPS standards, which, although less and less frequent, do still occur.

NEW CENTURY, NEW MILESTONES

In the coming years, prior to the operational implementation of EGNOS in European airspace, various operational test and validation activities will have to be performed. EUROCONTROL is cur-

rently developing a programme plan for these activities, supported by the member states planning to offer EGNOS services as well as by the ATS providers that will operate EGNOS. The ESTB will play a major role in many of these validation activities.

In the year 2000, the ESTB-V1 will be used for static and in-flight data collection activities in an early trials programme. The testbed will also continue to play an important role in demonstration activities. After this, when both the ESTB and the operational test and validation programme are more mature, the ESTB will be used to validate simulation tools used for requirements and standards validation and to collect statistical data for validation of the EGNOS signal-in-space and EGNOS-based operations.

Some European airports that intend to offer EGNOS-based approaches will develop these prior to the EGNOS Operational Readiness Review, with the testbed allowing a first validation of these procedures. The ESTB will also permit the collection of statistical data to support the ICAO Obstacle Clearance Panel to develop criteria for SBAS-based approaches.

The ESTB will not only be used for aviation but also to validate EGNOS for other modes of transport. Multimodal trials have already been planned for the year 2000 involving land, maritime, and rail users.

A Bright Future. Satellite navigation is a major element in the navigation strategy for Europe for the coming decades. The ESTB is driving the development and introduction of the European SBAS element, which will support radionavigation operations and precision approach procedures down to minima close or equal to those for ILS Cat-I. In addition, all users within the coverage of EGNOS will have a general navigation capability at their disposal better than 10 metres 95 percent of the time. This coverage area may even span the globe, once the issues related to the interoperability between the various SBAS systems have been settled.

As participants in the EGNOS project and members of the navigation, positioning, and timing communities, we are all encouraged by GNSS's progress thus far. Now, with the new Galileo constellation serving as a beacon on the satellite navigation horizon, we each have perhaps even more impetus to forge ahead with current plans — maintaining, if not stepping up, the developmental pace set during the past five years.

Europe has changed its role in the GNSS play's cast of characters, creating its own stage with the ESTB and EGNOS and writing its own script with the addition of Galileo. As the curtain rises on Act II, neither the audience nor the players can precisely predict what will unfold. No matter which side of the stage one sits on, though, this story of satellite positioning technology promises intrigue and excitement for many years to come. ◍

MANUFACTURERS

Euridis was developed by the French space agency **CNES** with funding from both CNES and the **French Civil Aviation Administration (DGAC).** MAGNET was originally developed by U.K. electronics company **Racal** with funding from both the European Commission and **National Air Traffic Services Ltd.** The **Defence Evaluation and Research Agency (DERA)** developed part of the airborne software that was used during the flight trials. The experimental airborne user platform (UP) employed during the ESTB trials consists of a modified 10-channel **NovAtel** (Calgary, Alberta, Canada) Millennium receiver connected to a standard L1\L2 GPS antenna. Software developed by **Stanford Telecom** (Reston, Virginia) decodes the ESTB signals. On board the aircraft, a dual-frequency **Ashtech** (now **Magellan,** Santa Clara, California) Z-12 geodetic receiver is connected to the same antenna as the UP. After a flight, data are post-processed using Ashtech's PRISM software. The new ESTB-Version 1 reference stations were developed by **Seatex** (Norway), using NovAtel Millennium receivers to acquire raw data from GPS and the GEO and an Ashtech GG24 receiver capable of receiving GPS and GLONASS data.

Edward Breeuwer *obtained his M.Sc. in electrical engineering from Delft University of Technology in 1992 and his Ph.D. from the same university in 1998 for his work on integrated navigation systems. Since October 1997 he has been working in the Satellite Navigation Centre of Expertise at the EUROCONTROL Experimental Centre, where he is involved in system research and development (R&D)–related activities focusing on implementation aspects of satellite navigation in civil aviation.* **Rick Farnworth** *graduated with a B.Sc. in electronic engineering from the University of Wales*

in 1988 and was awarded a Ph.D. in 1992 for his work on Loran-C coverage prediction modelling. He then joined the U.K. National Air Traffic Services (NATS) to work on civil aviation R&D projects. Since February 1996 he has been with EUROCONTROL *at its Experimental Centre in France, where he is a project leader responsible for various R&D efforts related to satellite navigation and* EUROCONTROL *contributions to the EGNOS Project.* **Paul Humphreys** *is also involved in the EGNOS Project as part of his role within the* EUROCONTROL *Experimental Centre.*

Andrew McGregor *joined the Defence Evaluation and Research Agency five years ago, after obtaining a Ph.D. in avionics from Cranfield University. He is a senior scientist working on satellite navigation's application to civil air traffic management and is project manager for the NATS flying programme. He has been responsible for many flight trials investigating the use of GPS and GLONASS for en route and approach operations, including tests of regional area augmentation, interference mitigation, and the evaluation of height monitoring systems.*

Philippe Michel *graduated from Ecole Polytechnique and Ecole Nationale Superieure des Telecommunications in Paris, France. After a few years at Thomson-CSF, he joined the European Space Agency (ESA) in 1989, where he worked on various telecommunications projects. He was in charge of the Satellite Navigation Laboratory when he joined the EGNOS Project in 1996. He occupies the post of EGNOS system manager within the ESA GNSS-1 Project Office, where he manages activities relating to EGNOS system engineering, ESTB implementation, preparation of EGNOS operations, and EGNOS integration and verification.* **Hugues Secretan** *is a CNES (the French space agency) engineer and has worked in the ESA GNSS-1 Project Office since 1998 as the ESTB manager. He joined CNES in 1983 as a ground segment engineer in the Guyana Space Centre in Kourou. From 1987 to 1994, he was in charge of the positioning phases of geostationary satellites (orbital and attitude manoeuvres on transfer orbits) in the CNES Flight Dynamic Centre in Toulouse. From 1995 to 1998, Secretan was the Euridis Project Manager.*

Steven J. Leighton *is the senior engineer for satellite-based augmentation systems (SBAS), within the same NATS directorate. He has been involved with satellite navigation systems for aviation applications since 1995. He is the NATS project manager for the MAGNET system and is responsible for the planning of all NATS research activities relating to SBAS technology. He received an M.Eng. in electronics from the University of Warwick.* **Kenneth J. Ashton** *is currently the deputy engineering manager — navigation, within the National Air Traffic Services (NATS) Directorate of Infrastructure Services in Gatwick, United Kingdom He has been with NATS for more than 25 years working as an engineer and project manager with ILS, VOR, NDB, DME, and satellite systems. He is working on NATS activities within EGNOS and has played a key role in the successful application of the MAGNET testbed to aviation applications.*
