Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

Executive summary

EGNOS Flight Trials, Evaluation of EGNOS Performance and Prospects

Description of work
Flight trials are performed with NLR's research aircraft at four locations in Europe for the dynamic verification of EGNOS (European Geostationary Navigation Overlay Service) under highly dynamic conditions as part of the EGNOS-AIV project phase. EGNOS performance was measured in terms of accuracy, availability and integrity. Also EGNOS prospects for the aeronautical community were demonstrated. An EGNOS-based offset approach procedure for the Lugano TMA was designed by Skyguide, the Swiss air traffic service provider, and used in approach trials, while for Almeria airfield RNAV procedures designed by AENA, the Spanish air traffic service provider, were tested in EGNOS-guided aircraft flight trials.

Results and conclusions
Results of EGNOS performance under dynamic conditions are provided in terms of accuracy, availability and integrity and presented vs. ICAO's requirements for GNSS Navigation Service Levels APV I, APV II and Cat I. Results of GPS/EGNOS guidance capability vs. ILS are provided in terms of Navigation Sensor Error, the Flight Technical Error and Total System Error. With an accuracy equal to or better than Cat I ILS, the obtained EGNOS guidance capability shows, although not yet fully mature at the time, the advent of a promising new European navigation aid for the aeronautical community, especially for those environments and procedures for which the traditional means such as ILS either cannot be used or are not available.

Applicability
Results are not generally applicable, but represent only the status of EGNOS at a specific moment during its development; the EGNOS system was still under construction and will improve in time. The measurement approach will be applicable in future EGNOS and Galileo trials, not only for aircraft trials, but also more general in ship, train and vehicle related trials.

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EGNOS Flight Trials, Evaluation of EGNOS Performance and Prospects

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Summary

In 2004 and 2005 EGNOS, the European SBAS implementation, was tested both under static and dynamic conditions as part of the EGNOS-AIV System Verification. The dynamic measurements were collected by means of aircraft flight trials. The objectives of these flight trials were primarily focusing on the EGNOS system verification; collected data were used as input for the EGNOS Operational Readiness Review, which was held in June 2005. Apart from the EGNOS system verification, the flight trials experiment set-up and selected locations also supported assessment of EGNOS' aircraft guidance capabilities under various flight conditions, showing possible prospects of EGNOS for the aeronautical community.

After briefly describing the EGNOS architecture and specifying the primary and secondary objectives of the EGNOS-AIV flight trials, the experimental set-up and execution of EGNOS flight trials at four locations in Europe are presented, including the design of the Lugano offset-approach and Almeria RNAV procedures. Results of GPS/EGNOS guidance capability vs. ILS are provided in terms of Navigation Sensor Error (NSE), Flight Technical Error (FTE) and Total System Error (TSE). This guidance capability together with EGNOS' accuracy, availability, integrity and continuity figures vs. ICAO's requirements for Navigation Service Levels APV I, APV II and Cat I shows, although not yet fully mature at the time, the advent of a promising new European navigation aid for the aeronautical community, especially for those environments and procedures for which the traditional means such as ILS either cannot be used or are not available.

Contents

(26 pages in total)

Abbreviations

AIV	Assembly, Integration and Verification
APV	Approach Procedure with Vertical Guidance
ATM	Air Traffic Management
CCF	Central Computing Facility
CPF	Central Processing Facility
EGNOS	European Geostationary Navigation Overlay Service
FIS	Flight Inspection System
FTE	Flight Technical Error
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HPE	Horizontal Position Error
HPL	Horizontal Protection Level
ICAO	International Civil Aviation Organization
IGS	Instrument Guidance System
ILS	Instrument Landing System
MCC	Mission Control Centre
MLS	Mean Sea Level
MOPS	Minimal Operational Performance Standard
NLES	Navigation Land Earth System
NSE	Navigation Sensor Error
PVT	Position Velocity Time
RF	Radio Frequent
R-FMS	Research Flight Management System
RIMS	Reference and Integrity Monitoring Systems
RNAV	Area Navigation
RWY	Runway
SARPs	Standards and Recommended Practices
SBAS	Space Based Augmentation System
SIS	Signal In Space
SNR	Signal to Noise Ratio
THR	Threshold
TSE	Total System Error
TUE	Test User Equipment
UTC	Universal Time Code
VPE	Vertical Position Error
VPL	Vertical Protection Level
WAN	Wide Area Network

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Introduction

The EGNOS verification flight trials described here are the dynamic part of the static and dynamic on-site EGNOS testing campaign after its operational deployment. It was the final activity of the EGNOS-AIV project phase, leading to EGNOS Operational Readiness Review milestone, June 2005. During the trials activities 31 out of the planned 34 RIMS were deployed, together with all four MCC's and six NLES. A varying number but in general two out of three GEO's was available, for most flight trials activities PRN 126, the IOR-W, was used as primary GEO. During in total 70 hours of flight tests under various conditions, EGNOS performance in terms of accuracy, availability, integrity and continuity was measured and verified vs. its system requirements and also vs. ICAO's GNSS requirements for Navigation Service Levels as specified in Annex 10 to the ICAO convention. These trials and subsequent analysis can be seen as a first step to validation of EGNOS for aeronautical application, in particular for ICAO's navigation service levels APV I and II.

Egnos system concept

As introduction to the flight trials the EGNOS mission and system concept is briefly summarized (please refer also [2]). The primary mission objective is to augment GPS and GLONASS by an additional signal from up to three geostationary satellites (GEO) according to DO-229 to increase position integrity and accuracy.

EGNOS provides for each GEO separately a synchronous, pipelined, real-time computational chain: GPS and GLONASS signals are received by reception stations at 33 locations (RIMS, plus one coupling EGNOS in real-time with UTC_LPTF providing standard UTC). The data from the reception stations are transmitted through a fully meshed wide area network (WAN) to the processing facility (CPF). The CPF performs a variety of checks on the received data in order to discard erroneous measurements and detect potential integrity failures. From the filtered data the wide area differential corrections and integrity data are computed and formatted as SBAS messages. The latter are scheduled for each GEO for transmission and sent one per second over the WAN to Uplink stations (NLES) for dissemination over the particular GEO. Through the RIMS network the CPF receives its previously generated data and thus can supervise the integrity of the data as well as of the system.
One cycle takes 5 seconds which includes buffer times to accommodate variations in the data transfer through the WAN. All subsystems in this chain have strict time windows within which the data for a particular cycle must arrive to be accepted or the failure is flagged to the operator.

The necessary time synchronization of all subsystems is achieved by use of the GPS signal and real-time software for processing.

The following figure reflects the main signal path and the involved subsystems.

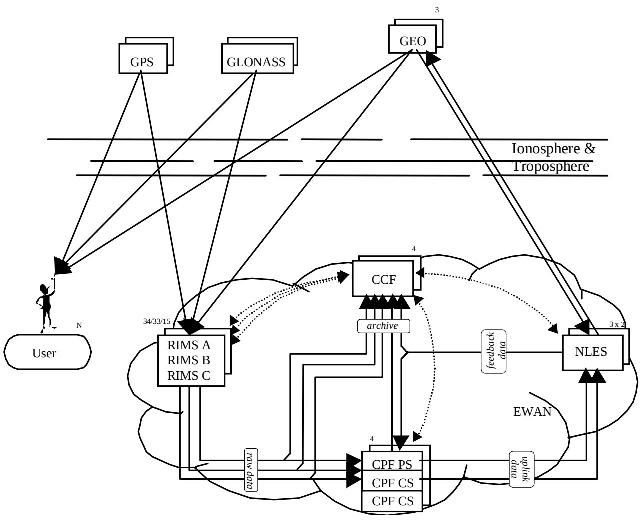

Fig. 1 Main signal paths in the EGNOS system

The CCF serves for monitoring, control and online data archival. Each uplink station provides an equipment called long loop through which the timing of the GEO signal is controlled such that it can be used as a GPS-like ranging signal. The fine-control at nano-second level is accomplished by steering orders computed at the CPF making use of the receptions from remote RIMS sites (for precise orbit determination).

To increase the availability CPF and NLES are realized in hot-redundancy. A CPF switch occurs from one to the next epoch undetectable to the user (after full CPF convergence), 5 CPFs are available in the system. Per GEO there are two NLESes, one radiating, the other in hot-backup mode. A NLES switch (triggered by the loss of the RF signal as detected by CPF through the RIMS network) effects the other NLES to start-up and stabilize the RF which takes 8 seconds causing a data gap of that duration which thus would be visible to the user. Excessive delays or packet losses over the WAN were found to cause negligible system performance effects at user level if the outage is at the order of maximum few seconds, otherwise partial degradation in affected regions within the service volume result. Also the GEO footprints overlap for redundancy reason, the effect of a GEO switch in the user domain was therefore a test objective during the flight trials (triggered by the loss of an initially selected GEO).

The CCF hosts the system operator who monitors and controls the system and mission. There are 4 CCFs in the system out of which typically two would run in hot-redundancy (with one taking the master role), the others in cold-redundancy (i.e. unmanned). The next diagram presents the external interfaces of EGNOS, to exchange mission relevant data (via the Performance Assessment facility PACF) and to provide additional data services.

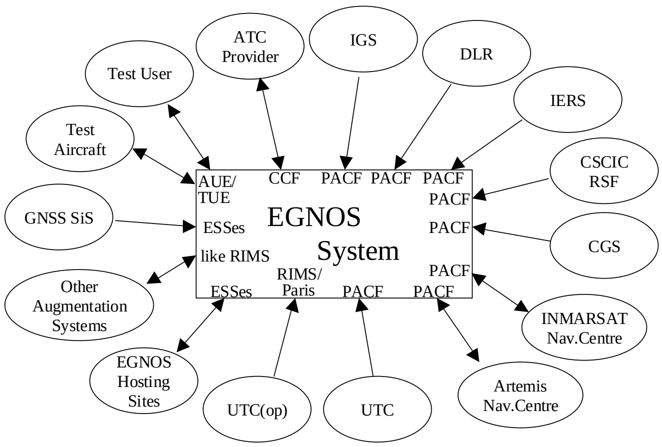

Fig. 2 Main signal paths in the EGNOS system

Flight trials objectives and locations

The overall objectives of the flight trials were twofold:

- 'To verify at technical level and also to demonstrate to user community, that EGNOS navigation performances are met by a user equipped with a MOPS compliant receiver under dynamic conditions.'
- 'To contribute, in complement to baseline verification activities, to system performance verification on the deployed system. For this purpose, flight trials activities schedule were arranged so that system performance qualification review could take into account observations results.'

From these high level objectives a number of parameters to be measured were derived in order to enable assessment of both EGNOS system performance qualification and also assessment of its capabilities in view of ICAO's GNSS requirements. These parameters were grouped into Category A (mandatory and at generic site), B (specific location required) and C (either not precisely identified within EGNOS-AIV or more related to application in civil aviation). Based on these identified parameters and taking into account the constraints of 70 available flight hours at maximal 4 different locations (thus limiting low value ferry hours and also airfield authorities able and willing to support the trials), the following sites were selected:

- Eelde (The Netherlands) for the generic parameters;
- Lugano (Switzerland) for EGNOS performance assessment in mountainous environment;
- Montpellier (France) for basic measurements at a different site at ECAC centre
- Almeria (Spain) for assessment of EGNOS performance at ECAC border.

Test system concept

Aim of the flight trials was on the one hand measurement of EGNOS performance parameters under dynamic conditions vs. ICAO's GNSS navigation requirements and on the other hand the more loosely defined assessment of EGNOS guidance capability in mountainous environment and in RNAV procedures, the FTE and TSE and the comparison of EGNOS with ILS characteristics. This aim resulted into an experiment set-up as depicted in figure A1 (ANNEX). The measurement set-up was comprised of both an aircraft integrated part and a ground-based part that in general was installed close to the runway. Functionality of the airborne equipment can be divided into three subsystems:

- EGNOS receivers
- Reference systems
- Aircraft guidance system with pilot in the loop

All EGNOS/GPS and GPS receivers were connected to the same antenna in order to obtain exactly the same signal enhancing comparability and avoiding lever arm corrections involvement. In addition to the TUE (the EGNOS Test User Receiver), a Topcon Legacy EGNOS receiver was applied for feeding the Research Flight Management System (R-FMS) with EGNOS/GPS PVT updates in order to provide guidance. This Topcon is known for its high frequency (20Hz), low latency position updates. (The TUE, with 1 Hz position updates, was not designed for aircraft guidance.) Finally a Septentrio PolaRx2 EGNOS receiver was applied on board as third receiver for two reasons: it provided possibilities to distinguish SIS anomalies from receiver specific behavior. A second reason is the fact that TUE raw data is less assessable than the popular Septentrio receiver for third party researchers, such as aeronautical research organizations, interested into analyzing the collected data.

The fourth receiver connected to the same GNSS antenna was a Trimble MS750 GPS receiver. This 'rover' receiver was used as one of the two truth reference systems. Together with a base station near the runway carrier differential truth reference positions of the aircraft could be obtained in post-processing. While providing decimeter accuracy, a disadvantage of this truth reference is its GNSS dependency, although the carrier differential position determination should be considered as a completely different technique. A Flight Inspection System (FIS) encompassing a laser tracker system provided for GNSS-independent reference positions, unfortunately with two drawbacks: its lower accuracy and the fact that it can only be applied during approximately 10 km final approach. A bonus was the introduction of the possibility to assess ILS accuracy during the same trails (in case ILS guidance was selected by the pilots).

The third on-board sub-system was related with the guidance investigations. The Topcon EGNOS receiver provided the Research Flight Management System (R-FMS) with PVT in order to provide EGNOS guidance to the pilot. This R-FMS is an in-house developed facility for research on various ATM related topics, such as data link, navigation and operational procedures. With this R-FMS the pilot could select the required procedure, which trajectory was available from its internal database as a sequence of 3D waypoints. By means of keeping the centre of a ‘Flight Director’ at the required location on the Primary Flight Display, the aircraft is optimally guided along straight as well as curved trajectory segments. The R-FMS provides for extensive data logging capabilities, enabling various analysis opportunities after the flight. The airborne part of the FIS system served both for control and logging of the laser tracker truth reference system and for logging of ILS receiver data.

Near the runway ground-based equipment was positioned at accurately known positions: the laser tracker, the ground-based Trimble GPS base station, a TUE and Septentrio counterpart of the airborne systems. These TUE and Septentrio EGNOS receivers were installed for enabling comparison of dynamically (airborne) acquired PVT with nearby statically obtained EGNOS PVT. In this way the effect of dynamics of the GPS/EGNOS performance, but also SIS shadowing events and aircraft induced multipath could be studied.

Test campaigns

In total three test campaigns were realized: first the final aircraft installation tests were executed in a few ‘shake down flights’ conducted at Eelde airfield in the Netherlands. After formal approval of the test results, the basic trials (Category A) were conducted at Eelde. This campaign was immediately followed by the November 2004 campaign at the Lugano and Montpellier airfields. After the Montpellier operations it was decided to discontinue the trials, because the EGNOS system was still too much under construction: due to ongoing development periods of excellent performance were alternated with periods of SIS unavailability or reduced system performance. Waiting for a more mature EGNOS was considered more fruitful, giving a more realistic view of the EGNOS performance and its prospects for aeronautical application. April 2005 the EGNOS trials were restarted with execution of the Almeria RNAV procedures

followed by a repetition of the Lugano trials. Almost all results discussed come from the trials of April 2005.
The following table summarizes the flight operation types at each location and realized flight hours.

Table 1 Realized Flight Hours and Approaches

Operation	Site	Flight Hours	Nr of Approaches
‘Basic’ approaches	Eelde	9	46
Mountainous approaches	Lugano	15	22 28
ILS look-alike Approaches	Montpellier	10	33
RNAV Procedures	Almeria	9	37
Ferry / en route	-	27	-
Total		**70 hrs**	**166**

Data processing

Data processing systems that were used in order to obtain the results shown below are the Flight Inspection System post-processing environment, GrafNav 7.0 for obtaining Carrier Differential data from raw GPS rover and base-station data at decimeter accuracy and EUROCONTROL’s PEGASUS tool, which is developed for analysis of data obtained in GBAS and SBAS type flight operational tests.

1. GrafNav

GrafNav is a PC-based software tool capable of obtaining PVT reference data in post-processing mode at decimeter accuracy, interfacing with raw data from GNSS-receivers data of several brands and types. It needs rover data and base station data, where obtained result accuracy and data quality increases with the number of applied base-stations and with the reverse of rover – base-station distance. Quality control and performance of the tool is excellent. GrafNav’s error estimation was checked in a relative way by combining rover data with simultaneously recorded data of base-stations at different locations. Comparing the obtained reference positions indicated the tool’s consistency and the correctness of its position error assessment.

2. Flight Inspection System

From comparing the laser tracker obtained reference positions with GNSS reference data it was determined that the laser tracker accuracy varied from decimeter accuracy at runway threshold to few meter accuracy at a 10 km distance, worse than expected on beforehand. The effect of reduced accuracy at larger distances finds its origin in the fact that the error has an angular component: the (small) errors in azimuth and elevation angles that are made build up to significant position errors at large distances. For this reason the FIS reference data was only used as quality check for the GPS carrier differential reference positions.

3. PEGASUS and AIV platform

PEGASUS 4.0 is used for analysis of Septentrio raw data. PEGASUS does not have a TUE interface, while the AIV-platform only processes TUE data. For this reason one should be careful when comparing Septentrio vs. TUE results using PEGASUS vs. AIV-platform: PEGASUS is RTCA DO 229C compliant, while AIV-platform complies with DO 229A.

Results

Concerning EGNOS operation during the flight trials, 5 RIMS of the deployed 31 were not available due to maintenance, but this caused only a negligible effect on the provision of the ionospheric corrections. During a few occasions network performance degraded causing a slight degradation of the system performance at user level, partly while flights were executed. Note also that at the time of the flight trials no GLONASS augmentation was in use. Although still not all identified corrections had been implemented the system yet demonstrated in the final part of the flight trial campaigns a good level of signal stability and good service accuracy and integrity performances adequate for conducting the flight trials.

1. General obtained results

In total 166 approaches were flown yielding 43 hours of on-location recorded data that has been subjected to analysis. (Ferry data was not analysed, however this could produce valuable additional results and statistics.)

In the table 2 the performance of this 43 hours data are presented in terms of availability during which APV-I and APV-II conditions were met vs. ICAO requirements. Between the 2nd and 3rd campaign the EGNOS system stability has improved considerably. The figures of the 3rd campaign are therefore more representative for what may be expected, although still fine tuning activities were going on.

Table 2 Obtained EGNOS availability figures

	Dynamic		Static		ICAO requirement	
	APV-I	APV-II	APV-I	APV-II	APV-I	APV-II
Total	89,5%	68,2%	87,3%	71,5%	99% to 99.999%	99% to 99.999%
2nd Campaign	83,8%	60,1%	78,3%	60,7%		
3rd Campaign	96,5%	78,1%	98,2%	84,9%		

2. EGNOS dynamic vs. static performance

EGNOS dynamic vs. static performance figures could best be assessed from data collected at Eelde in the Netherlands, where - contrary to Lugano (Alps) and Almeria (Sierra Nevada) - a clear view to the horizon in all directions is available. When comparing the dynamic PVT-accuracy, availability and integrity figures vs. those collected under static conditions at the same location and time, it learned that performance figures are almost identical. Analysis revealed that the major source of EGNOS/GPS performance deterioration comes from aircraft (banking or pitching) maneuvers, introducing short periods of shadowing of GPS and/or GEO satellites by the body of the aircraft or, not unimportant, deterioration of SNR, because of too low satellite 'elevation' caused by the tilt of the antenna during aircraft banking. An interesting example of such an occurrence is given below.

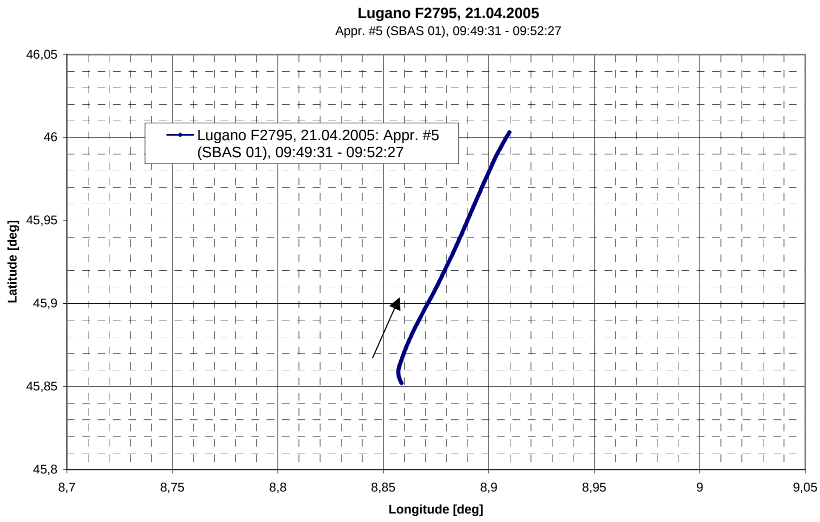

Fig 3a Horizontal trajectory causing loss of up to 3 satellites

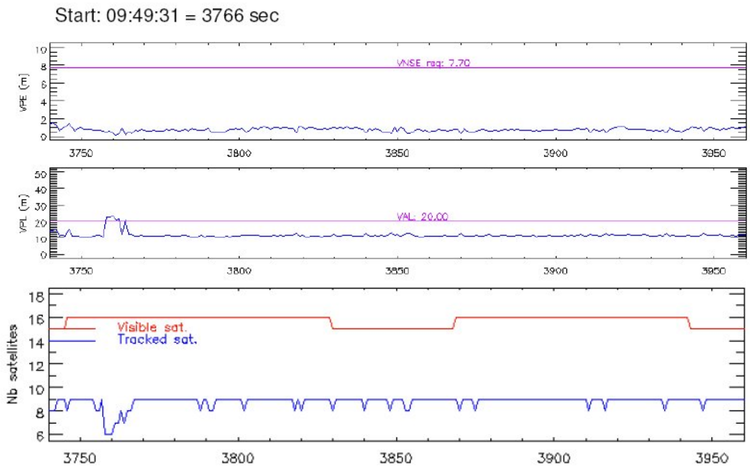

Fig.3b VPL increase during Lugano approach caused by loss of up to 3 satellites

This Lugano approach (21/04/2005, 09:49:31 – 09:52:27) starts with intercepting the SBAS trajectory at OLIVE Final Approach Fix introducing a sharp bend prior to flying the final approach to the runway (for the flight operational procedure, see also figure A2, ANNEX). The bend caused the number of corrected satellites used by the TUE to drop from 9 down to 6 during 8 seconds. Note that the number of visible satellites did not change! Consequently the XPL values increased to above APV II Vertical Alarm Limit, introducing a short APV II availability and continuity interruption of 8 seconds. Future developments on GNSS receiver and antenna specially designed for aeronautical usage could be capable of tackling this problem.

3. EGNOS performance vs. ICAO SARPs

During the flights executed within the third campaign EGNOS already show very promising accuracy, availability and integrity figures under dynamic conditions relative to the ICAO's GNSS navigation Service Levels APV I and II. During all analyzed hours of recorded data not even one integrity violation was recorded. Few percent of AVP I unavailability can be contributed to aircraft dynamics, while another few percent could be contributed to EGNOS instabilities still occurring now and then, which are likely to be solved in the near future. The best results so far were obtained during the 3rd campaign Lugano trials and provide excellent prospects for the future. The positional accuracy and availability figures, shown in figure 4 for the Lugano flight of 21/04/2005 8:17 – 10:34 UTC reveal its excellent performance, e.g. the measured 95% HPE and VPE were 1.3 m and 1.1 m (VPE better than HPE). What is especially interesting is the excellent 'safety index', i.e. the xPL/xPE ratio, which for the trial showed has a value in the order of 5 or higher.

Fig.4a HPL and HPE of Lugano flight 21/04/2005

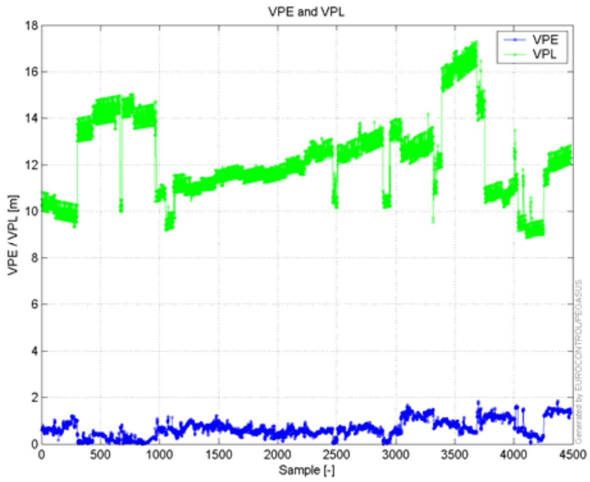

Fig.4b VPL and VPE of Lugano flight 21/04/2005

4. EGNOS performance in mountainous environment

The Lugano SBAS approaches were prepared and executed in order to demonstrate possible flight operational benefits provided by EGNOS for special (e.g. mountainous) environments. Already within the Nice and Sion ESTB trials possible GNSS benefits were demonstrated. The Lugano airfield is another example of an airfield with ‘a problem’. The problem of the Lugano airfield is a mountain in the extension of the runway centerline, blocking a standard ILS 3 degrees glide slope from Final Approach Fix to the runway. Instead of an ILS, Lugano Airfield operates a so-called IGS ‘Instrument Guidance System’ with a glide slope of 6.65°. Only very few aircraft types are certified for this steep approach, leaving Lugano with an unavailability problem for many airline operators. Another issue is the difficult missed approach procedure, requiring a sharp turn to the right and leaving very little time for hesitation. Skyguide, the Swiss

Air Navigation Service Provider has developed an experimental SBAS approach procedure (including missed approach) with a lateral offset relative to the runway centerline of 5°. From this direction the approach GS angle may be reduced to 5.50°. This reduced GS provides for a significant increase of aircraft types certified for this kind of procedure, when EGNOS would be available.

During the Lugano EGNOS operations the IGS approach procedure was flown 22 times, while the SBAS approach was used 28 times including the missed approach procedure. The demonstrated advantages of the SBAS procedure are evident for the airfield and the airliners and in addition, the pilots appreciated the new SBAS approach better than the standard published approach procedure, mainly because of its positive guidance during the missed-approach procedure (including its steep banking angle), which significantly reduces the pilot's workload during this critical, stressful situation.

5. Almeria RNAV procedures: EGNOS vs. ILS Cat 1 NSE, FTE and TSE

For the Almeria TMA trials AENA had designed 5 RNAV procedures. The procedures started at 6000 ft. above MSL and provided for straight and curved continuous decent approaches to RWY 26 and 08. An ILS was operational for RWY 26. An excellent scenario for testing the aircrafts Navigation System Error (NSE), Flight Technical Error (FTE) and Total System Error (TSE) for both GNSS guided and ILS guided operations. The definitions of NSE, FTE and TSE are illustrated in figure 5.

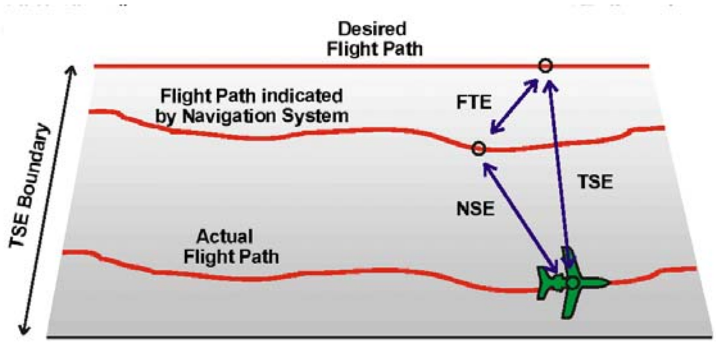

Fig. 5 Definition of NSE, FTE and TSE parameters (courtesy EUROCONTROL)

The FTE is provided as guidance information to the pilot during the flight, while the NSE and TSE can only be determined using truth reference after post-processing the data. In figure 6 the FTE of both GNSS (BASIG curved procedure to RWY 08) and ILS guidance are presented. The FTE during EGNOS procedures was recorded by the R-FMS, while the ILS FTE was obtained by the FIS recording the deviations of the aircraft's ILS receiver. The FTE in general find its origin in a combination of aircraft characteristics, guidance avionics, pilot and weather. In general the most important one of these sources is difficult to determine and different from occasion to occasion. The influence of the navigation sensor on FTE should be very limited. Note that the ILS-based FTE can be recorded during the last 10 km of final approach to runway threshold, while the GNSS-based FTE is provided during the complete RNAV procedure. During the RNAV procedure especially the horizontal FTE deviations are significant. These deviations are mainly introduced by the fact that in the horizontal plane the trajectory was composed of a combination of straight and fixed radius turn segments, which transition aircraft are unable to follow precisely for physical reasons. The obtained Almeria FTE's are larger than for instance those found for the Nice curved approach. The most important two differences: at Nice a Cessna Citation was used instead of the Swearingen Metro at Almeria and Almeria was very windy during the trials contrary to Nice [4].

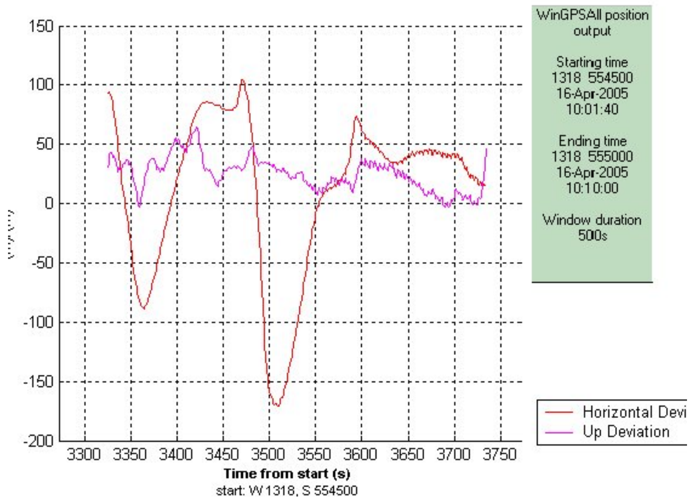

Fig. 6a Vertical and horizontal FTE's while flying an Almeria GNSS RNAV procedure

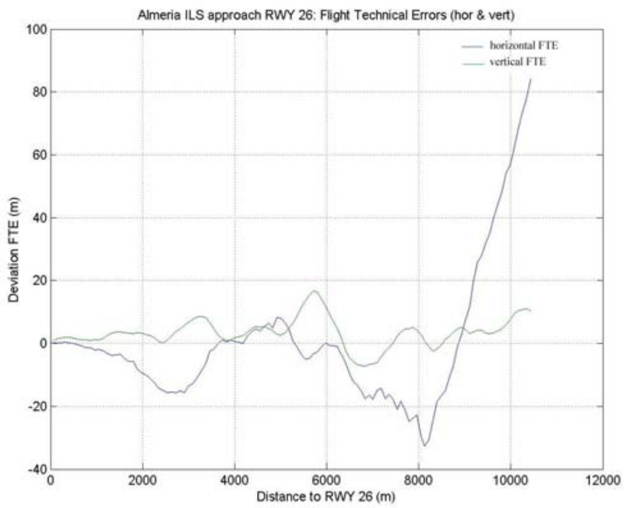

Fig. 6b Vertical and horizontal FTE's for Almeria ILS approach

In figure 7 instances of NSEs of both GNSS and ILS are presented. The EGNOS NSE is obtained using GrafNav (truth reference) and PEGASUS, while the ILS NSE is obtained using FIS. This latter ILS NSE measurement is somewhat less accurate, due to the very windy conditions during laser tracker operation. For path definition the following input and assumptions are used:

- The position of the localizer, direction of beam into extension of runway centerline (determined by surveying two THR positions) and runway width is half scale at THR.
- The GS nominal path has by definition 50 ft. elevation at THR and 3° glide slope subsequently.

The results show that:

- GNSS in general provides better NSE than ILS, especially at larger distances to THR;
- FTE in general is much larger than NSE and is the dominant component of the TSE.

It should be noted that although the ILS positional performance was worse than GNSS at larger distances to THR, it is still very well within ILS requirements (see [7] and [1]), while at larger distances ILS would not comply ICAO’s GNSS CAT I requirements. The origin of the difficulty of EGNOS complying with CAT I requirements, however is not caused by its accuracy, but by the very stringent integrity and availability requirements, i.e. the XPL’s.

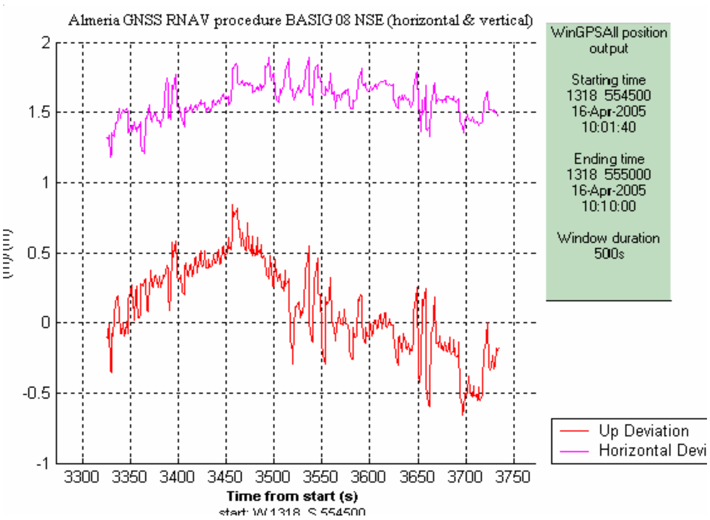

Fig.7a Vertical and horizontal NSE’s while flying an Almeria GNSS RNAV procedure

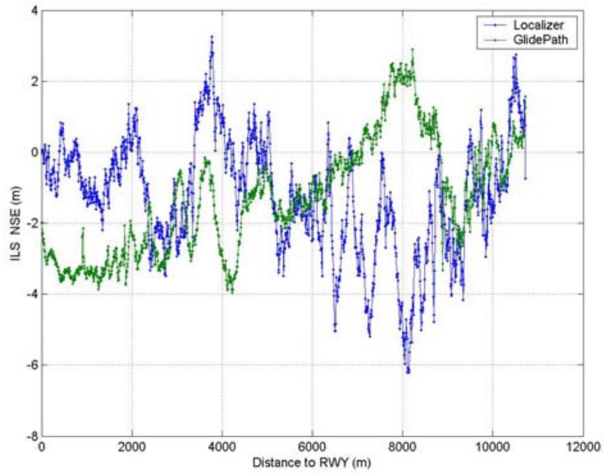

Fig. 7b Typical Localizer and GlidePath deviations measured when selecting ILS approach

Conclusions

Although the EGNOS system was not yet fully mature and stable at the time, within this project it already demonstrated the prospects that EGNOS may provide for the aeronautical usage within the ECAC area. The numerous and different flight operations in various environment, allowed to quantify EGNOS performance vs. ICAO's GNSS requirements in terms of accuracy, availability, integrity and continuity under various conditions, e.g. straight-in (ILS look-alike) approaches, RNAV procedures, special procedures in mountainous area.
The most important conclusions that may be drawn are:

- When in 'stable' condition the average in-flight EGNOS accuracy was better than 1 meter, well within even CAT I requirements;
- During 70 hours of flight data no integrity violation was observed;
- EGNOS availability performance vs. APV I is already almost demonstrated, although additional statistics is required. Unavailability is mostly due to small EGNOS problems that may be solved on short term and antenna / receiver design. APV II availability compliance is still to be demonstrated;
- No significant difference in performance was observed between four test sites.
- EGNOS is capable of providing excellent aircraft guidance, appreciated by the pilots;
- EGNOS may offer significant benefits for 'special' environments such as the Swiss Alps;
- Under standard flight conditions EGNOS Navigation System Error in general is significantly smaller than the aircraft's Flight Technical Error;
- EGNOS position accuracy demonstrated as equal to or better than Cat I ILS;

- Additional statistics and evidence in flight trials will need to be collected, when the EGNOS system has reached its full operational capabilities;
- Further improvements could be envisaged on SBAS receiver / antenna design specific for aeronautical application as well as improvements in its aircraft installation. Together with guidance avionics specially designed for SBAS input it may further improve SBAS performance for aeronautical application.

The results from the executed flight trials provide already a promising indication of future EGNOS capabilities. The performance figures presented are only an indication for one moment in time as improvements of the system were still ongoing.

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Annex

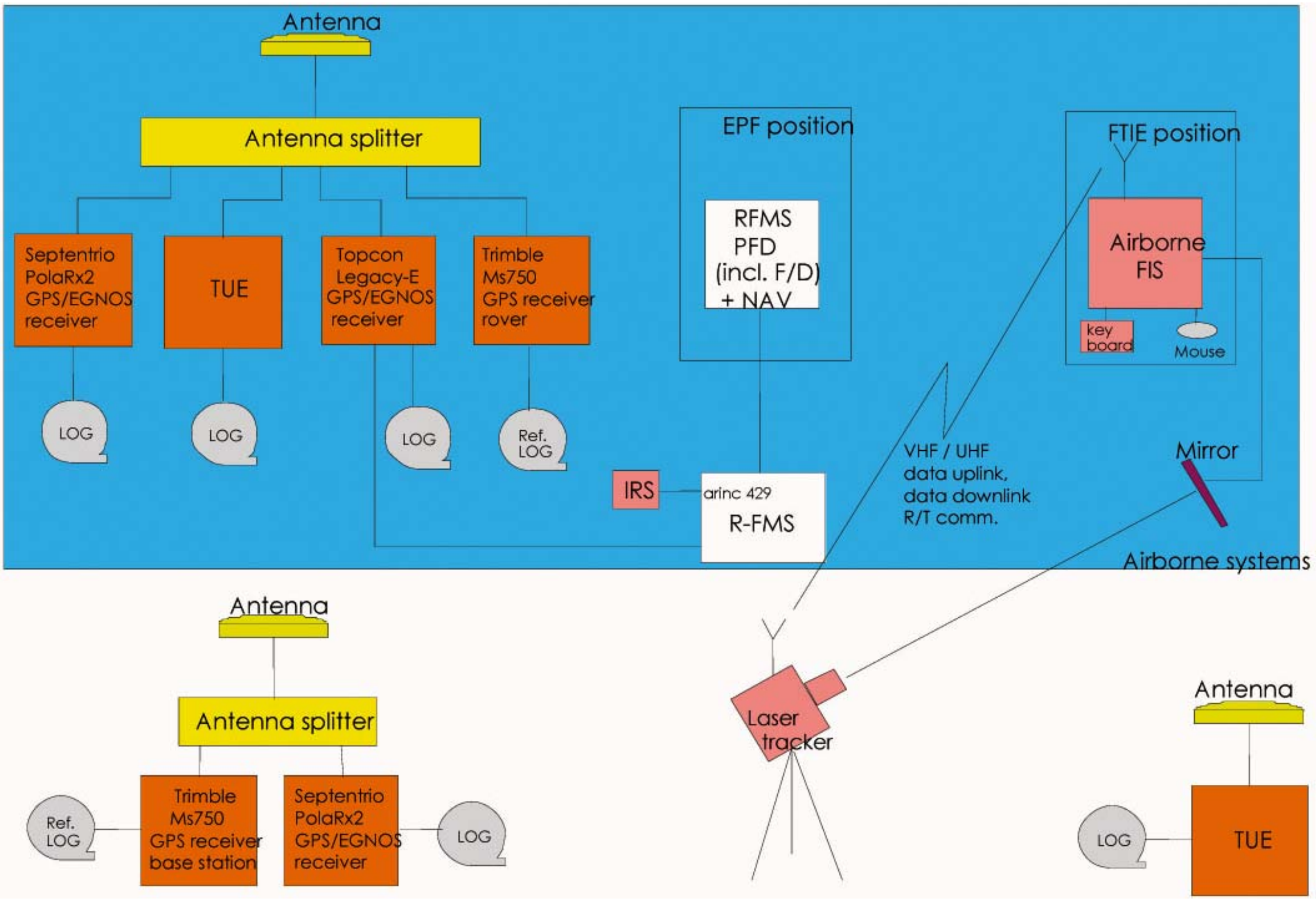

Fig. A1 Equipment integration scheme

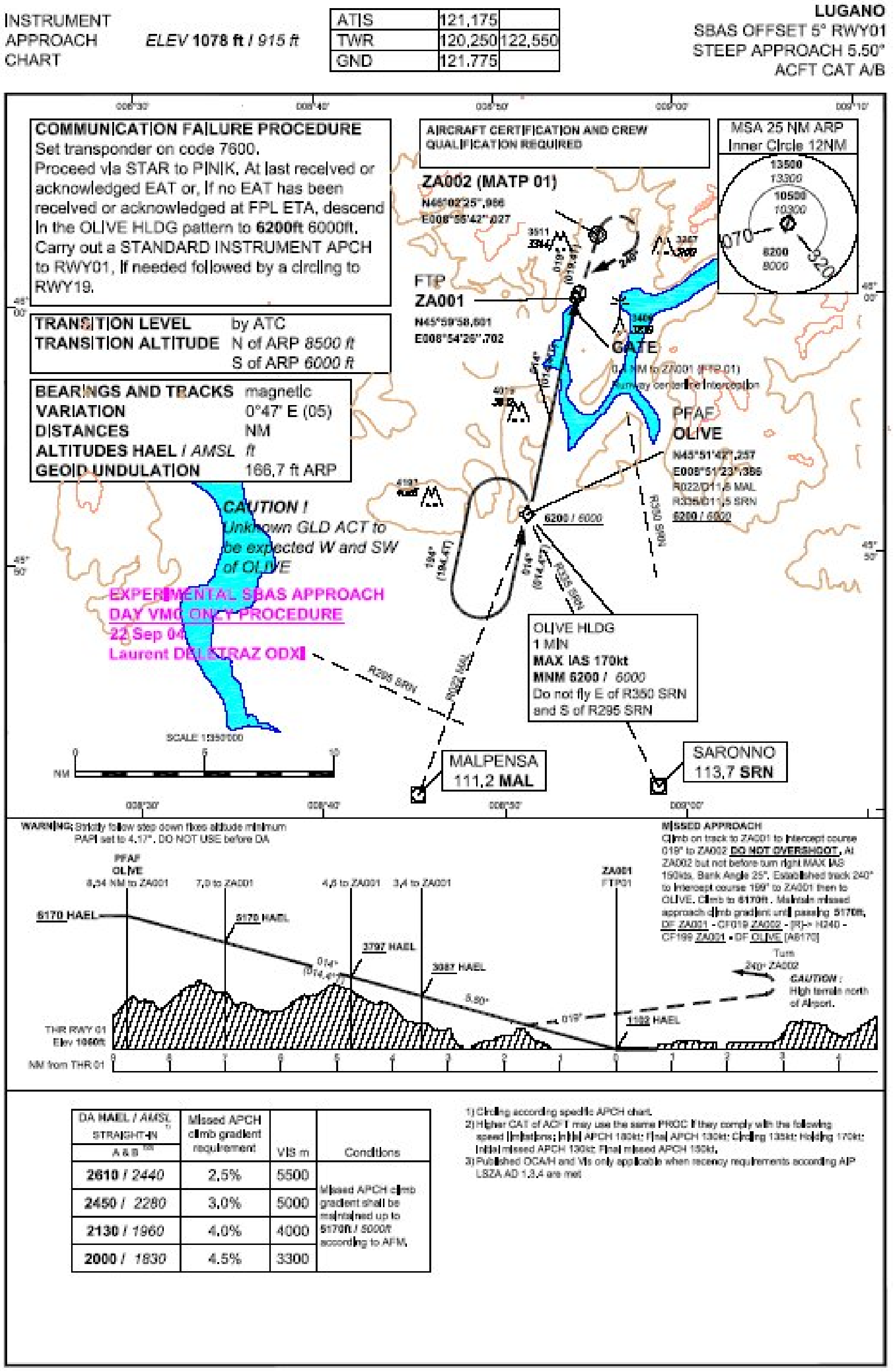

Fig.A2 Experimental Lugano SBAS Instrument Approach Chart