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Flying EGNOS Approaches in the Swiss Alps

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The European Geostationary Navigation Overlay Service (EGNOS) system is being developed in Europe to provide Global Positioning System (GPS) and GLONASS regional augmentation services to aviation, maritime and land users. The EGNOS system, as any other Wide Area Augmentation System (WAAS), relies on the broadcast of differential correction and integrity information in the pseudo-range domain, which are then used to provide a solution in the position domain. EGNOS is a major element of the European Satellite Navigation Program, which is jointly being implemented by the Commission of the European Union, the European Space Agency (ESA) and Eurocontrol (the European Organisation for the Safety of Air Navigation). It is also the first European step to the GALILEO system.

As part of the EGNOS validation activities, flight trials have been organised by ESA and the EGNOS Industrial Consortium at various locations in Europe during Spring 2005. To demonstrate the system capability in a challenging mountainous environment, tests have been conducted at Lugano airport in the Swiss Alps. Due to the difficult topography of the airport and its surroundings, the use of conventional ground based navigation aids present some limitations. For the trials, a new Satellite Based Augmentation System (SBAS) procedure has been designed to take advantage of the system flexibility. In particular, a reduction of the approach glide path angle has been achieved, potentially allowing more aircraft types to fly the approach than today. This article presents the operational benefits that could be obtained with the new test procedure. The very impressive EGNOS performance is also described in details, showing that it can support Approach Procedure with Vertical guidance (APV) operations even in a very challenging environment.

KEY WORDS

1. EGNOS. 2. SBAS. 3. Approach procedure.

1. INTRODUCTION. The city of Lugano, whose population amounts to about 30 000 inhabitants, is located on the Southern side of the Swiss Alps. Its famous banking and tourism industries makes it a very popular destination for many travellers every year. In this respect, Lugano's regional airport (LSZA) is an important part of the transportation infrastructure in the region. However, it is facing many challenges due to its difficult topographical situation. Indeed, the 1350-metre long runway lies at an altitude of only 280 metres above mean sea level and is surrounded by mountains as high as 2000 metres (see Figure 1). For this reason, providing navigation assistance to the regional airliners and the business jets operating into Lugano, is a demanding task. The challenging topography makes it difficult to take full benefit of the conventional ground based navigation aids. Under poor weather conditions, a special qualification is requested from the flight crew. Sometimes (on average between 15 and 20 days per year) the airport even has to be closed due to the high minima of the current procedure.

2. EGNOS. In order to improve the current situation in terms of navigation service provision, EGNOS is seen as a potential candidate. In particular, EGNOS will allow equipped aircraft to fly APV-I and APV-II approaches, as standardised by the International Civil Aviation Organisation (ICAO), with a permanent lateral and vertical guidance along the entire approach path. The characteristics of these two types of approach, from a Signal-In-Space perspective, are defined in Table 1 (see also [1]). For information purposes, the values for an Instrument Landing System (ILS) CAT-I precision approach have been added.

As a reminder, EGNOS is an augmentation system to the existing GPS, compliant with the ICAO Standards and Recommended Practices (SARPS) for SBAS [1]. As such it will be fully compatible with the other SBAS, namely WAAS in the United States, Multi-transport Satellite Augmentation System (MSAS) in Japan and GPS and Geostationary Earth Orbit Augmented Navigation (GAGAN) in India.

EGNOS technical qualification was successfully held in June 2005 and since July 2005 EGNOS has entered an 18-month initial operations phase. It should be completed by early 2007 with the formal qualification of the EGNOS operations and the start of the safety-of-life applications. At this time, certified receivers will be able to use EGNOS for the stringent applications of civil aviation.

Table 1. Characteristics of the Approaches with Vertical Guidance APV-I and APV-II and the CAT-I precision approach.

	APV-I	APV-II	CAT-I
Horizontal Accuracy requirement 95%	16·0 m	16·0 m	16·0 m
Vertical Accuracy requirement 95%	20·0 m	8·0 m	6·0 to 4·0 m
Integrity requirement	1–2 $\times 10^{-7}$ per approach	1–2 $\times 10^{-7}$ per approach	1–2 $\times 10^{-7}$ per approach
Time-to-alert	10 s	6 s	6 s
Availability requirement	0·99 to 0·99999	0·99 to 0·99999	0·99 to 0·99999
Continuity requirement	1–8 $\times 10^{-6}$ in any 15 s	1–8 $\times 10^{-6}$ in any 15 s	1–8 $\times 10^{-6}$ in any 15 s
Horizontal Alert Limit	40·0 m	40·0 m	40·0 m
Vertical Alert Limit	50·0 m	20·0 m	15·0 to 10·0 m

Figure 1. Approaching Lugano airport.

3. CURRENT APPROACH PROCEDURE. Currently, aircraft are lined up on the localiser beam of one the world's last Instrument Guidance System (IGS). The other approach located also within the Swiss alps is in Sion (LSGS). During the operations at the Kai Tak Airport in Hong Kong, the checker board approach also qualified as IGS. The approach uses all facilities and ground

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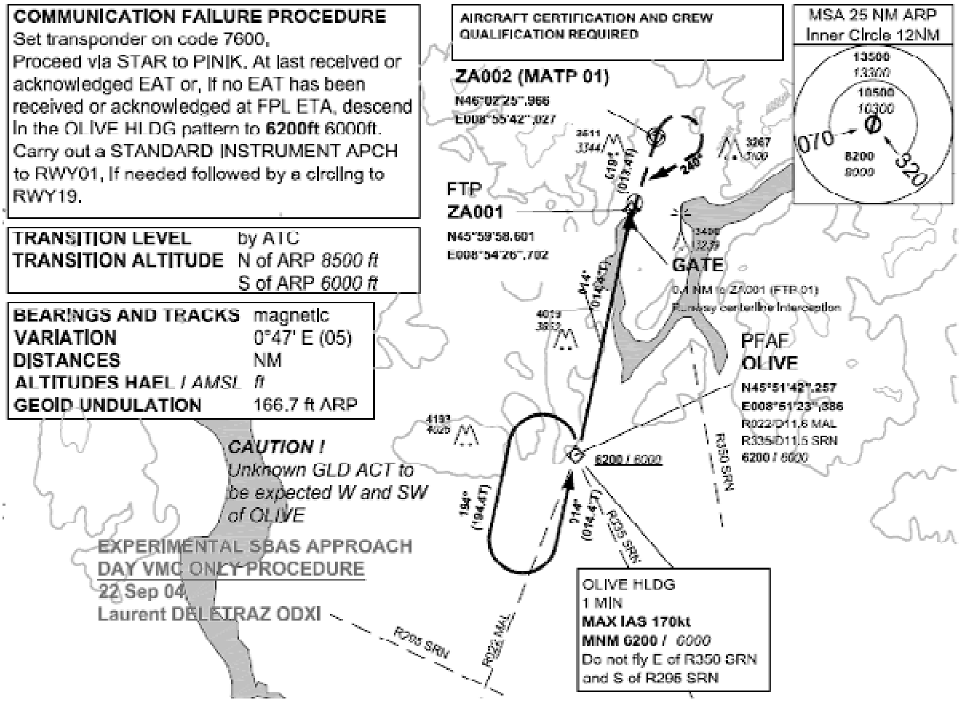

Figure 2. SBAS Test Approach Procedure Chart.

equipments of the ILS, but the published approaches are out of scope of the internationally recognised standards. For Lugano, the problem lies within the steep approach angle, currently flown at 6·5 degrees, but foreseen to be increased to 6·65 degrees. Only one aircraft worldwide is able of flying such procedures, the Canadian Bombardier Dash 8-300. In order to increase the availability of the airport, alternate Localiser/Distance Measuring Equipment (LOC/DME) approaches with a visual circling were introduced so as to allow aircraft to descend on the downwind leg of the approach and therefore come down the LOC beam on a shallower gradient.

4. APPROACH PROCEDURE FOR THE TRIALS.

When looking at the topographical layout of Lugano and it's surroundings, there is only one possible approach path with a 5·5 degrees nominal angle. Using ground based equipment to fly this path would imply installing a second Localiser antenna and changing the Nav setting in the cockpit on short final. The cost, the environmental impact and finally the possible safety concerns are currently being investigated. Using EGNOS would permit designing the same type of approach, alleviating all constraints mentioned above. This is the reason why an experimental offset SBAS approach has been designed by the instrument flight procedure experts of Skyguide (see Figure 2).

In Fall 2004 and Spring 2005, the EGNOS system was undergoing a lot of performance qualification testing at ESA in charge of the system development.

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Figure 3. NLR's Fairchild Metro II aircraft.

The objective was to demonstrate that the Signal-In-Space is meeting the stringent ICAO requirements. While most of the tests have been performed in static locations spread over the whole European Civil Aviation Conference (ECAC) area, some flight trials have been organised to demonstrate the EGNOS performance in real aviation conditions. Some have been conducted in the Netherlands, home of the Dutch National Aerospace Laboratory (NLR) who was in charge of executing the trials under an Alcatel Space Industries/Thales ATM contract. Other flight trials were performed en-route across ECAC and also on selected airports within ECAC area: Montpellier (France), Almeria (Spain) and Lugano. At Lugano, EGNOS-guided approaches have been flown in November 2004 (23 IGS and 20 SBAS) and April 2005 (3 IGS and 5 SBAS). In total, 26 IGS and 25 SBAS approaches have been successfully flown using the EGNOS signal.

5. EQUIPMENT.

The aircraft involved in the trials was a Fairchild Metro II belonging to the NLR (see Figure 3). The aircraft was fitted with the following different measuring equipments in order to assess the system performance during the trials:

- 1 Topcon GPS/EGNOS receiver to provide guidance to the pilot through the aircraft Research Flight Management System (R-FMS)
- 1 Trimble GPS receiver in order to build a reference trajectory of the aircraft using Differential GPS (DGPS) techniques in post-processing mode
- 1 GPS/EGNOS Thales Avionics receiver to assess EGNOS performance in flight
- 1 GPS/EGNOS PolaRx2 Septentrio receiver to assess EGNOS performance in flight

On the airport, one GPS/EGNOS PolaRx2 Septentrio receiver was also installed in order to monitor the system performance for a static user on the ground. This allows an investigation of possible system performance differences between static and dynamic users.

6. DATA PROCESSING.

The true position of the aircraft was computed in post-processing mode using a DGPS carrier phase solution. For this purpose, data collected by the Septentrio PolaRx2 receivers on the ground and in the aircraft were used. The processing was then done using GrafNav 7.50, a software specifically designed for dynamic applications. The resulting trajectory has a 1 second time interval between the positions which are accurate at the 0·1 metre level. It was therefore decided to use it as the truth reference for further analyses.

The EGNOS navigation solution was computed using Pegasus 4.0. This software has been developed by Eurocontrol in order to assess performance of SBAS systems like EGNOS. The GPS and EGNOS data collected onboard the aircraft and on the ground by the Septentrio PolaRx2 receivers were used for this purpose. Although all the EGNOS geostationary satellites were transmitting on that day, only PRN 126 (Inmarsat IOR-W, Longitude 25° East) was used to compute the augmented position. This is due to the fact that only one geostationary satellite is needed to get all the EGNOS data. The additional geostationary satellites can be seen as redundant ones that can be used in case of a failure. A smoothing filter of 100 seconds, as prescribed by the SARPS [1], was applied to the measurements and the minimum elevation angle of the satellites was set to 5 degrees.

For every epoch, the true position of the aircraft and the one determined by EGNOS were compared and the Horizontal and Vertical Position Errors (HPE and VPE) were computed. Based on these figures, it was then possible to derive all the system performance statistics that will be presented in the next section.

7. SYSTEM PERFORMANCE.

The major system performance parameters defined by ICAO have been assessed with the data collected during the flight trials. Whenever possible, a comparison between the airborne and ground collected data was performed. The results presented in the following paragraphs were obtained in Spring 2005, when the EGNOS system had reached sufficient maturity.

The accuracy of the EGNOS augmented position was brilliant. The 95-percentile horizontal error was between 0·7 and 2·0 metres in the different approaches, with an average value of 1·3 metre. Surprisingly, the vertical accuracy (95% value) was slightly better, ranging from 0·6 to 1·9 metre with an average value of 1·1 metre. With such an outstanding accuracy, the EGNOS system exceeds the ICAO requirements (see Table 1), and its user needs, with a very comfortable margin. The accuracy observed by a receiver located on the ground was in general not as good as the one in the air. This can be explained by the static location of the receiver which causes it to be more subject to multipath than in the aircraft, where multipath can be easily filtered thanks to aircraft dynamics. The different satellite geometries as seen from the air or on the ground are also a contributing factor.

The system integrity is assessed at the user level, and in the position domain, by the receiver computed protection levels. The horizontal and vertical protection

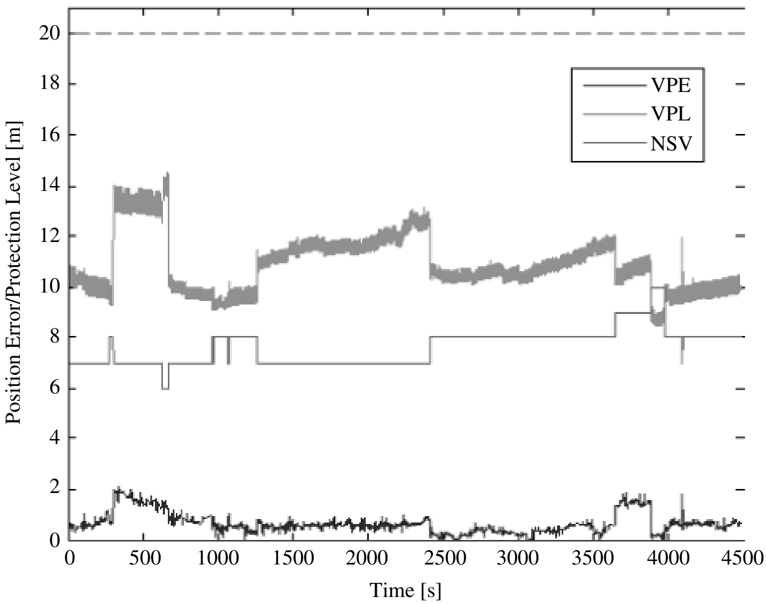

Figure 4. Vertical Position Error (VPE), Vertical Protection Levels (VPL) and number of GPS satellites used (NSV) for one flight. The dotted line represents the vertical alert limit for declaring the APV-II operation available.

levels are computed by the receiver, thanks to the parameters sent by the EGNOS system applied to the visible GPS constellation. These values are upper bounds estimates of the user error which are designed to protect the user with a 10^{-7} probability of failure. Although it is not possible to validate this very stringent system requirement with a few flight hours, no integrity event was detected during the trials. The minimum ratio observed between the protection level and the corresponding error was 4·4 (horizontal) and 5·5 (vertical). These high values further confirm that there is a positive margin in the EGNOS system integrity algorithms (see Figure 4).

The system availability was computed at user level by comparing the protection levels with the fixed alert limits defined for the APV-I and APV-II types of approach (see Table 1). For a sample to be declared as available, both the horizontal and vertical protection levels have to be below their respective alert limits. During all the flights, the availability of both APV-I and APV-II was always 100% (see for example Figure 4). During the trials, EGNOS therefore exceeded the 99% availability minimum required by ICAO. The fact that availability was always 100% during the trials means that no loss of continuity of the navigation function was detected. Once an approach procedure was initiated, it was conducted until the end with the guidance provided by the EGNOS system. This is of course not sufficient to prove that the EGNOS system is fulfilling its continuity requirements under all circumstances. However, this is a good indication of the potential of this system.

In a mountainous and challenging terrain, the question of satellite availability is always of great importance. In particular, the availability of two geostationary satellites is crucial for safe EGNOS operations. One satellite link is indeed always

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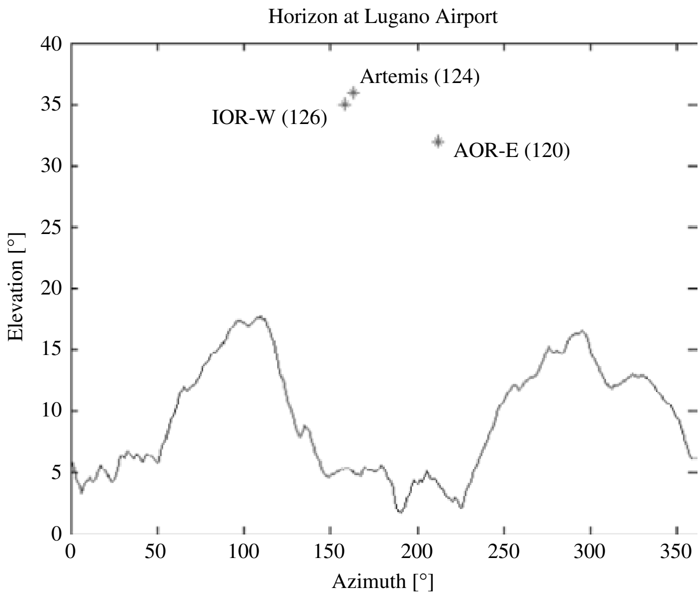

Figure 5. Horizon at Lugano Airport and location of the three EGNOS geostationary satellites.

necessary to receive the corrections and the second one is a backup in case of a signal loss on the first satellite. Although Lugano is located in a valley with very steep mountains, the horizon is sufficiently clear to enable a good reception of all three EGNOS geostationary satellites (see Figure 5). This was confirmed by the fact that no single EGNOS message was lost during the flight tests.

8. OPERATIONAL BENEFITS.

From an operational point of view, the following benefits are observed when using the new test SBAS procedure:

- The use of a satellite navigation system like EGNOS permits the definition of a procedure, that would not constrain the current airport layout. The same procedure, supported by ground based infrastructure, would require that a large portion of the light aviation grass parking would need to be closed to position the Localiser antenna. The final approach path would also cross the localiser beam of the offset antenna and could possibly be subject to interference by the landing aircraft. Such a situation would possibly alter the position of the holding, therefore making the situation more complex.
- All SBAS equipped aircraft could benefit from the system and reach Lugano on a close to permanent basis. This is mainly due to the reduced glide path angle and the potential lower minima of the new procedure. It can therefore be said that the airport availability would be improved with such a procedure.
- The use of a sole system could also reduce the cockpit workload. The alternate dual localiser option implies that the aircrew needs to change navigation sensor in a safety critical part of the flight and re-intercept the landing localiser. SBAS could allow a single approach without frequency change on final.

- The pilots' feedback was very positive. It was less demanding for them to maintain the correct approach speed on the new SBAS approach than on the steep IGS approach. The transition at the decision altitude between the SBAS approach and the final segment on the Precision Approach Path Indicator (PAPI) was not an issue as enough time was available to do so. During the entire approach procedure, they did not experience any impression of insufficient terrain clearance.

9. CONCLUSION. The flight tests conducted in Lugano in 2005 confirmed the excellent performance of the EGNOS system at various locations within the ECAC area. The one-sigma accuracy was found to be at the sub-metre level both in the horizontal and vertical dimensions. The availability of the system to offer APV-I and APV-II approach capability was always 100%. The system did not produce any integrity event and the integrity margins at the user level were found to be important.

All these findings show that, from a technical point of view, EGNOS is able to provide an APV capability even in a challenging terrain. This is an important advantage compared to the traditional ground based radio navigation aids which have limited performance in such an environment.

From an operational point of view, the implementation of such a procedure using EGNOS signal is beneficial for the airport, as the investments are close to non-existent. For the operators, new equipment is available at a relatively low cost and would rapidly be compensated by the reduction of diversion flights. For the Air Navigation Services Provider (ANSP), either approach mode, ground based or satellite based is convenient, and the handling of such traffic would be relatively easy to be instructed and applied in the daily operations. APV also has the advantage of a better availability than a ground based Localiser (interference through agricultural equipment being currently one reason of losing the approach).

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