Challenging EGNOS in the Swiss Alps

1 Biography

Olivier Perrin graduated from the Swiss Federal Institute of Technology (EPF) in Lausanne with a M.Sc. in Geomatics Engineering in 1999. After working as a surveyor in Australia, he joined the GNSS Team of skyguide (Swiss Air Navigation Services Ltd) in December 2000. Since then, he has been working on different aspects of the EGNOS project. His work includes demonstration projects in view of the EGNOS validation for civil aviation in Switzerland.

Dr. Maurizio Scaramuzza is head of the GNSS Team at skyguide, located in Zürich, Switzerland. Before joining skyguide in 1999 he was Assistant and Research Associate at the Geodesy and Geodynamics Laboratory (GGL) at the Swiss Federal Institute of Technology (ETH) in Zürich, Switzerland, and wrote a PhD on the investigation of error- and system modelling of GPS based approaches and landings.

Thomas Buchanan has been functioning as head of the Instrument Flight Procedure group in skyguide for the last 6 years. His previous experience was built up during the ATCO training for Tower and Approach in Geneva, and 3 years of experience within the regulatory function of the Swiss Federal Office for Civil Aviation. Active member in several European working groups developing criteria for the use of RNAV within Terminal Airspaces.

Santiago Soley graduated with a MSc in Telecommunication Engineering from the Universitat Politecnica de Catalunya in 1998. He started to work on Satellite Navigation in 1997 with Indra-Espacio S.A. In 1999 he joined the ESA GalileoSat Team to work on the Definition Phase of Galileo. Since October 2000 he has been working as a consultant for EUROCONTROL at their Experimental Centre in the GNSS Programme Office, giving technical support in various activities related to GNSS-1 Operational Validation.

Pierre-Yves Gilliéron graduated from the Swiss Federal Institute of Technology Lausanne in 1988. He started his professional career in photogrammetry and digital mapping. He joined the Geodetic Eng. Laboratory in 1997 where he worked as research scientist on various navigation projects. He is member of the board of the Swiss Institute of Navigation (ION-CH).

Adrian Waegli graduated with the M.Sc. degree in Geomatics Engineering at the Swiss Federal Institute of Technology Lausanne in 2003. His diploma thesis focused on the integrity concept of EGNOS with special emphasis on the ionospheric corrections.

2 Abstract

In view of the operational validation of EGNOS, some early tests are being performed with the EGNOS System Test Bed (ESTB). This prototype has been broadcasting an EGNOS-like signal since early 2000. The performance of ESTB is reduced compared to the full-deployed EGNOS, but it gives the opportunity to test EGNOS equipment and gain experience. Eurocontrol, skyguide and the Swiss Federal Institute of Technology in Lausanne (EPFL) are active in data collection and analysis in order to study the signal-in-space performance for the civil aviation users.

The objective of this work was to analyse the system's performance during flight tests in the Swiss Alps where the topography is a challenge for satellite-based navigation systems. Sion regional airport was selected for its location in a valley surrounded by very high mountains. Moreover, the use of EGNOS on regional places is expected to bring significant operational benefits. A new GNSS procedure including both the approach and a special missed-approach with a 89° turn in the valley was designed for these tests. A total of 13 approaches and missed-approaches were flown in November 2002 by a Dornier 128 belonging to the Technical University of Braunschweig (TUBS) and a King Air 100 belonging to SENASA (Sociedad para las Enseñanzas Aeronáuticas Civiles S.A.). Around 8 hours of data were recorded from different receivers on the ground and in the air.

This paper shows that the accuracy and integrity obtained during the tests with the EGNOS System Test Bed fulfils the stringent requirements of civil aviation even in a difficult environment. However, some progress still has to be made on the availability and continuity parameters. This will be the case once the real EGNOS will be operational. It also demonstrates that EGNOS-based procedures are feasible and that it could bring important operational benefits to regional places with a limited ground navigation infrastructure.

3 Introduction

skyguide, the Swiss Air Navigation Services Provider (ANSP), is taking part in the EGNOS development through its involvement in the EGNOS Operators and Infrastructure Group (EOIG), in the European Satellite Services Provider (ESSP) and in the GNSS-I Operational Validation (GOV) working group. As an ANSP, it will be responsible for providing the EGNOS service to the civil aviation community in Switzerland. For this purpose, the signal-in-space will have to be validated against the requirements of the Annex 10 to the convention of the International Civil Aviation Organization (ICAO) [1] once it becomes operational. Preparatory work has already started at skyguide. Eurocontrol, the European Organisation for the Safety of Air Navigation, is coordinating the efforts of its member states in the GNSS (Global Navigation Satellite System) program. For what concerns EGNOS, Eurocontrol set up the GOV working group. This group, composed of the main European ANSPs, is assessing the technical performance of SBAS (Space Based Augmentation Systems) in view of the future operational use by civil aviation. Early EGNOS demonstrations and tests have been performed recently by the GOV members, using the EGNOS System Test Bed (ESTB). One good example of this work is the Nice flight trials, where an SBAS-equipped aircraft flew a curved approach into Nice airport in September 2001 [2].

In order to take a step forward, skyguide and Eurocontrol decided to conduct ESTB flight trials in Switzerland in 2002. This country offers a challenging mountainous environment with peaks up to 4600 metres in its alpine region. This particular aspect was not assessed during the Nice flight trials, and it is of great interest for all GNSS-related applications. Sion's regional airport was selected as a good example of a demanding location. It lies in the East-West oriented Rhone valley at an altitude of 400 metres and is surrounded by mountains (see Figure 1). Because of this particular topography, the airport is difficult to manage in terms of radio navigation aids, and a GNSS-based infrastructure is expected to bring significant benefits. In particular, the missed-approach could benefit from this new guidance system.

Figure 1: Sion Airport

The objective of these tests was to determine the potential of SBAS in a mountainous environment. To do so, data have been collected during flight trials and then processed. The four major parameters used to define the performance of a navigation system (accuracy, integrity, availability and continuity) have been computed, analysed and compared to the civil aviation requirements. The Swiss Federal Institute of Technology in Lausanne also took part in these trials. The aim of this research is the development of analysis tools for the monitoring of the EGNOS signals. In a first step, the ionospheric corrections were analysed [3].

4 The EGNOS System Test Bed

The ESTB is an EGNOS prototype, available since February 2000, that allows users to perform early tests and developments. It consists of 13 reference stations collecting GPS data over Europe and two processing centres in Toulouse, France, and Hönefoss, Norway (see Figure 2). The augmentation message is broadcast to the users via two Inmarsat geostationary satellites, the Atlantic Ocean Region East (AOR-E) and the Indian Ocean Region (IOR). Because of its reduced size compared to EGNOS, the performances of this test system will not be as good as the future operational system. The service area is also of reduced size.

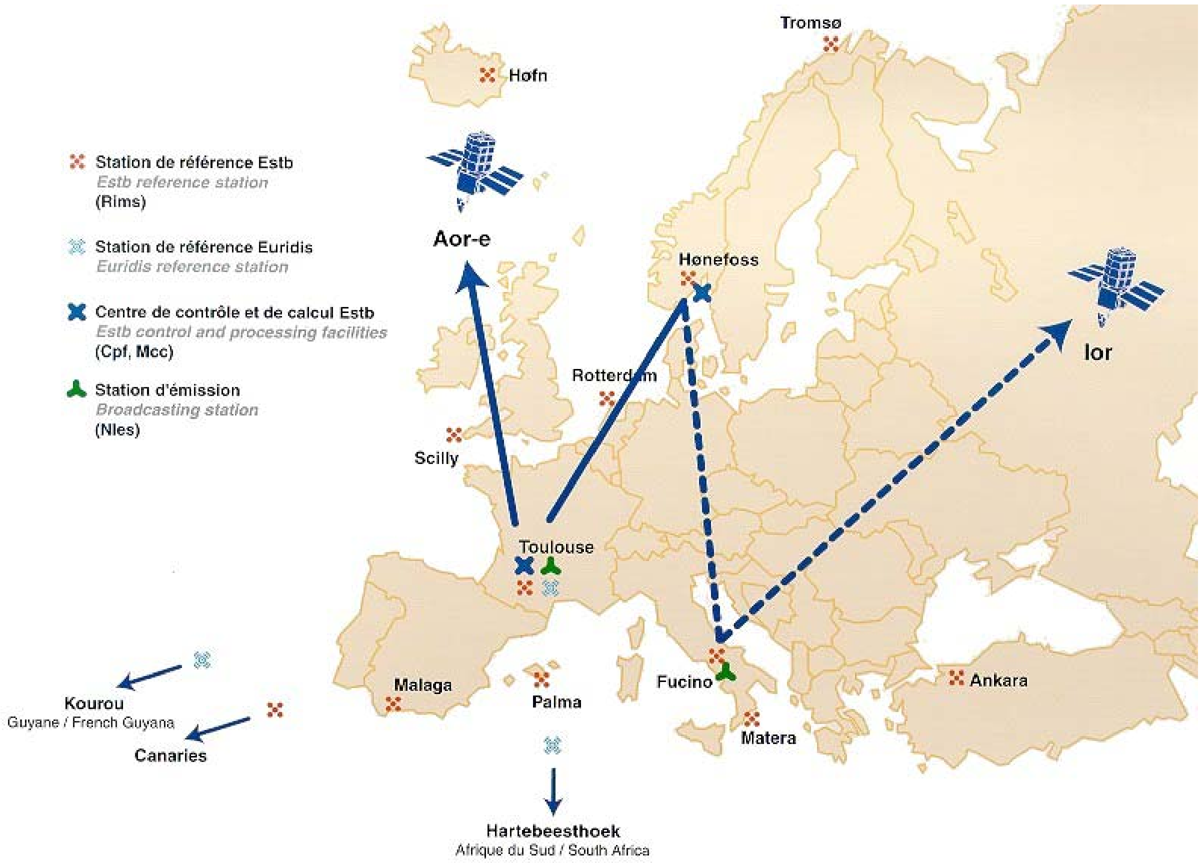

Figure 2: The EGNOS System Test Bed

During the tests, the ESTB was operating in mode 2 and in accordance with the DO229B RTCA standards [4]. This means that pseudorange corrections and ionospheric corrections were provided to the user. The GPS satellites clock corrections were also broadcast, but no orbit corrections were available. On November 18th 2002, all of the ESTB reference stations were available. However, on November 27th 2002, the two Italian stations at Fucino and Matera were not usable due to maintenance activities. The AOR-E geostationary satellite was the one used to provide corrections during the tests because of its higher elevation angle at the Sion location than IOR. The GPS constellation [5] was composed of 28 operational satellites, but PRN21 being unusable, only 27 satellites were available.

5 Test Procedure

The current instrument flight procedure in Sion relies on an Instrument Guidance System (IGS) with a 6° glide slope and an offset of 7° relative to the runway. The minimum descent altitude on the IGS is 3000 ft above the aerodrome elevation for adequately trained crew and the last 7 nautical miles of this approach have to be flown in Visual Meteorological Conditions (VMC). The departure from Sion is even more difficult due to the surrounding mountains, which can be as high as 4000 metres. Aircraft must be capable of high climb gradients even in the case of an engine failure. Under difficult meteorological conditions, it is common that pilots have to remain on the ground until the weather improves.

skyguide's instrument flight procedure team defined a new test approach procedure, with the objective to overcome some of the above-mentioned limitations (see Figure

3). It starts at SANET at 16000 ft and follows the current procedure up to ALETO. From this point, the SBAS procedure is different. The final approach starts at ALETO and ends at GS001 at 4520 ft. If the pilot then initiates a missed-approach, it follows the valley's topography and makes a right turn at GS002, therefore avoiding the very high surrounding mountains. The climb gradient of this missed approach is much lower than the current one, therefore allowing low-performance aircraft to fly the procedure safely. More flexibility is also offered by this procedure, allowing the pilot to chose to perform a new approach or divert to another airport like Geneva. The minimum descent altitude of the approach part is only slightly improved, due to the current stringent PANS-OPS (Procedures for Air Navigation Services, Aircraft operations) procedure design criteria.

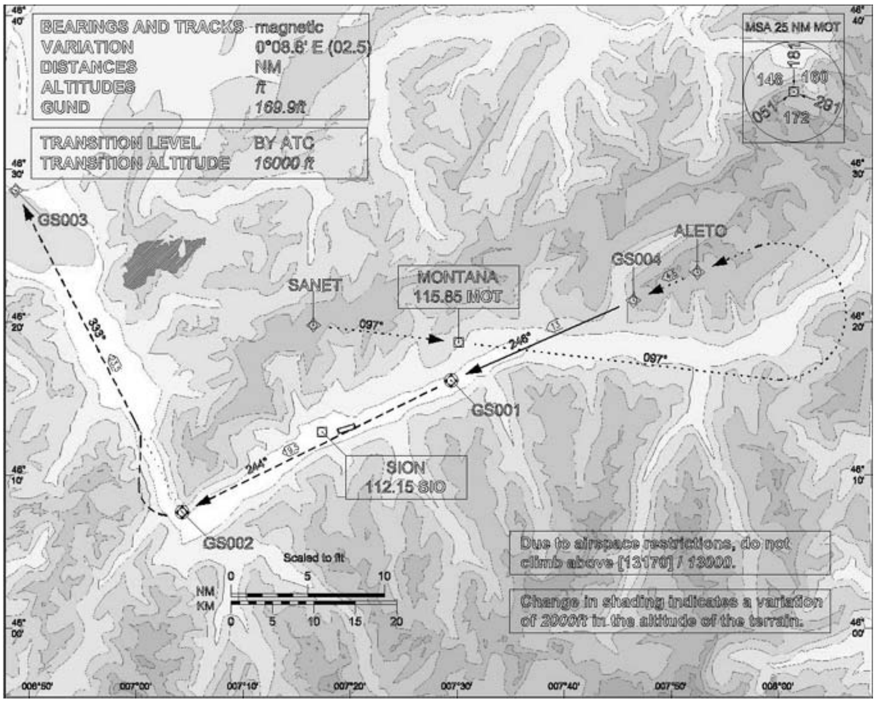

Figure 3: The new SBAS test procedure

Because of the challenging topography of the region, it is not possible to use conventional terrestrial-based radio navigation aids to fly the missed-approach part of this procedure in instrumental conditions. Therefore, the only possible solution is to use a satellite-based type of guidance. EGNOS is expected to have the flexibility to perform such operations, while fulfilling the very stringent civil aviation requirements in terms of accuracy and integrity [1]. This is the reason why the ESTB was chosen to provide guidance. This system being only a prototype, the test flights were requested to take place in VMC, for safety reasons.

Two entities were selected by Eurocontrol to fly the test procedure. The first one is the Technical University of Braunschweig (TUBS) in Germany who owns a Dornier DO128-6. A total of 7 approaches and 7 missed approaches for a flight time of 3 hours and 57 minutes were flown on November 18th 2002. A King Air A-100 operated by SENASA (Sociedad para las Enseñanzas Aeronáuticas Civiles S.A.) and equipped by GMV and Aena flew another 6 approaches and 6 missed approaches on November 27th 2002 during 3 hours and 45 minutes. The shared use of the airspace in the vicinity of Sion resulted in an operative limitation of the maximum useable flight altitude. During the test flights all movements were requested to remain at or below

13000ft. For this reason, the final approach point was redefined at GS004, allowing an intercept of the final path at 13000ft.

6 Receivers setup

The TUBS aircraft was equipped with three separate dual-frequency Novatel GPS antennas. A signal splitter delivered the signal from the first antenna to a Stanford User Platform and to an OEM3 GPS-only receiver. The Stanford User Platform includes a Millennium Novatel receiver and provided guidance information to the pilot in the form of a Course Deviation Indicator (CDI). A Novatel OEM3 SBAS-capable receiver used the second antenna and logged raw GPS and ESTB data on a computer using the Slog utility from Novatel. The third antenna used a second signal splitter to feed both a Novatel OEM4 Data logger and a Septentrio DL Pola-Rx2. Both the Novatel Data Logger and the Septentrio receiver had the capability to store raw data on an internal memory card.

The SENASA plane was equipped with one dual-frequency Novatel GPS antenna feeding two SBAS-capable Novatel receivers. One Millennium STD WAAS Propak receiver was providing guidance information to the pilot via the Flight Management System (FMS) and one OEM4 was configured to store raw data.

Two SBAS-capable Novatel receivers were located at two different locations on the airport, some hundreds of metres apart. They were simultaneously collecting GPS and ESTB data in order to assess the system performance for a static user. Moreover, they were used as reference stations with the objective to compute the true trajectory of the aircraft. Two additional stations belonging to the AGNES (Automatisches GPS Netz Schweiz) permanent GPS network from swisstopo (Swiss Federal Office of Topography) and located 20 and 35 km away from Sion were also used for this purpose. Two Leica System 500 geodetic receivers belonging to EPFL were collecting GPS data for precise positioning of the antennas in the WGS84 (World Geodetic System 1984) reference system.

The data recorded with the Novatel OEM3 receiver during flight 1 on 18.11.02 are not complete due to a configuration change during the flight. In addition, the SBAS receivers did not compute any position at the beginning of this flight because some ESTB data were missing due to a reconfiguration of the system. 10 epochs are missing for the Novatel OEM3 during flight 1 on 27.11.02, probably due to a problem with the receiver itself because the other receivers performed well at the same time. In addition, the ground Novatel OEM4 receiver stopped logging data at one stage during flight 2. During flight 2 on 27.11.02, both the onboard OEM3 and OEM4 receivers experienced some problems at the same time, while the ground receivers performed well. This was due to the ionospheric corrections being unavailable for one GPS satellite and the aircraft position at that moment.

7 Data processing

The data post-processing was performed using PEGASUS version 2.0 [6]. This software has been developed by Eurocontrol with the support of TUBS and is compliant with RTCA standards DO229B [4]. The first step was to convert binary Novatel data into the standard PEGASUS ASCII format. Then, a position solution and the corresponding protection levels were computed. The protection levels are designed to provide users with an upper bound on their position error, therefore providing the integrity information needed for safety-of-life applications. As required by the ICAO Standards and Recommended Practices (SARPs) [1], a first-order smoothing filter with a 100 seconds time constant was applied to the raw measurements.

In order to assess the performance of the ESTB positioning, the true position of the aircraft had to be determined for the whole duration of the flights. For this purpose, GPS code and carrier measurements from stations on the ground and receivers in the plane were used. In a first step, the coordinates of the ground receivers were determined using a precisely surveyed reference point in the neighbourhood and two Leica System 500 geodetic receivers belonging to EPFL. A dual frequency differential GPS carrier phase solution with fixed integer ambiguities was then computed using the GrafNav post-processing software version 6.03. Baselines from the different base stations were merged together by GrafNav, allowing optimal results to be computed. As this solution typically provides a 1-sigma accuracy of 0.1 metre or better, it was used as the true trajectory of the aircraft.

8 Analysis Methodology

Different types of operations are defined by the ICAO SARPS [1]. Besides the well known Precision Approaches going from Category 1 to Category 3, new types of approaches using GNSS lateral and vertical guidance have been defined. The so-called Approaches with Vertical Guidance (APV) are defined in terms of accuracy, integrity, availability and continuity (see Table 1). Their respective Alert Limits are also defined (see Table 2).

A definition for each parameter can be found in [7]. The accuracy is defined as the position error that will be experienced by a user with a certain probability at any instant in time and at any location in the coverage area. In general, the probability is required to be 95%. The integrity risk is defined as the probability that a user will experience a position error larger than the Alert Limit without an alarm being raised within the specified Time-to-Alarm at any instant in time and at any location in the coverage area. The availability is the probability that a user is able to determine his position with the required accuracy and is able to monitor the integrity of his determined position at any instant in time and at any location in the coverage area. The continuity is defined as the probability that a user is able to determine his position with the required accuracy and is able to monitor the integrity of his determined position at any location in the coverage area over a minimum time interval applicable to the corresponding phase of flight.

Operation	Horizontal Accuracy 95%	Vertical Accuracy 95%	Integrity	Time-to-alert	Continuity	Availability
NPA	220 m	N/A	$1-1\cdot10^{-7}$/h	10 s	$1-1\cdot10^{-4}$/h to $1-1\cdot10^{-7}$/h	0.99 to 0.99999

APV-I	220 m	20 m	$1\text{-}2\cdot10^{-7}$ per approach	10 s	$1\text{-}8\cdot10^{-6}$ in any 15 s	0.99 to 0.99999
APV-II	16.0 m	8.0 m	$1\text{-}2\cdot10^{-7}$ per approach	6 s	$1\text{-}8\cdot10^{-6}$ in any 15 s	0.99 to 0.99999
Cat 1	16.0 m	6.0 m to 4.0 m	$1\text{-}2\cdot10^{-7}$ per approach	6 s	$1\text{-}8\cdot10^{-6}$ in any 15 s	0.99 to 0.99999

Table 1: ICAO requirements for GNSS

Operation	Horizontal Alert Limit	Vertical Alert Limit
NPA	556 m	N/A
APV-I	556 m	50 m
APV-II	40.0 m	20.0 m
Cat-1	40.0 m	15.0 m to 10.0 m

Table 2: Alert Limits for different operations

For each sample, a comparison between the PEGASUS result and the true trajectory was performed. As the same antenna was always used for the truth reference and the ESTB solution, no offset was taken into account. By computing the position difference, the Navigation System Error (NSE) was evaluated. This was divided into the Horizontal Position Error (HPE) and the Vertical Position Error (VPE). For each, flight, the 95 percent value of this error was computed and compared to the SARPS requirements.

The integrity of the navigation solution was also assessed using the Horizontal Protection Level (HPL) and Vertical Protection Level (VPL) values computed by PEGASUS. These values depend on the quality of the corrections that are being sent by the ESTB and the satellite constellation’s geometry relative to the user. An integrity failure exists if the HPE is greater than the HPL or if the VPE is greater than the VPL. If this happens, the system is said to be sending Misleading Information (MI) to the user. If, in addition, the HPE or the VPE exceeds the corresponding alert limit then this is referred to as Hazardously Misleading Information (HMI). If an HMI occurs, then the user should be warned within the time-to-alert specified by the phase of flight.

The availability of each type of operation is defined as the percentage of the time where the system was fulfilling the accuracy and integrity requirements. When either protection level is higher than the corresponding alert limit, the system is said to be unavailable for the intended operation.

A continuity of service analysis has also been performed. Analyses were performed on intervals of 15 seconds when the navigation function was available at the start of the interval for the intended operation. If, during this time interval, the system was declared not available due to a protection level becoming higher than the alert limit, then a continuity failure was declared.

Finally, a Flight Technical Error (FTE) analysis has been conducted between the waypoints GS004 and GS001. FTE refers to the accuracy with which the aircraft is controlled. It was computed as the lateral and vertical difference between the ESTB indicated position and the desired flight path. It usually depends on whether the aircraft is flown by hand by the pilot or by the autopilot. Although the FTE determination was not the main objective of these trials, it was expected to provide interesting results.

These analyses were first performed for each entire flight, which comprised 3 or 4 approaches. A subsequent and more detailed analysis looked at the different phases of flight corresponding either to an approach, a missed approach or the transition flight. Data from each SBAS-capable receiver was used in order to perform comparisons between different receivers, different phases of flight and different locations.

9 Results

9.1 Geostationary satellite availability

A preliminary analysis of Sion’s topography (see Figure 4) showed that the AOR-E geostationary satellite should always be visible during the entire flight down to the ground. The highest mountain has an elevation angle of 20° towards the South, while the AOR-E satellite has an elevation angle of 32° at an azimuth of 210°. As a comparison, the IOR satellite can only be seen at an elevation angle of 14° at an azimuth of 115°. The flight tests confirmed the AOR-E availability, as no loss of this satellite was observed, either due to terrain masking or aircraft manoeuvres.

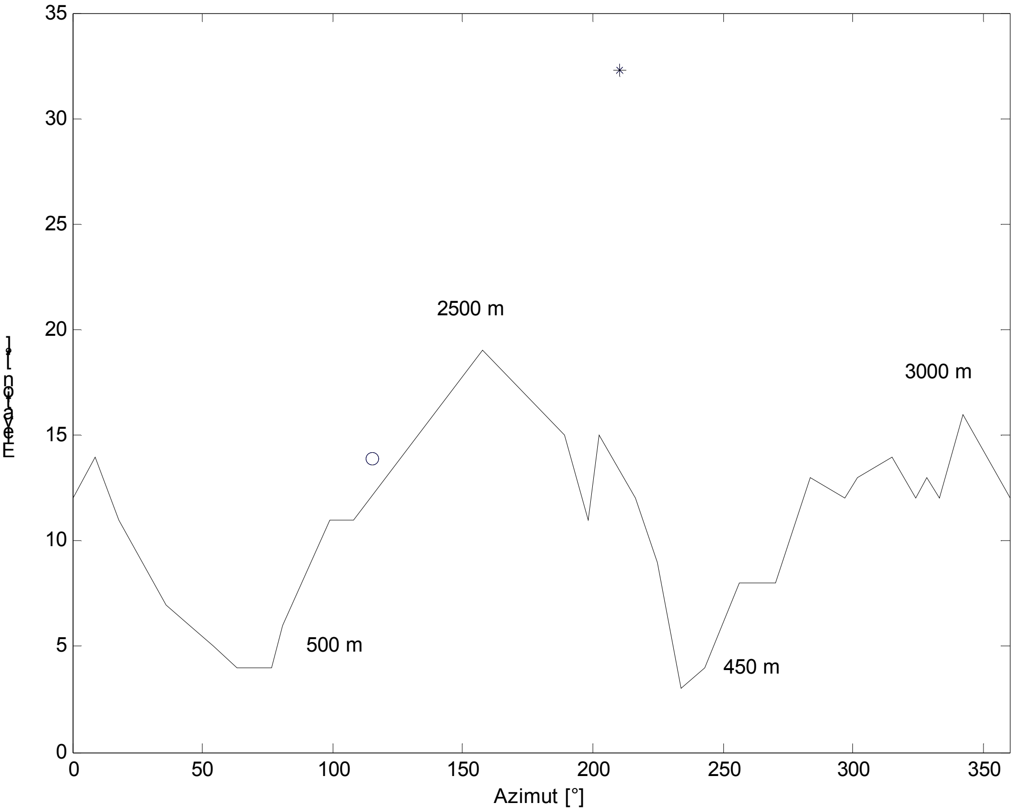

Figure 4: The horizon at Sion Airport with the AOR-E (*) and IOR (o) geostationary satellites

9.2 Accuracy

The accuracy figures for the different receivers on 18.11.02 are shown in Table 3. Those for the 27.11.02 are shown in Table 4.

Location	Flight	Duration	Receiver	HPE 95%	VPE 95%
Airborne	1	4594 s	Novatel OEM3	1.2 m	2.1 m
Airborne	2	7721 s	Novatel OEM3	1.3 m	3.4 m
Airborne	2	7721 s	Novatel OEM4	1.3 m	4.6 m
Ground	1	4703 s	Novatel OEM3	0.9 m	2.2 m
Ground	1	4705 s	Novatel OEM4	0.9 m	1.7 m
Ground	2	5873 s	Novatel OEM4	1.0 m	3.2 m

Table 3: Accuracy of the different receivers on 18.11.02

Location	Flight	Duration	Receiver	HPE 95%	VPE 95%
Airborne	1	6931 s	Novatel OEM3	1.2 m	1.5 m

Airborne	1	6941 s	Novatel OEM4	1.2 m	1.6 m
Airborne	2	6483 s	Novatel OEM3	1.8 m	1.6 m
Airborne	2	6559 s	Novatel OEM4	1.8 m	1.4 m
Ground	1	6941 s	Novatel OEM4	1.0 m	1.5 m
Ground	2	6601 s	Novatel OEM3	1.6 m	1.7 m
Ground	2	6601 s	Novatel OEM4	1.6 m	1.5 m

Table 4: Accuracy of the different receivers on 27.11.02

No significant difference appears between the different phases of flight and the different receivers in terms of accuracy. HPE on Flight 2 (27.11.02) is worse than the average. It is the same for VPE on Flight 2 on (18.11.02). The changing satellite constellation during the different flights can explain such behaviours. The comparison between static and dynamic data seems to indicate that the static measurements have a slightly better accuracy.

9.3 Integrity

In the entire data set analysed, which comprises a little bit less than 8 hours of flight, no misleading information was discovered. The integrity was always provided with the protection levels overbounding the position error. A typical Stanford plot representing one flight can be seen in Figure 5.

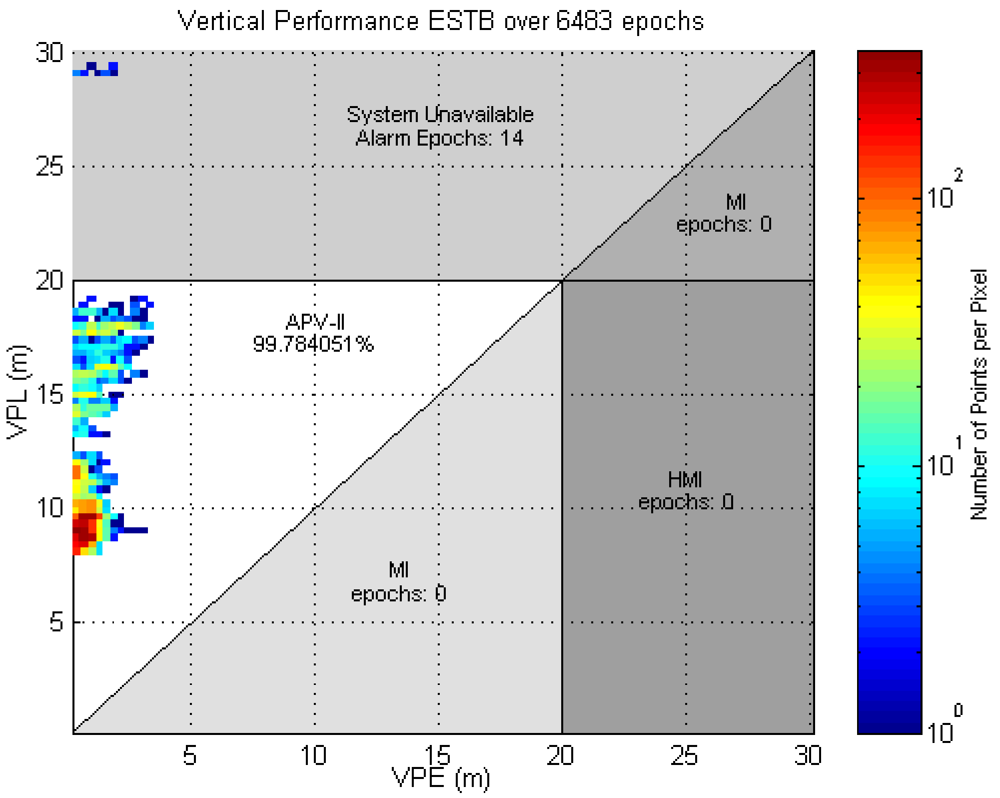

Figure 5: Stanford plot for integrity analysis

9.4 Availability

Using PEGASUS, the availability of each type of operation has been determined. The figures for horizontal Category 1 (H Cat-1), vertical APV-I (V APV-I), APV-II (V APV-II) and Category 1 (V Cat-1) can be seen in Figure 6 for the 18.11.02 and in Figure 7 for the 27.11.02.

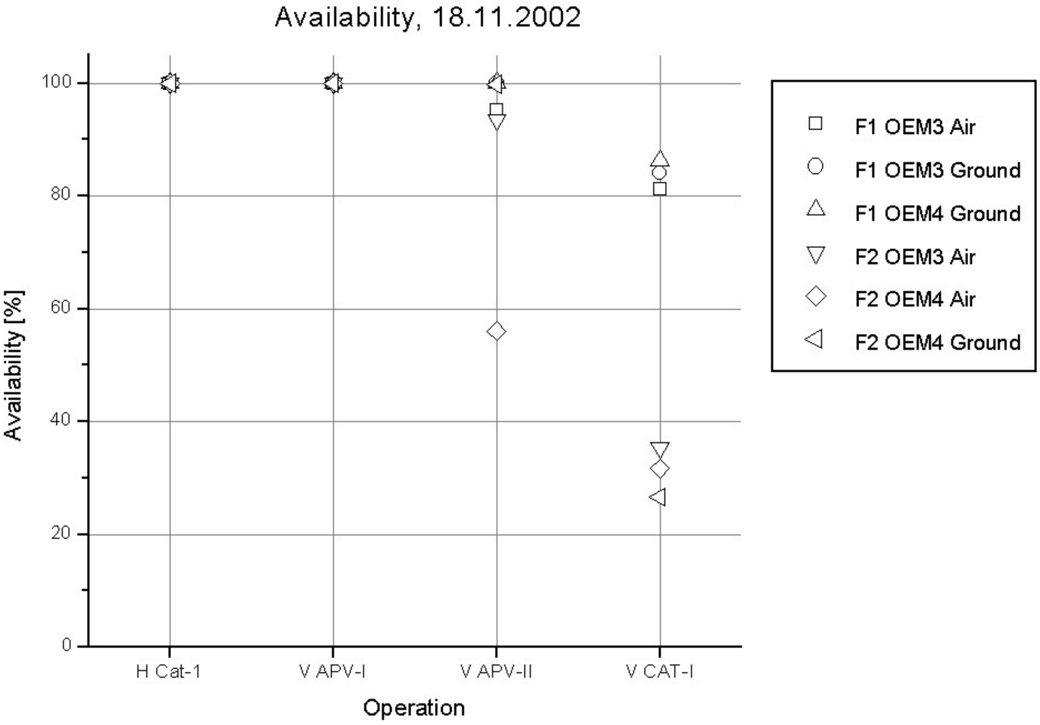

Figure 6: Availability figures for flights 1 and 2 (F1 and F2) and receivers OEM3 and OEM4 on 18.11.02

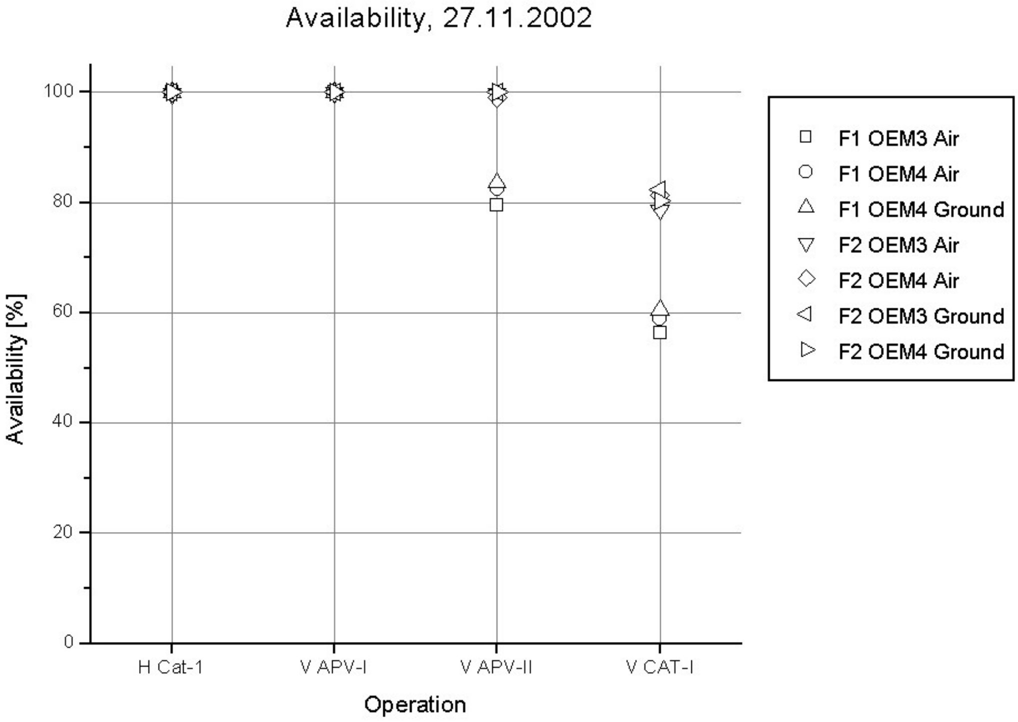

Figure 7: Availability figures for flights 1 and 2 (F1 and F2) and receivers OEM3 and OEM4 on 27.11.02

The availability of horizontal Category 1 and vertical APV-I is always 100%, except on one flight. In order to explain the important variations of availability of the other operations, the number of satellites used by PEGASUS and the corresponding Dilution Of Precision (DOP) factor are shown in Table 5.

Date	Flight	Receiver	Satellites		HDOP		VDOP	
			Min	Mean	Mean	Max	Mean	Max
18.11.02	1	OEM3	6	8.5	1.2	2.3	1.6	3.2
18.11.02	2	OEM3	4	7.4	1.2	3.3	1.9	5.0
18.11.02	2	OEM4	4	6.8	1.2	3.2	2.2	6.9
27.11.02	1	OEM3	4	6.0	1.8	3.3	2.5	5.2
27.11.02	1	OEM4	4	6.1	1.7	3.3	2.4	5.2
27.11.02	2	OEM3	4	6.5	1.4	12.1	1.9	5.4
27.11.02	2	OEM4	4	6.6	1.3	4.3	1.8	5.4

Table 5: Number of satellites used by PEGASUS for each flight and the corresponding DOP factors

The large variations in availability can be explained by the increased vertical errors during some parts of the flights. These are mainly due to the small number of GPS satellites being used in the navigation solution and a corresponding increase in the DOP factors. This effect is due to the reduced number of ESTB monitoring stations meaning that some satellites or ionospheric grid points are not monitored constantly. The position of Switzerland on the edge of the ESTB coverage area is a negative factor for what concerns availability.

9.5 Continuity of service

The continuity figures observed during the tests are shown in Figure 8 for the flights on 18.11.02 and in Figure 9 for the 27.11.02. The continuity is separated in Horizontal (H Cat-1) and Vertical (V APV-I, V APV-II, V Cat-1) continuity, as it is the case for the other parameters.

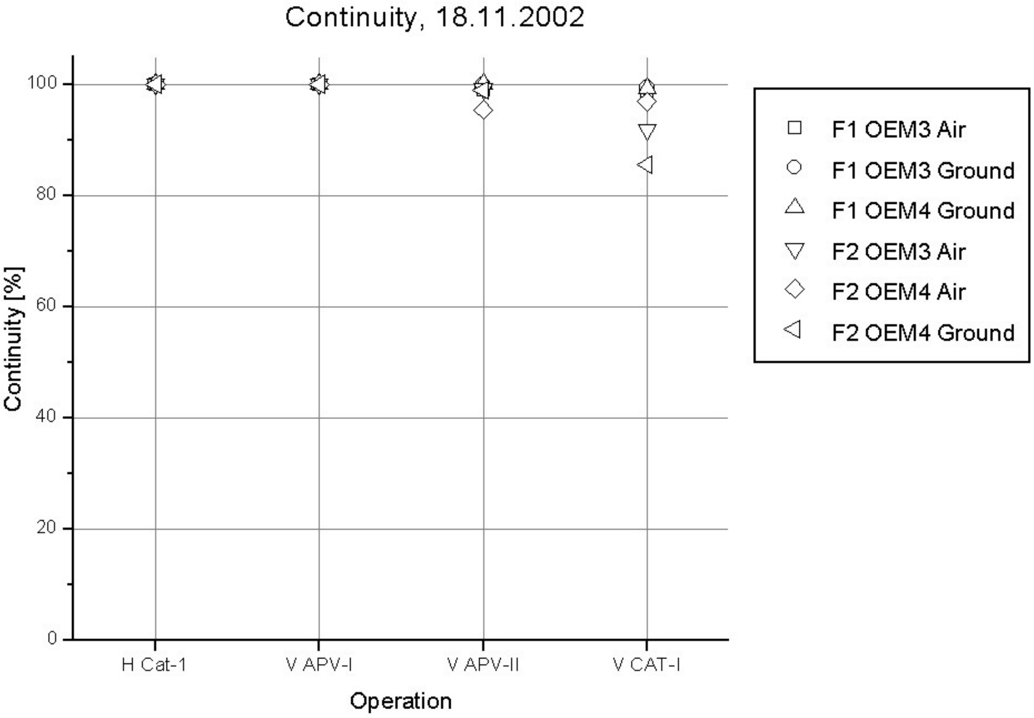

Figure 8: Continuity figures for flights 1 and 2 (F1 and F2) and receivers OEM3 and OEM4 on 18.11.02

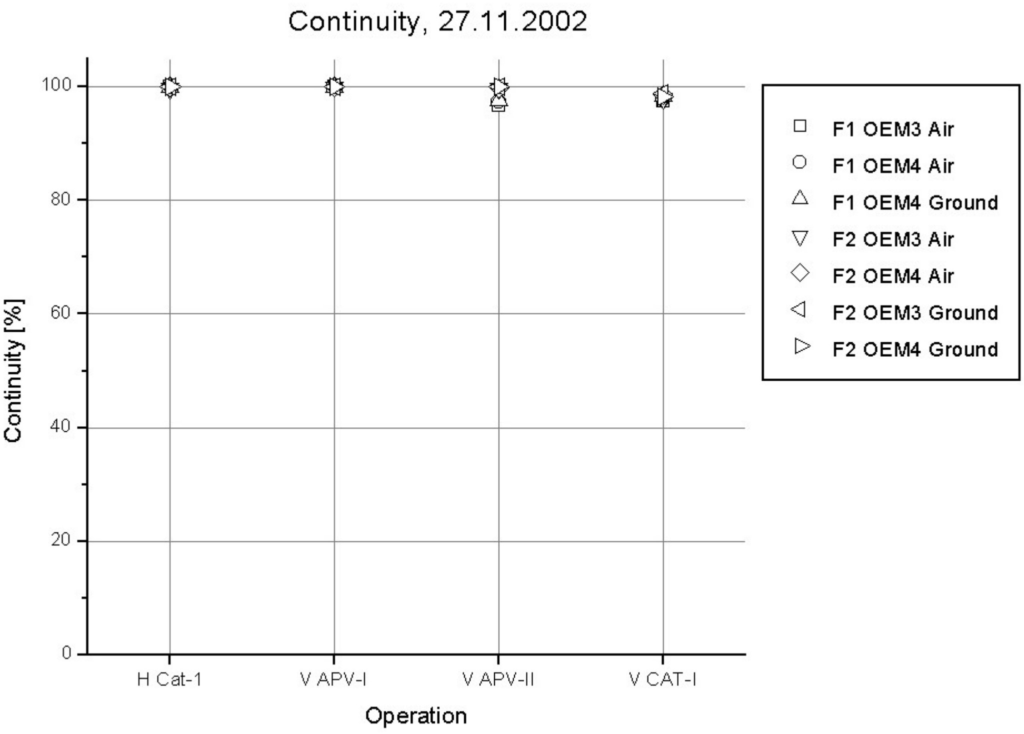

Figure 9: Continuity figures for flights 1 and 2 (F1 and F2) and receivers OEM3 and OEM4 on 27.11.02

No significant differences between the different phases of flights and receivers have been observed. The horizontal continuity value for Category 1 operations was always 100%, except for the OEM3 receiver on the second flight on 27.11.02 where it was 99.77%. The vertical continuity for APV-I was always 100%. The continuity figures are usually higher than the availability ones because the periods where the system is unavailable are grouped together.

9.6 Flight Technical Error

Flight Technical Error and Total System Error (TSE) results for one approach during flight number 1 on 18.11.02 are shown in Figure 10. These results show that the FTE is at least one order of magnitude higher than the NSE. The main part of the TSE therefore comes from the FTE. This is partly due to the fact that the pilots were flying the procedure by hand using a CDI.

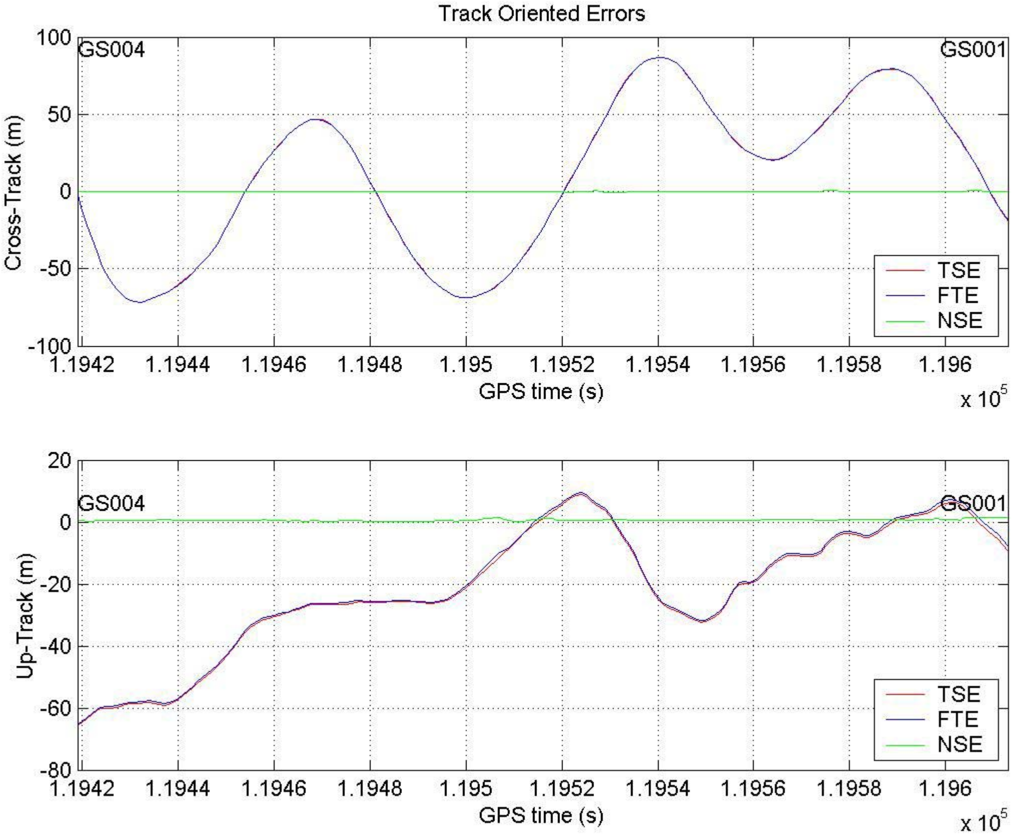

Figure 10: Flight Technical Error (FTE), Navigation System Error (NSE) and Total System Error (TSE) for one approach

9.7 Pilot's feedback and procedure benefits

Both crews were positive on the operational benefits of such navigation systems in mountainous terrain, such as the Rhone Valley in the vicinity of Sion airport. The procedure was easy to fly, even if some changes might be requested on the avionics side that could help reduce the FTE. The current system specifications require that the CDI sensitivity changes at 30NM from the Airport Reference Point (ARP) and on short final at 2NM. This "rectangular sensitivity zone" is a significant adaptation on the "conical zones" such as found for Instrument Landing System (ILS) approaches. The deviation indication should decrease step-wise while approaching the landing threshold. The used criteria were too restrictive in the Rhone valley and improvement of the PANS-OPS criteria should be foreseen after the evaluation of flight data. One of the crews indicated that the use of such a system below the minimum safe altitude requires the full and certified deployment of the EGNOS system.

EGNOS and its architecture proved to be an easy and low-cost system for the implementation of precise navigational solutions on remote airfields or on topographically difficult environments such as Sion. In further steps, the redesign of departures and possibly segmented approaches would increase the availability and the operational use of Sion. Currently the IGS approach (using a 6°-approach angle) limits the choice of aircraft to Short Take-Off and Landing (STOL) aircraft (RJ85/100, ATR42/72, etc.). A redesign of the procedure with a less steep descent angle could facilitate the approach to other types of operations.

Furthermore, on a more global basis, the use of EGNOS would increase the availability of the navigation solution, in view of the implementation of P-RNAV or even RNP-RNAV. This is particularly valid when losing the line of sight of the remote DME (Distance Measuring Equipment) stations situated on the other side of the alpine chain.

10 Conclusion

The objective of this study was to assess the current ESTB performance for an aviation user in Switzerland. The accuracy, integrity, availability and continuity parameters were assessed based on the SARPS requirements.

During the tests, the ESTB always fulfilled the 95% horizontal accuracy requirement of 16.0 metres and the 95% vertical accuracy requirement of 6.0 metres for a precision approach of Category 1. Only on one flight the Vertical Position Error exceeded the more stringent accuracy limit of 4.0 metres for Category 1. However, the limited number of samples collected during this study does not allow us to draw significant conclusions from a statistical point of view. The comparison between static and dynamic data seems to show that the static measurements have a better accuracy. The Navigation System Error observed during the tests was significantly smaller than the Flight Technical Error, which is the driving factor of the Total System Error.

No integrity failure was detected during the tests. The protection levels always overbounded the position errors and therefore correctly protected the user. More analysis would be necessary to demonstrate that the integrity requirements are always fulfilled.

The horizontal availability up to Category 1 and the vertical availability up to APV-I were always 100%, except on one flight. However, large variations were detected in the APV-II and Category 1 vertical availability. This is due to the reduced infrastructure of the ESTB in terms of monitoring stations.

The continuity of service figures show that, except on one flight, no continuity failures occur for the horizontal Category 1 and vertical APV-I type of approach. For the more stringent operations, the continuity was lower than the SARPS requirements.

In conclusion, the ESTB performed very well during the tests, even if some progress still has to be made for some parameters. The introduction of EGNOS is expected to solve much of the current shortcomings. From an operational point of view, the use of EGNOS at regional airports and in challenging mountainous terrain has proved to provide significant benefits. The benefits that could be gained in the missed-approach part of flight have clearly been demonstrated. The pilots' feedback after the test was positive even if the procedure was impressive to fly.

The experience gained in data collection and processing with the ESTB was very valuable. The results obtained were very promising for EGNOS but more work has to be performed. In particular, the development of tools that would allow each individual correction type to be validated is of great interest. Developments are currently taking place both at Eurocontrol and EPFL.

11 References

[1] International Standards and Recommended Practices, Aeronautical Telecommunications, Annex 10 to the Convention on International Civil Aviation, Volume 1.

[2] Approaching Nice with the EGNOS System Test Bed, Santiago SOLEY, Rick FARNWORTH, Edward BREEUWER, ION NTM 2002

[3] Evaluation de mesures dynamiques pour la navigation aérienne dans le cadre du projet EGNOS, Adrian Waegli, 2003

[4] Minimum Operational Performance Standards for Global Positioning System / Wide Area Augmentation System Airborne Equipment, RTCA/DO-229B

[5] Global Positioning System Standard Positioning Service Performance Standard, US Department of Defense, October 2001

[6] Pegasus*Plus, Software User Manual, Eurocontrol, 2003

[7] Performance Evaluation of Satellite Navigation and Safety Case Development, Eurocontrol Experimental Centre, Report No. 370, 2002