European Augmentation Service - a GNSS Monitoring in South Europe Region

Salvatore Gaglione, Armando Pacifico, Mario Vultaggio
salvatore.gaglione@uniparthenope.it, a.pacifico@email.it, mario.vultaggio@uniparthenope.it

Department of Applied Sciences: Navigation Section, Università degli Studi di Napoli "Parthenope"

Abstract

In the Civil Aviation field, the international trend (through ICAO, EUROCONTROL) is to adopt one positioning system that allows to follow more flight phases. This will allow to release themselves by ground installations and optimize the traffic flows following the aRea Navigation (RNAV) concept. In order to realize this goal the European Scientific Community is focusing on Augmentation Systems based on Satellite infrastructure (SBAS - Satellite Based Augmentation System) and on Ground based one (GBAS - Ground Based Augmentation System).
The goal of this work is to present some results on SBAS and GBAS performances.
Regarding SBAS, after the acquisition of a Novatel OEM4 SBAS receiver, the Department of Applied Sciences of Parthenope University created a monitoring station that reflects as much as possible a standardized measure environment for EGNOS Data Collection Network (EDCN), established by Eurocontrol.
The Department of Applied Science decided to carry out a own monitoring survey to verify the performance of EGNOS that can be achieved in South Europe region, a zone not fully covered by official (EDCN) monitoring network.
Regarding GBAS, starting from a data set of measurements carried out at the GBAS of Milan-Linate airport where we worked on a ground installation (GMS – Ground Monitoring Station) that supervises the GBAS signal and that represents, for our purposes, the Aircraft subsystem. So the set of collected data is to be considered in RTK mode and after the measurements session we processed them with the software PEGASUS v 4.11. Both experiences give us the possibility to evaluate the GNSS1 performance that can be achieved.

Keywords: GNSS, SBAS, GBAS, Satellite Navigation, Parthenope.

1. Introduction

Since 1993, the civil aviation community, through RTCA (Radio Technical Commission for Aeronautics) and the ICAO (International Civil Air Navigation Organization), worked on the definition of GNSS augmentation systems that will provide improved levels of accuracy and integrity. These augmentation systems have been classified into three distinct groups: Space Based Augmentation Systems (SBAS), Ground Based Augmentation Systems (GBAS) and Aircraft Based Augmentation Systems (ABAS).

RTCA and ICAO diligently provided performance requirements and standards for GNSS and GNSS augmentation systems. The ICAO Standards and Recommended Practices (SARPS) include standards for SBAS, GBAS and ABAS as well as standards for GPS and GLONASS. The SARPS are intended to establish signal in space and performance standards such that interoperability is supported around the world.

Without establishing standards for the airborne equipment, ICAO adopted an alternative approach by stating the requirements that all kinds of GNSS receiver and GBAS equipment have to satisfy.

These are defined as RNP (Required Navigation Performance) and are specified for each flight phase:

- NPA (Non Precision Approach) or with RNP 0.3 NM;
- Approach with Vertical Guidance with RNP 0.3/125 (feet);
- Approach with Vertical Guidance with RNP 0.03/50;
- CAT I with RNP 0.02/40;
- CAT II with RNP 0.01/15;
- CAT III with RNP 0.003/0.

Figure 1 compares the Required Navigation Performance (RNP) per phase of flight with the existing or expected GNSS system performance.

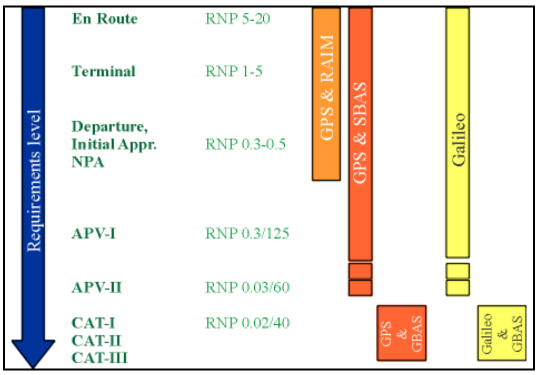

Figure 1. Aviation Phases of Flight versus GNSS Performance

A RNP is associated to the flight phase in function of the following parameters:

Table 1. RNP [2][3]

RNP	Cat.	Accuracy (Hor./Ver.)	Integrity (Prob. and Alert Time)	Availability	Continuity
0.3/125	APV I	± 0.3 NM 125 ft	$1-10^{-5}$ / h	0.95	$1-10^{-4}$ / h
0.03/50	APV II	± 0.03 NM 50 ft	$1-3.5\times10^{-7}$ / h 6 sec.	0.9975	$1-10^{-5}$ / h
0.02/40	Cat. I	± 0.02 NM 40 ft	$1-3.5\times10^{-7}$ / h 6 s.	0.9975	$1-10^{-5}$ / h
0.01/15	Cat. II	± 0.01 NM 15 ft	$1-2.5\times10^{-9}$ / h 1 sec.	0.9985	$1-6\times10^{-6}$ / h
0.003/0	Cat. III	± 0.003 NM	$1-2\times10^{-9}$ / h 1 sec.	0.999	$1-6\times10^{-6}$ / h

The 95th percentile values for GNSS position errors are those required for the intended operation at the lowest Height Above Threshold (HAT), if applicable. The definition of the integrity requirement includes an alert limit against which the requirement can be assessed.

The civil aviation community rightly considers that GNSS will support air navigation and its requirements only with a suitable augmentation system (e.g. GBAS).

2. GBAS

The Ground-Based Augmentation System (GBAS) is a safety-critical system that augments the GPS Standard Positioning Service and provides enhanced levels of service supporting all phases of approach, landing, departure and surface operations within its area of coverage. GBAS will initially be applied to the approach phase of flight as an alternative to ILS CAT I.

The GBAS system consists of three primary subsystems, as shown in the figure 2:

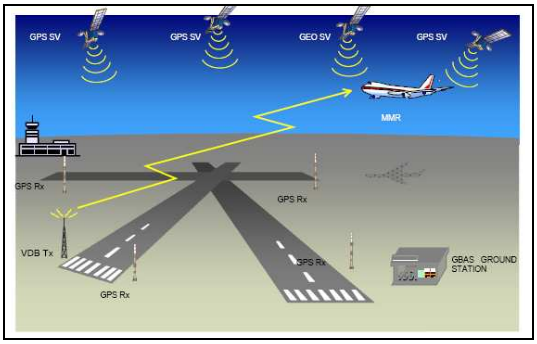

Figure 2. GBAS overview

a) GNSS Satellite subsystem produces the ranging signals and navigation messages. The satellite signals received by the GNSS receivers are subject to various error sources. Some of these error sources would be compensated through the use of differential techniques in the GBAS system.

b) GBAS ground subsystem uses two or more GNSS receivers. It collects pseudo ranges for all GNSS satellites in view, computes and broadcasts differential corrections and integrity-related information for them based on its own surveyed position. The transmitter broadcasts pseudorange corrections, integrity parameters and various locally relevant data such as Final Approach Segment (FAS) data, referenced to the World Geodetic System (WGS-84). The ground station has the capability to support multiple approaches and runways, when it uses an antenna with an omni directional pattern.

c) Aircraft subsystem, within the area covered by the ground station may use the broadcast corrections to compute their own measurements according to the differential principle. After selection of the desired FAS for the landing runway, the differentially corrected position is used to generate navigation guidance signals. These signals are lateral and vertical deviations as well as distance to the threshold crossing point of the selected FAS and an integrity flags. Concerning with the frequency selection, it tunes to the correct frequency using a channel number consisting of five numeric characters. The channel number enables the airborne subsystem also to select the Final Approach Segment (FAS) data block that defines the correct approach. The correct FAS data block is selected by the Reference Path Data Selector (RPDS) which is included as part of the FAS definition data in one of the broadcast message. In order to minimize the impact upon current aircraft design and operational procedures, guidance information output is intended to be consistent with ILS requirements ("ILS look-alike"). This procedure will reduce the certification effort of these Multi-Mode Receivers (MMR), of which the GBAS aircraft subsystem forms a part.

3. SBAS

EGNOS has been developed by the European Space Agency (ESA) in co-operation with the European Commission and Eurocontrol. The system is made up by 3 segments:

a) Space segment, already existing GPS constellation and 3 Geostationary satellites broadcasting WAD (Wide Area Differential) corrections and integrity information. Geostationary satellites improve the system geometry increasing the availability;

b) Ground segment, 34 stations RIMS (Ranging and Integrity Monitoring Stations) monitoring all satellites in view. 4 MCC (Mission Control Centre) providing to generate the WAD (Wide Area Differential) corrections, integrity message, ionosphere corrections and the ephemeris for every geostationary satellite. EWAN (EGNOS Wide Area Network) is the network that allows the connection of the ground segment elements. 4 NLES (Navigation Land Earth Station) that upload the SBAS messages on GEO satellites.

c) Support segment, the EGNOS Support Facilities are composed of the Performance Assessment Check out Facility (PACF) and the Application Specific Qualification Facility (ASQF). The PACF is a centralized facility that provides Operations support, Engineering support and some Maintenance and Logistics support capabilities for the EGNOS Operations system. The ASQF is a centralized facility that provides the technical interface to EGNOS users and will provide technical analysis of EGNOS performances versus agreed service levels.

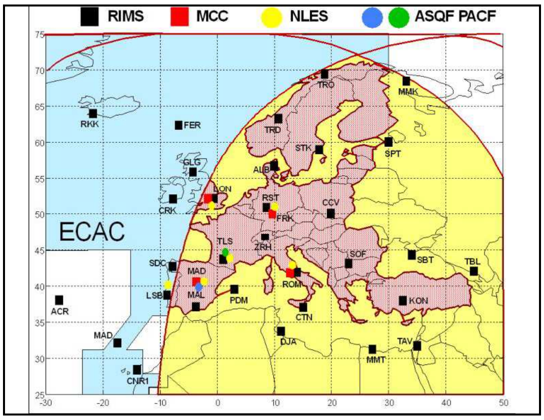

Figure 3. SBAS ground segment

d) User segment, users of aeronautic, maritime and ground transport by SBAS receivers used to adapt the data provided by the service to the different applications. Using the same L1 frequency, the GEO satellites broadcast signals very similar to the GPS ones.

Before going into service in 2007, EGNOS is under final phase of testing; the future goal will be to provide the positioning service also for the aviation approach APV1 and APV2 (Approach with Vertical Guidance) and generally for the so-called safety-of-life applications about ground-maritime-air navigation. When EGNOS will be full operative, it will be able to provide a hi-accuracy position service providing to the user also the integrity information.

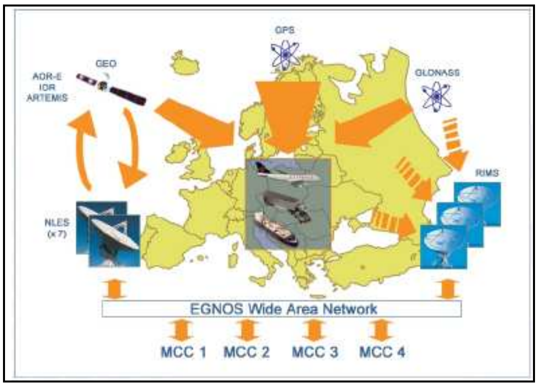

Figure 4. SBAS overview

The integrity information provides the users a certified bound error for their estimated position; this is fundamental for the applications it's destined to.

EGNOS is currently in its Initial Operation Phase (IOP) and is handed over to a commercial operator, the European Satellite Services Provider (ESSP).

4. General approach to the Protection Level

The standards established by the ICAO fix some thresholds for the following parameters:

- Accuracy, defined as the difference between the estimated position and the real one. The accuracy must be referred to both horizontal plane and along vertical. Considering that the errors of satellite systems are a function of satellites' geometry, the probability that the position error doesn't get over an assigned value must be at least 95%.
- Integrity, intended as the ability of the system to recognize and point out any system dysfunction that can compromise the required performance for the operation that you are carrying out. The integrity is defined by the probability to point out such dysfunction and the Time To Alert (TTA) intended as the time between the happen of the dysfunction and the sign of such event to the user.
- Availability, defined as the time percentage within which the system is able to work providing the performances required by operation. Such parameter is function of the measure environment features and receiver technology.
- Continuity, intended as the ability of system to allow to end the undertook operation without any break of service caused by anomalies that can compromise the safety. Such parameter is defined by the probability that system is available throughout the operation if it was available at the beginning.

The accuracy of a navigation system is defined in term of Total System Error (TSE) which is referenced to a required flight path defined for each phase of flight. In order to follow the required path, the aircraft navigation system estimates the aircraft's position and generates commands (either to a cockpit display or to the autopilot). Error in the estimation of the aircraft's position is defined as Navigation System Error (NSE) which is the difference between the aircraft's true position and its displayed position (see figure 5).

The difference between the required flight path and the displayed position of the aircraft is called Flight Technical Error (FTE) and contains aircraft dynamics, turbulence effects, man-machine-interface problems, etc.

The vector, sum of NSE plus FTE, is the Total System Error. Since the actual Navigation System Error can not be observed in real-time without a high-precision reference system (the NSE is the difference between the actual position of an aircraft and its computed position), a method has to be found in order to define an upper bound including this error.

The Horizontal Protection Level HPL is the radius of a circle in the horizontal plane (the plane tangent to the WGS84 ellipsoid), with the centre at the true aircraft position, which describes the region which is assured to contain the indicated horizontal position. It is the horizontal region for which the missed alert requirements can be met.

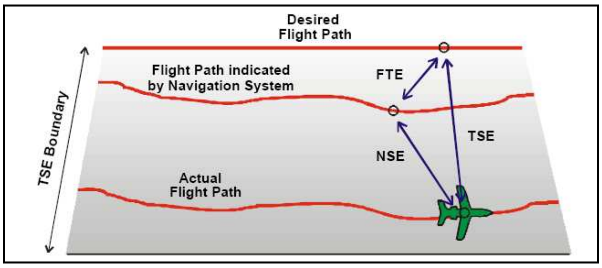

Figure 5. Navigation System Error, Flight Technical Error and Total System Error [1]

The Vertical Protection Level VPL is the half length of a segment on the vertical axis (perpendicular to the horizontal plane of the WGS84 ellipsoid), with the centre at the true aircraft position, which describes the region which is assured to contain the indicated vertical position. It is the vertical region for which the missed alert requirements can be met.

The protection levels are a function of the satellite constellation and the estimated SBAS performance. Thus, using the GBAS correction data, the protection levels can be determined without using actual pseudorange measurements.

The computed protection levels must be compared to the required Alert Limits AL for the particular phase of flight. If the protection level is smaller than the required alert limit, then the phase of flight can be performed. However, if the protection level is greater than, or equal to, the required alert limit, then the integrity of the position solution can not be guaranteed in the context of the requirements for that particular flight phase.

$$\begin{aligned} XPL < XAL & \quad \textit{Integrity can be assured} \\ XPL \geq XAL & \quad \textit{Integrity can not be assured} \end{aligned} \qquad (1)$$

with XPL (horizontal or vertical) protection level and XAL (horizontal or vertical) alert limit. The protection levels are tie to the availability of service for a given operation by table 2; XAL are upper thresholds for protection levels for a given operation.

Table 2. Availability of service for a given operation and protection levels

Operation	**Alert Limits (XAL)**		
	HAL	VAL	[units]
APV-I	40	50	[m]
APV-II	40	20	[m]
CAT-I	40	12	[m]

5. GBAS Results

We start from a 24h data set of measurements carried out by the GMS on September 5th 2005. The used post processing software was PEGASUS v 4.1 developed by Eurocontrol.

The horizontal deviation is showed in the following figure 6:

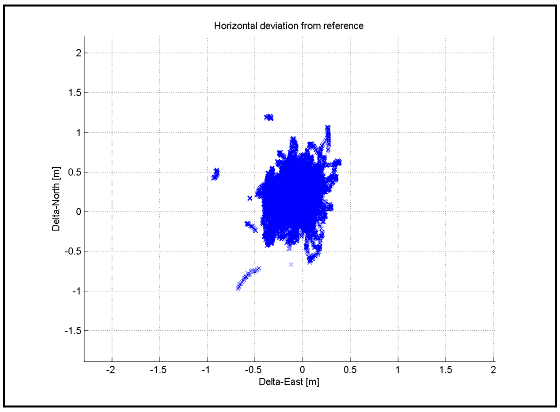

Figure 6. Typical GBAS Horizontal Deviation

This distribution shows that all the errors fall in the range ± 1 mt. The largest errors arise when the GBAS correction are not applied.

In order to verify the Integrity requirement another test is run. In the figure 7 we compare the protection levels and its relative position errors.

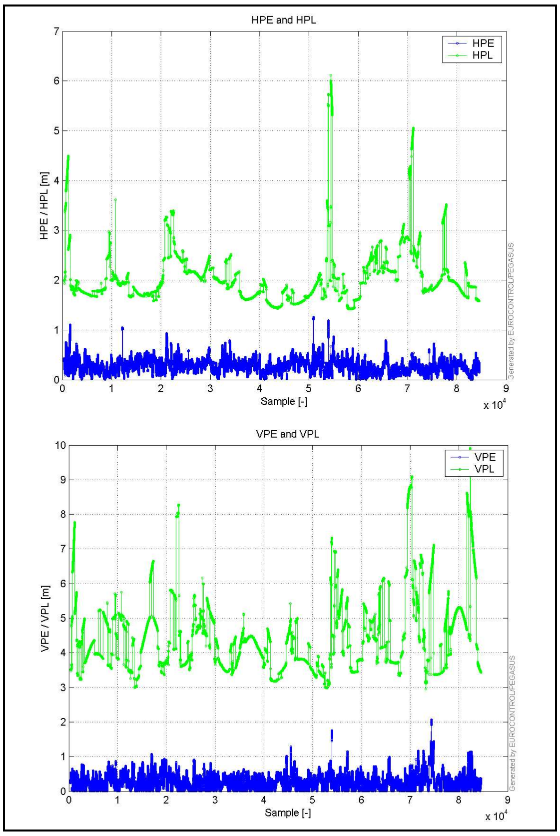

Figure 7. GBAS Position Error and Protection Level.

From the above figure, it’s easy to check that integrity is always verified. From the statistical analysis the following results arise:

Table 3. GBAS Statistical Analysis

	μ (m)	**PE95%, PL99% (m)**
HPE	0.276321	0.5
HPL	2.049175	4.4
VPE	0.284767	0.7
VPL	4.478636	8.5

5. SBAS Results

In the frame of EGNOS data collection, analysis and evaluation, Eurocontrol established a standard environment of measurement. The Department of Applied Sciences – Navigation Section, University of Naples Parthenope has activated a own monitoring station with a Novatel OEM4 receiver. The considered data are referred to a precise position in the WGS84:

- Lat: 41.11780220° N
- Lon: 13.89404250° E
- Height: 69.7197 mt

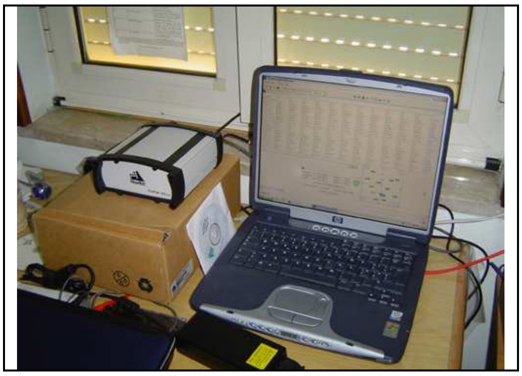

Figure 8. Hardware of data storing

Figure 9. Antenna position

We have considered 24h data set of measurements carried out by our station on May 21st 2006. The used post processing software was PEGASUS v 4.11 developed by Eurocontrol.

The horizontal deviation is shown in the following figure 10:

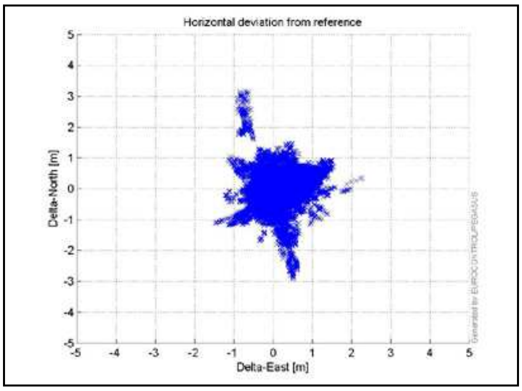

Figure 10. Typical SBAS Horizontal deviation

This distribution shows that all the errors fall in the range ± 1,5 mt, the rising of deviation is tied at the epochs of low number of satellites used in position solution or bad satellites geometry.

As for as the protection levels, these parameters are used for integrity trial and they directly influence the availability of service for APV operations.

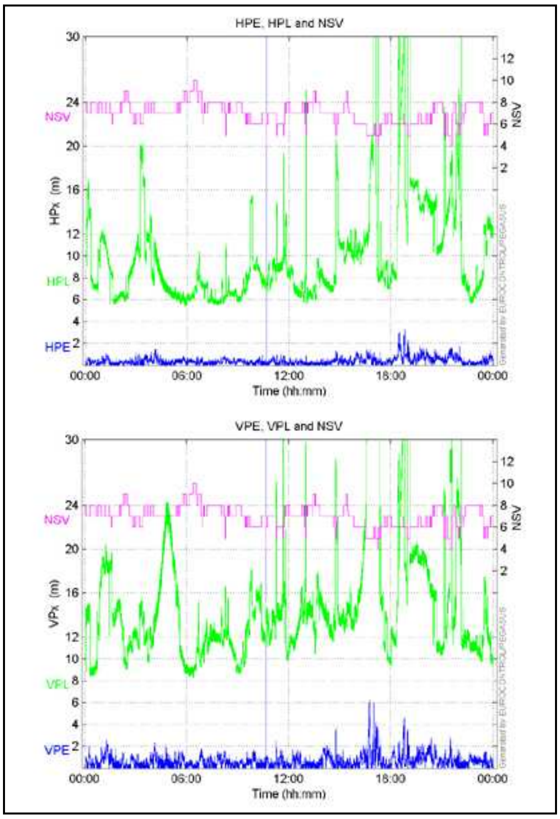

Figure 11. SBAS Position Error, Protection Levels and NSV used in position solution.

From the above pictures, it’s easy to check that the integrity is always verified for EGNOS, too.

From the statistical analysis the following results arise:

Table 4. SBAS Statistical Analysis

	μ (m)	PE95%, PL99% (m)
HPE	0.403883	0.98
HPL	9.943469	31.89
VPE	0.643893	1.60
VPL	14.673397	68.14

6. Conclusions

The goal of this work is to verify the performance of Augmentation Systems in South Europe.

We processed the data set of measures collected in the unique Italian GBAS Installation (Milano–Linate, Italy) and for EGNOS in the Department of Applied Sciences of Parthenope University Monitoring Station. The used software is Pegasus v 4.1 currently regarded as a benchmark in the European research. This is the first attempt to develop these procedures in the Italian context.

A set of statistical test has been curried in order to verify its efficiency that results very satisfactory both for GBAS and EGNOS. This is partly due to the static mode of the instruments. A further development of this research could investigate the implication of a dynamic positioning.

As application of the Augmentation Systems (e.g. in Air Navigation) in future we’ll be able to plan some procedures that use the SBAS for initial approach and GBAS for final approach.

The future works of our research Group will be focused on a Dynamic Test.

For the GBAS we want to create a Virtual installation to generate in post process the GBAS Correction.

References

1. *"PEGASUS Plus Technical Notes"*, EUROCONTROL.
2. *"Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using GPS"*, RTCA Document 208, July 1991.
3. *"RTCA: Minimal Operational Performance Standards for GPS/WAAS Airborne Equipment"*, Doc. No. Do 229 A, June 1998.
4. *"MARS3 Technical Notes for Pegasus"*, rif. PEG-GBAS-TN02.
5. A. Pacifico, *GNSS Operational Validation, Monitoraggio e Validazione del segnale EGNOS* – Thesis in Satellite Navigation, University of Naples Parthenope, Naples, Italia (December 2005).
6. S. Gaglione, T. Cozzolino: *"ESTB – EGNOS System Test Bed"*, Atti Istituto Italiano di Navigazione IIN, vol., Roma 2004.
7. S. Gaglione, M. Vultaggio *"The GBAS – Ground Based Augmentation System - an Italian Experience"*, European Navigation Conference 2006 (ENC2006), Manchester, UK, 7-10 May 2006.
8. A. Pacifico, M. Vultaggio, *"EGNOS: First results of the European SBAS system"*, European Navigation Conference 2006 (ENC2006), Manchester, UK, 7-10 May 2006.