GNSS for an aviation analysis based on EUPOS and GNSS/EGNOS collocated stations in PWSZ CHEŁM

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ABSTRACT: Under the umbrella of PWSZ Chelm, taking account of future implementation of navigation using EUPOS and GNSS based on EGNOS several planned actions were carried out in the 2005-2006. The actions in particular contribute to:

1. ICAO and EGNOS requirements and coverage area (Chelm Town located near Polish-Ukrainian border is also at the east border of planned EGNOS coverage for ECAC states).
2. Preparatory activities to establishing the EUPOS station in PWSZ Chelm. Cooperation of PWSZ Chelm and ULC (Polish Aviation Regulator) in the frame of conventional NAV aids use and GNSS implementation in aviation.
3. Analysis of ICAO requirements and methods of testing SIS (Signal In Space) needed to certify GNSS in Poland for use for an aviation.
4. Preparatory activities to establishing the EGNOS SIS monitoring station based on EUROCONTROL Pegasus software and GNSS/EGNOS receiver Septentrio PolaRx2e.
5. Analysis of methods for exchange of information between EUPOS and EGNOS SIS station to initiate the application of satellite positioning systems to air navigation in Poland.

The project EUPOS is a European initiative aiming at establishment of a uniform DGNSS (Differential Global Navigation Satellite System) basis infrastructures in Central and Eastern European countries including Chelm Town where PWSZ is localized playing vital role in GIS/GNSS implementation in the region and Polish aviation.

1 ICAO STANDARDS FOR GNSS

1.1 *Overview of SBAS*

SBAS, as defined in the SARPs, has the potential to support en-route through Category I precision approach operations. Initial SBAS architectures will typically support operations down to APV. SBAS monitors GPS and/or GLONASS signals using a network of reference stations distributed over a large geographic area. These stations relay data to a central processing facility, which assesses signal validity and computes corrections to each satellite's broadcast ephemeris and clock. For each monitored GPS or GLONASS satellite, SBAS estimates the errors in the broadcast ephemeris parameters and satellite clock, and broadcasts corrections. Integrity me sages and corrections for each monitored GPS and/or GLONASS ranging source are broadcast on the GPS L1 frequency from SBAS satellites, typically geostationary (GEO) satellites in fixed orbital slots over the equator. The SBAS satellites also provide ranging signals similar to GPS; however, these ranging signals cannot be received by Basic GNSS receivers. SBAS messages ensure integrity, improve availability, and provide the performance needed for APV and Category I precision approach operations. SBAS uses two-frequency range measurements to estimate the ranging delay introduced by the Earth's ionosphere, and broadcasts corrections applicable at predetermined ionospheric grid points. The SBAS receiver interpolates between grid points to calculate the ionospheric correction along its line-of-sight to each satellite. In addition to the clock, ephemeris and ionospheric corrections, SBAS assesses and broadcasts parameters that bound the uncertainty in the corrections. The User Differential Range Error (UDRE) for each ranging source describes the uncertainty in the clock and ephemeris corrections for that ranging source. The Grid Ionospheric Vertical Error (GIVE) for each ionospheric grid point describes the uncertainty in the ionospheric corrections around that grid point. The SBAS receiver combines these error estimates with estimates of the uncertainties in its own pseudorange measurement accuracy and in its tropospheric delay model, to compute an error model of the navigation solution.

A system providing GNSS satellite status requires a few reference stations and simple master stations that provide integrity only. Providing basic differential corrections requires more reference stations and a more complex master station to generate clock and ephemeris corrections. Providing precise differential corrections requires more reference stations in order to characterize the ionosphere and provide ionospheric corrections. The four SBASs under development (EGNOS, GAGAN, MSAS, WAAS) all provide precise differential corrections. Ranging, satellite status and basic differential correction functions are usable throughout the entire GEO coverage area, and are technically adequate to support non-precision approaches by providing monitoring and integrity data for GPS, GLONASS and SBAS satellites. The only potential for integrity to be compromised is if there is a satellite orbit error that cannot be observed by the SBAS ground network and that creates an unacceptable error outside of the SBAS service area. This is, however, very unlikely for en-route, terminal and non-precision approach operations. For a service area located relatively far from an SBAS ground network, the number of visible satellites for which that SBAS provides status and basic corrections will be reduced. Since SBAS receivers are able to use data from two SBASs simultaneously, and to use autonomous fault detection and exclusion when necessary, availability may still be sufficient to support approval of some operations.

A State may obtain SBAS service by either: co-operating with another State (called the SBAS service provider) that has developed and deployed an SBAS; or, by developing its own SBAS. A State might choose the former if its airspace is within the service provider's coverage area. It would then have to negotiate an agreement with the SBAS service provider covering such aspects as the type of service and compensation arrangements. A State adjacent to the SBAS service area could possibly extend the SBAS service area into its airspace without hosting any SBAS infrastructure, or it could field reference stations linked to the SBAS service provider's master stations. In both cases the SBAS service provider's GEO satellites would broadcast data that would cover the SBAS service areas of both States. In any case, it is a State's responsibility to monitor the performance of the SBAS within its airspace, and provide a status monitoring and NOTAM service.

1.2 *SBAS-EGNOS*

The objective of the EUROCONTROL SBAS project is to support EUROCONTROL member States in achieving the operational approval for the use of GPS augmented by a Satellite Based Augmentation System. The SBAS system covering Europe is called the European Geostationary Navigation Overlay Service (EGNOS). This project provides a co-ordination platform for all issues related to the operational validation of SBAS systems, supporting member States and encouraging a harmonised approach to operational approval throughout ECAC. It covers both the operational validation and the safety assessment.

EGNOS is being developed by the European Space Agency (ESA) in co-operation with the European Union and Eurocontrol. The system provides additional signals to users of satellite navigation services, broadcast through geostationary satellites guaranteeing the integrity of GPS so that it can be used in support of safety-of-life services such as civil aviation. The various Member States that are investing in EGNOS intend to offer air navigation services and operational procedures that make use of the system. In order to obtain maximum benefits from EGNOS, operational approvals need to be achieved as early as possible. The key goal of this project is to expedite the approval process by identifying all the tasks that must be carried out, who should perform them and ensuring that they are done. Each State offering EGNOS services will have to go through a safety assessment and operational approval process. A harmonized approach to operational approval throughout ECAC will be most efficient and is preferred. ESA will perform an extensive EGNOS verification campaign but this will focus on the signal-in-space as seen by a network of independent reference stations. Within the particular environment of an aircraft performing an operation, ESA will perform demonstrations but the results of these will not be applicable to the industrial consortium building EGNOS. As a result additional validation activities will need to be performed within the EUROCONTROL SBAS project to demonstrate compliance with the EGNOS Mission Requirements Document for Civil Aviation.

This part of the SBAS project is called GNSS-1 Operational Validation (GOV). The EGNOS Safety Case Team (ESCT), developing the EGNOS Safety Case, require the output from the operational validation activities for use in the assessment of the safety of operations performed using EGNOS. GOV will need to provide the evidence that EGNOS meets all the necessary performance requirements. The Safety Case will show that the use of EGNOS is safe for its intended operations based on an agreed set of assumptions. Whereas the initial focus of GOV will be on EGNOS, the project will provide knowledge, experience and tools that will be used to support future GNSS validation activities for Ground-Based Augmentation Systems for Category I, II and III precision approach and landing. The experience will also contribute to the validation of the second-generation of satellite navigation systems, in particular GPS Block IIF and Galileo.

2 ASSUMPTIONS FOR TESTS

According to ICAO requirements it is necessary to use applicable equipments such as a hardware and software.

The monitoring station consists of:

– An antenna (PolaNt (L1/L2);

– GPS receiver Septentrio PolaRx2;
– Personal computer;
– Software (RxControl Septentrio).

We use for *PolaRx2* instrument mode with 15 dual-frequency GPS channels and 3 single frequency SBAS channels. We collect measurements on C/A-, P1-, P2-code and L1-, L2-carrier phase and Doppler counts in 1 Hz output rate. The 1 seconds output was decimated to 30 seconds output rate. The time of measurements is synchronized with true GPS time in range of 1 ms.

PolaRx2@ is a versatile multi-channel, dual-frequency GNSS receiver that can be connected to up to 3 antennas. As part of the *PolaRx2* family of high-end satellite navigation receivers, it uses an advanced GNSS chipset and tracking and positioning algorithms, resulting in low noise performance and hi gh tracking stability.

Fig. 1. The antenna used for tests (mounted on PWSZ building)

Implemented on a single Euro-card size board, it brings heading/attitude and other multi-antenna applications within economical and practical reach with a possibility changing dates via RS 232 in RINEX. The *PolaRx2* receiver was connected to the PolaNt (L1/L2) antenna with conical radome during the experiment.

For collecting *PolaRx2* data we use the RxControl program with our own superstructure. Main disadvantage for continuous running of receiver on any permanent station is that the RXControl software doesn't start logging of measurement to files automatic after the on-site computer starts.

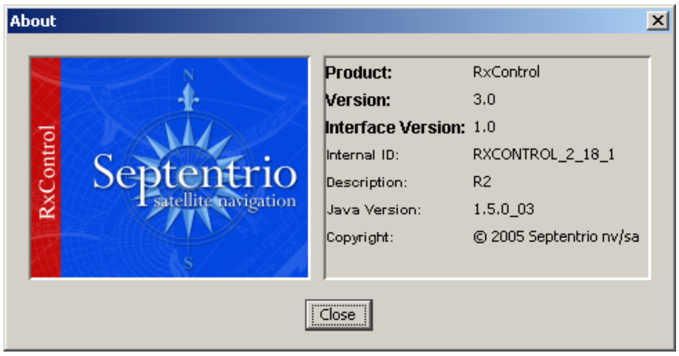

Fig. 2. The software used for tests

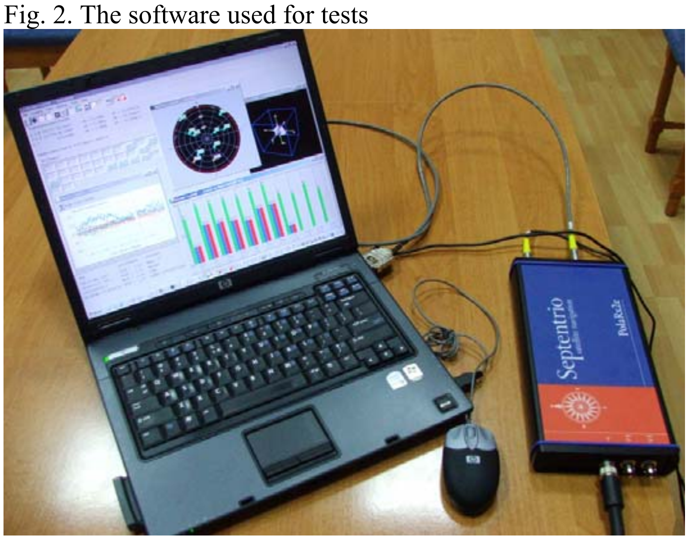

Fig. 3. The test equipment configuration

3 MESSAGES FOR ANALYZES

The table mentioned below depicts EGNOS messages connected with integrity. It is crucial to analyze $1{,}38 \times 10^9$ trials to carry out a validation of RNP for the integrity during non-precision approaches and $1{,}38 \times 10^9$ during precision approaches Cat. I.

SBAS message	information content
2-5	fast clock and ephemeris corrections, UDRE
6	UDRE for all satellites
7	UDRE temporal degradation info
24	mixed fast and slow clock and ephemeris corrections, UDRE
25	slow clock and ephemeris corrections
26	ionospheric corrections, UIVE

Fig. 4. EGNOS messages

The Horizontal and Vertical Protection Levels (XPL),which are computed from broadcast EGNOS messages, to protect users from potential degradation of the GPS system, expressed in terms of Horizontal and Vertical Navigation Error (XNSE) above a certain user level, called the Alert Limit (XAL). Several cases for the relation between XNSE, XAL and XPL exist, however, two cases are very important from a safety perspective:

1. XPL<XNSE<XAL: System is available but not safe, not leading to a hazardous situation, called Misleading Information (MI).

2. XPL<XAL<XNSE: System is available but not safe and leading to a hazardous situation, called Hazardous Misleading Information (HMI).

Both cases are considered as an SBAS out of tolerance condition, and are assumed in EGNOS as non-integrity events. The EGNOS system will guarantee that the probability of occurrence of those events is below 2×10^{-7} in 150 seconds. Potential error sources that may provoke these out of tolerance conditions include:

Fast and Slow correction / User Differential Range Error (UDRE) mismodelling Grid Ionospheric Vertical Delay (GIVD) / Grid Ionospheric Vertical Error (GIVE) mismodelling

Extensive local errors (multipath and/or receiver noise (due to interference))

It is assumed here that the contribution to XPL out-of tolerance of tropospheric under bounding errors at the receiver is negligible.

It is important to note that the receiver recorded some parameters as:

MI – Misleading Information (XPE>XPL)

HMI–Hazardous-Misleading Information (XPE> XAL>XPL)

These parameters have to analyze for each approach and landing procedures.

4 RESULTES OF EXPERIMENTS

4.1 *The monitoring station*

It is important to distinguish between the SBAS coverage areas and service areas. The SBAS coverage area is defined by GEO satellite signal footprints. Service areas for a particular SBAS are established by a State within an the SBAS coverage area. That is why it is necessary carrying out trials in Chelm, because this city is situated on the border of EGNOS coverage area.

The localization of the monitoring station on the roof of the State School in Chełm is a good choice. A recorded satellite signal has a very good quality. The graph mentioned below depicts the accuracy of the antenna.

φ = N 051°07'48,08888064"	RMS =	0,518m	φ = N 051°07'48,09416202"
λ = E 023°28'49,20663773"	RMS =	0,273m	λ = E 023°28'49,20899637"

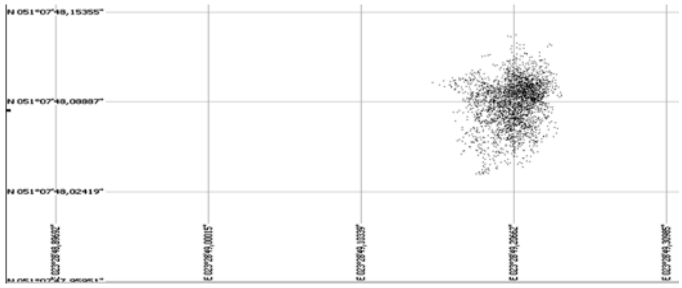

Fig. 5.. The recorded antenna positions

EGNOS messages transmitted form PRN120 and PRN126 satellites were recorded. An accurate analyze recorded dates will be carried out in the near future.

The figure 5 presents SkyPlot view with marked satellite, that transmitted EGNOS corrections.

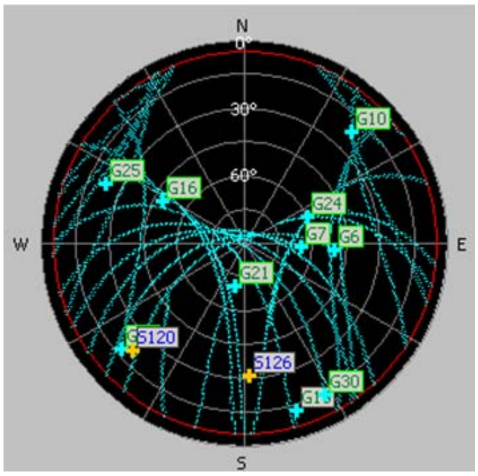

Fig. 6. The SkayPlot view

Recorded parameter values as MI – 7 and HMI – 236 show us, that EGNOS service does not meet requirements for APV, especially near the border of EGNOS coverage area.

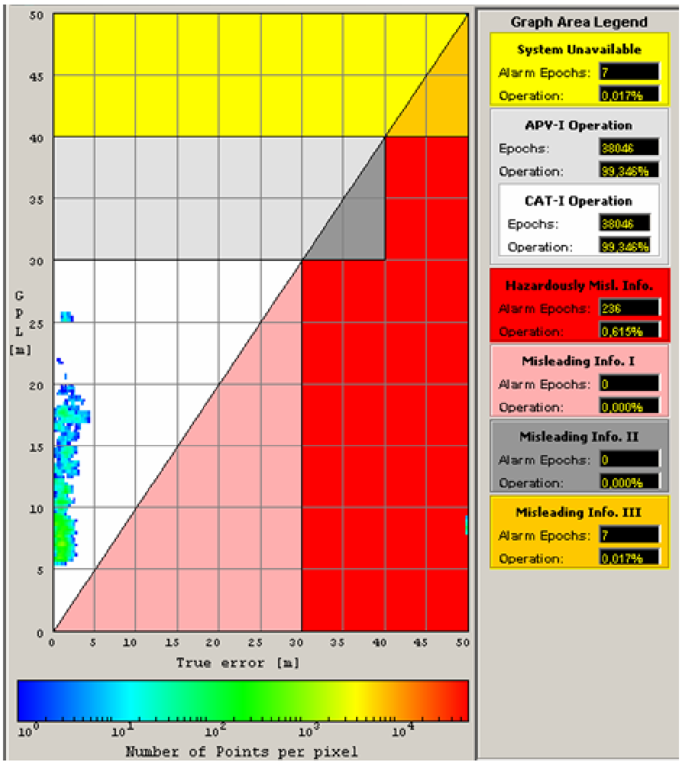

Fig. 7. Misleading Information recorded by the monitoring station

It has to be underlined that our testing system has recorded many epoches containg System Unavailable alarm. This means limiting the availability of system by 74%. This value is to low to meet ICAO requirements. That is why initial evaluation of EGNOS do not allows to qualifies for APV on the border of coverage area.

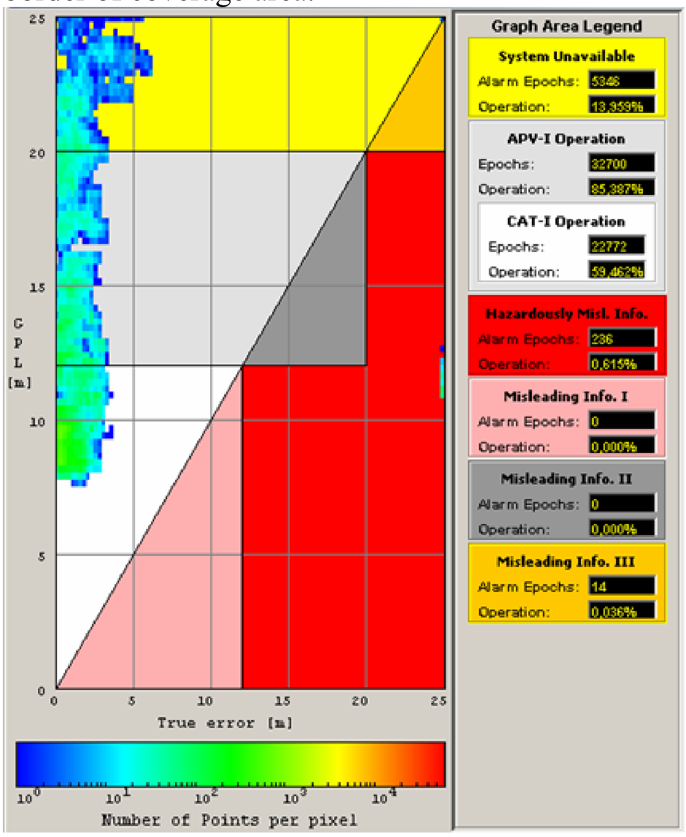

Fig. 8. Misleading Information recorded by the monitoring station

5 DATES RECORDING

We are going to analyze SIS with software called Mat Lab and PEGASUS. PEGASUS (Prototype EGNOS and GBAS Analysis System Using SAPPHIRE) is a prototype which allows analysis of GNSS data collected from different SBAS and GBAS systems and using only algorithms contained in the published standards. The tool has been developed in the frame of the GNSS-1 operational validation activity defined in the EUROCONTROL SBAS project and aims to be a first step forward the development of a standard processing and analysing tool to be used for the future EGNOS operational validation. PEGASUS was designed to facilitate the output data handling and interchange. The tool provides several functionalities such as computation of position and GNSS systems attributes like accuracy, reliability, and availability simulating MOPS-compliant receivers, computation of trajectory errors, prediction of accuracy and availability with the req integrity and simulation of GBAS Ground Station processing algorithms.

Thanks to these programs it will be possible to compute HPL, VPL, HPE, VPE parameters.

6 CONCLUSIONS

It is not possible to verify the appearance of the facts, described by probability from 10^{-7} to 10^{-9} by using traditional methods of testing the system. It is obvious to carry out the approach to landing in 10^{7} it is not enough for our technical and time-consuming abilities.

For our references to be possible to deal with requirements of the GNSS to be registered by monitoring stations parameters it is necessary to change them (defined as "for operation" or "for the time of the flight") to 1/s.

Taking into consideration, described above, all the requirements for EGFNOS it is necessary to mention that the certification of parameters of the EGNOS is possible only and solely thanks to joining the methods of systematic analysis using the statistic survey gained by properly constructed monitoring stations (such as the one that was tested in PWSZ in Chelm)

The station in Chelm is design for navigation and real time position determination with accuracy of3 m up to 0.5 m, dependent on the used rover station equipment, providing compressed and encoded DGNSS correction data via: Internet, GPRS/GSM, VHF radio/radio broadcast.

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ICAO Załącznik 10 Tom 1 Pomoce Radionawigacyjne – Rozdział 3 Warunki Techniczne dla Pomocy Radionawigacyjnych Tabela 3.7.2.4-1.

Dokumentacja Septentrio: PolaRx2/2e User Manual.