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EGNOS BASED APV PROCEDURES DEVELOPMENT POSSIBILITIES IN THE SOUTH-EASTERN PART OF POLAND

ABSTRACT

On 14th and 15th March 2011 for the first time approach with vertical guidance (APV-I) was conducted on Polish territory in Katowice, Kraków and Mielec. This was the milestone for GNSS (Global Navigation Satellite System) and Area Navigation (RNAV) use as a new instrument approach chance for NPA (Non-Precision Approach) and PA (Precision Approach) in Poland. The paper presents the experiment study of EGNOS SIS (Signal in Space) due to APV (Approach with Vertical Guidance) procedures development possibilities in the south-eastern part of Poland. Researches were conducted from January 2014 till June 2014 in three Polish cities: Warszawa, Kraków and Rzeszów. EGNOS as SBAS (Satellite Based Augmentation System) in according with ICAO's Annex 10 has to meet restrictive requirements for three dimensional accuracy, system integrity, availability and continuity of SIS. Because of ECAC (European Civil Aviation Conference) states to EGNOS coverage in the eastern part of Europe, location of mention above stations, shows real usefulness for SIS tests and evaluation of the results [EUROCONTROL, 2008].

Keywords:
EGNOS, Approach with Vertical Guidance, Signal in Space evaluation.

INTRODUCTION

The European Geostationary Navigation Overlay Service (EGNOS) as a joint project of the European Space Agency, European Commission and Eurocontrol (European Organization for the Safety of Air Navigation), the first step to GNSS and precursor to Galileo is European wide area Satellite Based Augmentation System

(SBAS), which main task is to evaluate and broadcast correct GPS (Global Positioning System) data over whole continent by improving integrity via real-time monitoring, accuracy via differential corrections, availability and continuity [European Commission, 2009].

EGNOS uses a combination of geostationary satellites and ground-based stations to receive, evaluate, correct and send back data to GPS receivers. RIMS (Remote Integrity and Monitoring Stations) collect data from the GPS satellites and transmit it towards a processing facility, MCC (Master Control Centers) process, elaborate to be diffused and format of the EGNOS signal, NLES (Navigation Land Earth Stations) transmit data towards geostationary satellites [ESA, 2009].

Three types of positioning services are provided: Open Service (OS) available since 1st October 2009 mainly support mass market, Commercial Data Distribution Service (CDDS) using Internet to broadcast data for commercial and professional users requiring enhanced performance, Safety of Life Service (SoL) providing the most stringent level of signal-in-space performance to all Safety of Life users in particular aviation via geostationary satellites available since 2nd of March 2011.

In order to take benefit from SBAS performance in Europe (EGNOS) in 2002 a new classification of the instrumental approach procedures was established, two levels were defined: APV I and APV II, because SBAS failed to reach approach procedures CAT I, however still provides geometric vertical guidance [OPTIMAL, 2007]. Sometime later LPV was introduced, means Localizer Performance with Vertical guidance and referring to APV I, II. The ICAO OCP (Obstacle Clearance Panel) prepared materials for LPV procedures design, from now on titled ‘RNAV(GNSS)’, with addition of minima box line, LPV in it. Placed the procedures in the sensor-based approach (SBAS as a sensor). It should be mentioned that LPV procedure is based on the RNAV concept, which permits aircraft operation on any desired flight path within the coverage of ground or space based navigation aids or within the limits of the self-contained aids also combination of these [OPTIMAL, 2007]. From the beginning EGNOS performance is being monitored and work is in progress for system development in the territory of Poland [Felski A., Nowak A., 2012].

LOCALISER PERFORMANCE WITH VERTICAL GUIDANCE PROCEDURES CONCEPT

The instrument APV procedures consist of four phases of flight: Initial Approach, Intermediate Approach, Final Approach and Missed Approach (when reaching Decision Altitude/Height, pilot has to decide to proceed and land visually if runway is visible, if not — go around and fly the missed approach procedure published) — parts of approach segments [ICAO, 2008]. As mentioned before, SBAS seems to be the first satellite based system that can support FAS (Final Approach Segment) which is the most ‘sensitive’, important and dangerous part of the instrumental approach procedures based on aircraft’s avionics equipment most time without vertical and horizontal visibility. Currently SBAS (EGNOS) augments the GPS and probably GLONASS system in the future in order to meet the necessary accuracy, integrity, availability, continuity envisaged for APV procedures. These approaches are similar and equivalent to the legacy of ILS (Instrument Landing System), radio beam transmitter that provides a direction for approaching aircraft (which tuned their receiver to the system frequency) providing precision lateral and vertical guidance. But more economical because of no navigation infrastructure needs to be installed on the airfield with minimal equipment installed in the aircraft [ICAO, 2013].

There are 63 LPV approaches in use till 2014 in Europe, the most of them is situated in France, Germany and Switzerland. However over 2000 LPV approaches in USA based on WAAS (Wide Area Augmentation System) and FAA (Federal Aviation Administration) published 300 new approaches each year [www.egnos-portal.gsa.europa.eu].

Two kinds of benefits improvements of the instrumental approach due to SBAS use are related to APV procedures use and RNAV concept usage [ICAO, 2007].

1. APV Segment based on EGNOS benefits:

   - approach procedures are safer than conventional NPA, because of geometric vertical guidance provision,
   - reduced the CFIT (Controlled Flight Into Terrain) not allowed to perform ‘dive and drive’ navigation which occur without vertical guidance information,
   - improve capacity and regularity at airports without ILS or out of service provides a procedure having lower operational minima than in a NPA,
   - reduced noise because of a constant descent angle through FAS,
   - due to RNAV/Baro-VNAV (Barometric Vertical Navigation) procedures, EGNOS APV temperature restriction does not exist,
   - because of decommissioning ground-based navigation aids, costs are saved (but back-up system is needed in case of SIS unavailability.

2. RNAV concept usage benefits:

   - ATC workout reduction,

- possibility of improved flight tracks establishment,
- reduction of traffic dispersion as in case of conventional approach procedures.

EGNOS SIGNAL-IN-SPACE

The EGNOS signal-in-space is being broadcasted using three GEO (Geostationary Earth Orbit) satellites Artemis, Inmarsat AOR-E, Inmarsat IOR-W, operating on frequency L1 (centered at 1575.42 MHz). Each second using RHCP (Right-Hand Circular Polarization) system transmits a navigation message containing 250 bits of information. Message contains both fast corrections which is related to rapidly-changing errors like for example GPS satellite clock errors, slow corrections like ephemeris, clock drift errors. Its format is compliant with provided standards, also with other SBAS systems. Due to ICAO Annex 10 requirements each SBAS SIS, in this case EGNOS SIS has to meet standards showed in table 1 [ICAO, 1996].

Table 1. ICAO Signal-in-Space requirements for SBAS system

	Accuracy 95%		**Integrity**				**Continuity**	**Availability**
	Lateral	**Vertical**	**Integrity Risk**	**Time to Alert**	**Horizontal Alert Limit**	**Vertical Alert Limit**		
APV I	16 m	20 m	$1 - 2 \times 10^{-7}$	10 s	40 m	50 m	$1 - 8 \times 10^{-6}$	0.99 to 0.99999
APV II	16 m	8 m	$1 - 2 \times 10^{-7}$	6 s	40 m	20 m	$1 - 8 \times 10^{-6}$	0.99 to 0.99999
CAT I	16 m	6-4 m	$1 - 2 \times 10^{-7}$	6 s	40 m	15 to 10 m	$1 - 8 \times 10^{-6}$	0.99 to 0.99999

According to table 2 four important factors which characterized each SBAS system are stringent for precision landing instrumental approaches: accuracy, integrity, continuity and availability [Fellner A., Banaszek K., Trominski P., 2010].

1. Accuracy:
   Difference between the estimated position and the actual position. For a large set of independent samples, at least 95% should fulfill accuracy requirements. It's defined to ensure pilot acceptance, since it represents the errors which will be

experienced. The requirement is for worst-case geometry under which is the declaration of the system availability. Accuracy of the position domain has to be less than 16 m in the horizontal and 20 m in the vertical space with 95% confidence level.

2. Integrity:
   Measure of the trust which can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of the system to alert the user when the system should not be used for the intended instrumental approach phase. The necessary level of integrity for each operation is established with respect to specific alert limits. When the integrity estimates exceed these limits, the pilot is to be alerted within the prescribed time period. Allowable probabilities of non-integrity event (probabilities of Hazardous Misleading Information) per landing approach, are $1–2\times10^{-7}$ for the horizontal and vertical components each.
   Misleading Information situation, occur where there was an HPE/HPL and VPE/VPL ratio of more than 1-real MI (Misleading Information) or more than 0.75-near MI.
3. Continuity:
   The ability of the SBAS to provide function required and performance at the initiation of the intended operation. It's occur as an indication to provide usable service within the specified coverage area of the system. Availability of SIS is the percentage of time that navigational signals transmitted from external sources are available for use. The availability is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities. The local availability of EGNOS SBAS for APV shall be better than 99% over the nominal operational lifetime of the service.
4. Availability:
   SBAS system ability (comprising all elements necessary to maintain aircraft geographical position within the defined airspace) to perform its function without interruption during the intended operation. To specify, continuity is the probability that the specified system performance will be maintained for the duration of a phase of operation, presuming that the system was available at the beginning of that phase of operation, and predicted to exist throughout the operation.

APV POSSIBILITIES EXPERIMENTAL PHASE

The experiment was conducted in three Polish monitoring stations placed in Warszawa, Kraków and Rzeszów. In each Septentrio PolaRx 2/3 receiver was used for record research samples. The PolaRx is a high-end dual frequency GNSS receiver, available as a standard Eurocard-size board. This receiver provides:

- dual frequency high sensitivity tracking of GPS signals (code tracking maintained down to 19 dB-Hz);
- tracking of the L2C signal;
- simultaneous tracking on up to three antennas for attitude determination;
- simultaneous tracking of up to six SBAS;
- high accuracy code, carrier, and Doppler measurements at sampling rates up to 10 Hz;
- decoded and/or raw navigation messages for both GPS and SBAS satellites;
- Receiver Autonomous Integrity Monitoring;
- high accuracy RTK positioning using either the RTCM (including version 3.0) or CMR standard;
- PPS input and a 10 MHz input for precise receiver frequency and time control,
- compact and robust SBF data format.

The study was performed on recorded data from the period of time between 1st of January 2014 and 30th of June 2014 in each of three station in cities mentioned before, samples were recorded in every second twenty four hours per day, for samples evaluation Pegasus 4.7.5 was used [own study]. Experiment results are shown in the tables 3–5.

Table 3. Experiment results for Warszawa

	APV-I					HPL[1]	VPL[2]	DE[2]
	HNSE*	**VNSE****	**AV*****	**HPE******	**VPE*******	**99%**	**99%**	**APV**
JANUARY	1.524	1.505	99.568	1.042	0.622	14.869	22.285	4.074
FEBRUARY	1.564	1.618	99.055	1.033	0.712	16.277	24.159	7.333
MARCH	1.744	1.710	99.871	1.141	3.160	18.533	25.902	3
APRIL	1.701	1.653	99.489	1.086	0.683	18.248	25.234	5.923
MAY	1.604	1.527	99.357	0.997	0.630	18.029	25.952	14.703
JUNE	1.631	1.357	99.466	0.997	0.543	18.012	25.738	6.625
MEAN	1.628	1.562	99.468	1.049	1.058	17.328	24.878	6.943

* Horizontal Navigation System Error [m]
** Vertical Navigation System Error [m]
*** Availability [%]
**** Horizontal Position Error [m]
***** Vertical Position Error [m]

[1] Horizontal Protection Limit [m]
[2] Vertical Protection Limit [m]
[3] Discontinuity Events

Table 4. Experiment results for Kraków

	APV-I					HPL	VPL	DE
	HNSE	VNSE	AV	HPE	VPE	99%	99%	APV
JANUARY	0.681	1.165	99.544	0.348	0.494	20.936	27.095	2
FEBRUARY	0.797	1.275	99.905	0.397	0.523	21.482	29.12	23.857
MARCH	0.872	1.302	99.942	0.437	0.533	21.664	28.459	2.4
APRIL	0.793	1.4025	99.871	0.3985	0.5985	19.844	26.134	3.916
MAY	0.717	1.347	99.566	0.378	0.586	17.888	24.946	1.769
JUNE	0.744	1.348	99.936	0.402	0.643	17.463	24.612	1.333
MEAN	0.767	1.306	99.794	0.393	0.563	19.879	26.728	5.879

Table 5. Experiment results for Rzeszów

	APV-I					HPL	VPL	DE
	HNSE	VNSE	AV	HPE	VPE	99%	99%	APV
JANUARY	0.763	7.485	99.790	0.377	0.639	23.821	30.490	3.833
FEBRUARY	0.917	1.620	99.911	0.447	0.727	22.413	30.576	2.090
MARCH	0.909	1.642	99.978	0.423	0.739	23.195	31.835	1.666
APRIL	0.843	1.619	99.785	0.412	0.666	22.398	29.047	2.8
MAY	0.831	1.455	99.585	0.432	0.599	20.933	27.956	2.333
JUNE	0.846	1.278	99.945	0.429	0.504	20.318	28.506	2.111
MEAN	0.852	2.517	99.832	0.420	0.646	22.179	29.735	2.472

RESULTS

The main factor which characterize every navigation satellite system is accuracy, in every station both horizontal and vertical (HNSE, VNSE) meet ICAO Annex 10 requirements for SBAS APV procedures, however in Kraków records of position was the most accurate (0.767 m for horizontal navigation system error, 1.306 m for vertical navigation system error).

Secondly due to six months calculations, there was no integrity events in all stations results were not even close to 0.75 (HPE/HPL and VPE/VPL) for near Misleading Information, which is a superb result. As was mentioned above, integrity is ‘a measure of trust’ for each system, especially when we’ve got to deal with aviation. That is why EGNOS is real trustworthy for APV implementation.

Next factor taken into consideration was continuity, the ability of system to provide it’s function. The best results were in Rzeszów, to almost 4 events per month, however in Kraków to almost 24 discontinuity events in February with mean of 5.879 per month and in Warszawa to almost 15 discontinuity events in May with mean 6.943 per month. As we can see above, some of discontinuity events appeared, that is why in this case the system needs ‘attention’ and appropriate actions.

The last but not least is availability which is strictly related with continuity, showed during detailed analyzed of SIS days without required percentage precise, although average of each month is more than 99% and the ICAO requirements are met. The best results were in Rzeszów with mean availability of 99.832% for six months to 99.468% mean availability in Warszawa.

CONCLUSIONS

After detailed analyze according to tables above and experiment results some conclusions were made about accuracy, integrity, continuity and availability of the EGNOS system in polish monitoring stations in Warszawa, Kraków and Rzeszów due to APV procedures implementation in Polish territory.

All three factors (accuracy, integrity and availability) meet ICAO Annex 10 requirements shown in table 2, however as said before in Results, there were discontinuity events in all three cities taking part in the experiment. That is why in this case EGNOS does not always met ICAO Annex 10 system requirements for continuity.

To sum up the foregoing conclusions, in spite of days with continuity inefficiency, EGNOS as SBAS APV procedures main system used to supply indispensable information is READY for IMPLEMANTATION in the South-Eastern part of Poland and this region airfields. However second emergency system or source of navigational data should exist for now on until EGNOS continuity inefficiency would be removed.

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STRESZCZENIE

W dniach 14 i 15 marca 2011 roku po raz pierwszy w Polsce przeprowadzono eksperymenty podejścia z zachowaniem wymogów APV-I na lotniskach Katowice, Kraków i Mielec. Był to kamień milowy dla technologii GNSS oraz nawigacji obszarowej (RNAV), albowiem

wykorzystano nowe rozwiązania zarówno dla podejścia nieprecyzyjnego (NPA), jak i precyzyjnego (PA). Artykuł przedstawia analizy eksperymentów pod kątem zastosowania sygnałów EGNOS dla podejścia APV w południowo-wschodniej części Polski. Prowadzono je od stycznia do czerwca 2014 roku w trzech polskich miastach: Warszawie, Krakowie i Rzeszowie. EGNOS jako odmiana SBAS (system wspomagający bazujący w kosmosie) wedle zapisów Aneksu 10 ICAO powinien spełnić wymogi dotyczące dokładności wyznaczenia pozycji w przestrzeni, wiarygodności systemu, dostępności i ciągłości sygnałów. Wobec stanowiska Europejskiej Konferencji Lotnictwa Cywilnego (ECAC), że EGNOS powinien zapewnić pokrycie wschodniej części Europy, lokalizacja wymienionych stacji dowodzi rzeczywistej użyteczności dla testowania sygnałów EGNOS i jego doskonalenia.