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EXAMINATION OF EGNOS SAFETY-OF-LIVE SERVICE IN EASTERN SLOVAKIA

ABSTRACT

The first PBN approach procedures in Slovakia became operationally effective at Bratislava and Košice airports as of 5 February 2015. The article presents the results of EGNOS Safety-of-Life Service preliminary examination in eastern Slovakia, just before official introduction of these procedures. The practical examination includes static test and test flight made with Cessna plane taking off at the airport in Bidovce — LZBD (just 16 km from international airport in Košice) and passing a route along eastern border of Slovakia. In this region the performance of EGNOS could be unsatisfactory due to lack of RIMS stations to the east from there. The experiment was performed on October 13, 2014 in cooperation of the Air Force Academy in Deblin, the Department of Aviation of Technical University in Košice and University of Warmia and Mazury in Olsztyn.

Keywords:

GNSS, GPS, SBAS, EGNOS, Safety-of-Life, satellite navigation.

INTRODUCTION

EGNOS (European Geostationary Navigation Overlay Service) system is being built in Europe since 1994. The system over the past 20 years, underwent various stages of development. Originally the Full Operational Capability (FOC) of the system was planned for 2004, but numerous problems encountered along the way of the system's development have seriously delayed this moment. Finally all three services offered by the system are operational and available to the users across Europe since 2012.

EGNOS is a part of SBAS group systems (Satellite Based Augmentation System) and currently supports the operation of Global Positioning System (GPS) in Europe. The system was developed and put into operation by the European Union represented by the European Commission, the European Space Agency (ESA) and Eurocontrol (European Organisation for the Safety of Air Navigation) [Allien et al. 2009]. ESA watched over the proper development, validation and practical use of EGNOS since 2009. In contrast, Eurocontrol was responsible for establishing requirements for the users of the system in civil aviation. The task of the European Union was the development of requirements for the other users of the system.

EGNOS supports GPS since 2005 through the transmission of signals via geostationary satellites, derived on a basis of terrestrial network of permanent stations and control centers which supervise the proper operation of the system [Allien et al. 2009].

Currently EGNOS supports the GPS system by:

- improvement of the positioning accuracy;
- providing information concerning integrity of positioning;
- synchronizing time in which user's position is calculated with UTC time (Coordinated Universal Time).

The practical operation of EGNOS system can be divided into the following steps (Fig. 1):

- collecting data from GPS satellites by RIMS;
- determination of corrections and associated with them errors which is used for calculation and generation of EGNOS messages by MCC;
- transmission of EGNOS messages to system users via GEO satellites.

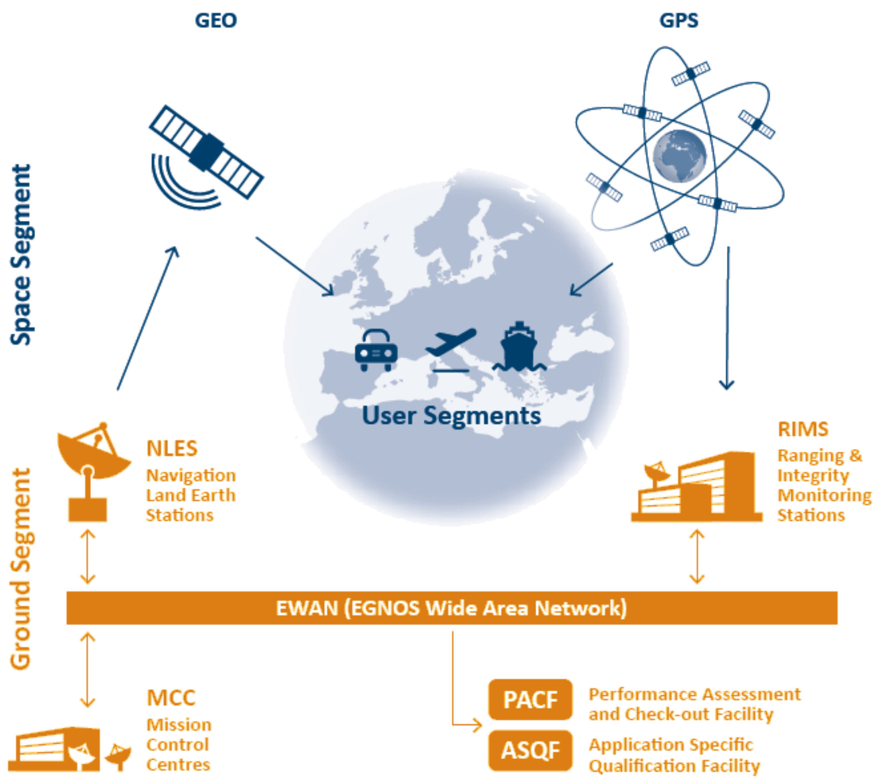

Fig. 1. EGNOS Architecture [source: European GNSS Agency, 2015]

EGNOS IN AVIATION

Prior to the implementation of EGNOS in aviation, it is necessary to fulfill a number of requirements and adapt to existing international guidelines required by ICAO (International Civil Aviation Organization). The basic premise of validation of EGNOS is to prove that the system can be used in safety of live applications. This is only possible if the EGNOS signal — SIS (Signal-In-Space) over the area covered by the validation procedure meets the international requirements contained in the ESSC (EGNOS System Safety Case) [Department of Defense et al. 2014; GSA, 2015]. On March 2, 2011 the Safety-of-Life (SoL) Service of EGNOS, devoted mainly to aviation users, was officially announced operational. Two weeks later on March 14, 2011 in the Katowice Airport, for the first time in Poland, a plane has completed successful approach and landing using satellite navigation system, however official implementation of LPV procedure in Katowice was introduced much later on April 3, 2014.

To use EGNOS in aviation the system validation in particular localization in needed, as well as official flight procedure design and certification. Today over 150 European airports use EGNOS-based flight procedures (LPV) and it is estimated that by 2018 the number will increase to 440. These procedures provide a cost effective alternative equivalent to conventional ILS CAT I instrument landing procedures. LPV procedures offer similar performance without the need for significant on-site infrastructure installation and maintenance. For these reasons, they are becoming a very valuable navigation aid to small and medium-size airports, increasing safety and accessibility to those aerodromes.

From February 5th 2015, two airports in the Slovak Republic are able to use EGNOS-based approach procedures in their runways. The airports of Bratislava and Kosice are the first ones in the Slovak Republic to publish these type of procedures that will allow a safer and more efficient air navigation. The publication of LPV procedures at these Slovak airports has been possible through the funding of ACCEPTA, a European grant given by the GSA (European GNSS Agency) to foster the use of EGNOS in the aviation domain. LPS SR š.p. (Air Navigation Service Provider of the Slovak Republic) conducted all the necessary tasks to design and certify these procedures. Moreover LPS intends to implement the use of EGNOS in three more Slovak airports (Pieštany, Žilina and Poprad-Tatry) in the next two years [http://www.essp-sas.eu/news/3].

INTEGRITY OF NAVIGATION SYSTEM

According to the Federal Radionavigation Plan [Department of Defense et al., 2014] integrity is the measure of the trust that can be placed in the correctness of the information supplied by a PNT (Positioning, Navigation and Timing) system. Integrity includes the ability of the system to provide timely warnings to users when the system should not be used for navigation. Its characteristics is presented by the 'protection levels' which can be computed using information transmitted by EGNOS [Oliveira et al., 2009; RTCA, 2013]. The maximum values — 'alarm limits' — have been established depending on the phase of flight or type of approach.

Horizontal Protection Level (HPL) is defined by the radius of the circle (in the horizontal plane) centered on the actual position, describing the zone guaranteed to contain the horizontal position calculated (Fig. 2). Vertical Protection Level (VPL), according to definition, is the length of the half of cylinder axis which is centered on the actual position corresponding to the zone guaranteed to contain the vertical position calculated (Fig. 2) [RTCA, 2013]. The HPL and VPL values depend on DOP indicators, the satellite clock, ephemeris, ionospheric, tropospheric errors and other factors affecting GNSS positioning [Tiberius et al., 2008].

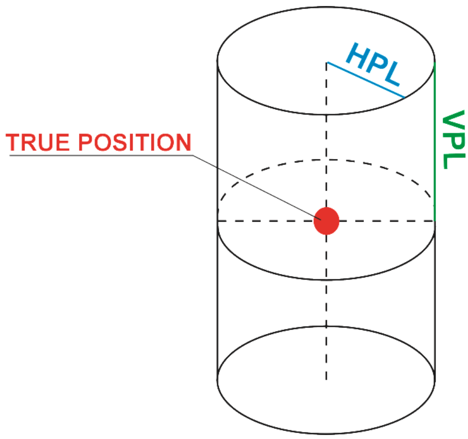

Fig. 2. Graphical interpretation of HPL and VPL

The values of HPL and VPL can be calculated on the basis of following formulas:

$$HPL = K_H d_{major}; \quad (1)$$

$$VPL = K_V d_U, \quad (2)$$

where:

K_H — a factor bounding user's horizontal position with a probability of 10^{-9} (for en-route navigation K_H = 6.18 and for precision approach K_H = 6.0);

d_{major} — corresponds to the error uncertainty along the semimajor axis of the error ellipse;

K_V — a factor bounding the user's vertical position with a probability of 0.5×10^{-7} (K_V = 5.33);

d_U — variance of model distribution that overbounds the true error distribution in the vertical axis.

The quality of GPS/EGNOS positioning depends on particular location of user and therefore monitoring of system's performance should be at the location of its use [Felski and Nowak, 2013], [Felski and Nowak, 2012]. The lack of RIMS stations east of Warsaw until recently caused not satisfactory quality of EGNOS accuracy and integrity in Eastern Europe [Felski et al., 2011; Grzegorzewski et al., 2012]. However, the last survey carried out in the north-eastern Poland, after application of new EGNOS software, proved that positioning with the use of EGNOS in this area has been improved [Grunwald et al., 2015].

STATIC TEST

For the practical field tests the airport in Bidovce — LZBD was selected. The experiment was performed on October 13, 2014 in cooperation of the Air Force Academy in Dęblin, Department of Aviation of Technical University in Košice and University of Warmia and Mazury in Olsztyn. The airport in Bidovce is located just 16 km from international airport in Košice, therefore EGNOS performance in Bidovce corresponds to its performance in Košice. The airport accepts aerial and general aviation flights, it is situated at 300 meters of elevation, the owner of the airport is SNA Flight School Košice.

In the first phase of research a static test of EGNOS performance was conducted. The measurements were carried out at the point next to the runway, in the area free from obstructions (Fig. 3). Septentrio AsteRx2e dual-frequency receiver with SBAS option connected to PolaNt_GG antenna was used at the site to log data. The logging interval was set to 1 second and duration of static session was about 90 minutes. In order to determine accurate coordinates of the point the data acquired from ASG-EUPOS system was used. Although ASG-EUPOS is a Polish system, it was possible to generate two virtual VRS stations on the Slovak territory (Fig. 3) which allowed for determination of coordinates of our station with centimeter level of accuracy. Precise position of the station was used for further analyses.

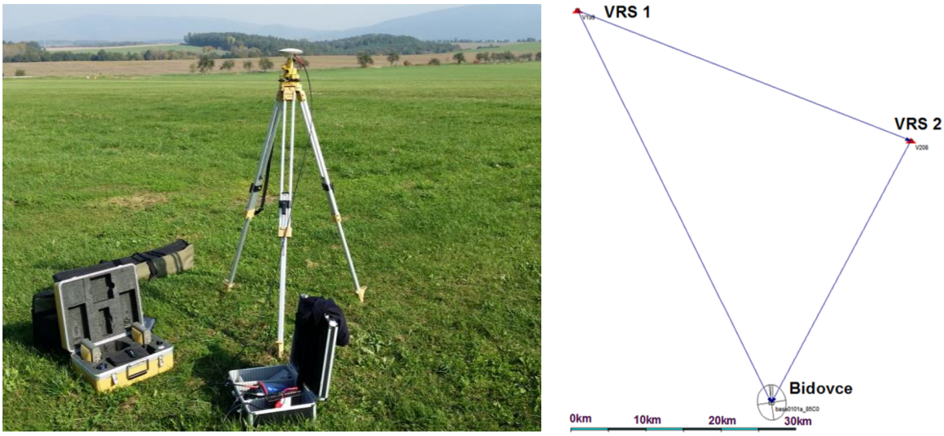

Fig. 3. Tested in static mode location and network of points taking part in adjustment

For every analyzed epoch (1 second interval) real-time position using GPS/EGNOS solution was determined. The software used for calculation was self-developed application named PP_SBAS_Analyzer. In the calculation algorithm 'precision-approach' mode was adopted, which uses the maximum age for applying the correction data according to the RTCA (2013) and determines the values of HPL and VPL based on the defined appropriate parameters (formula 1 and 2). Elevation mask was set to 5 degrees and pseudoranges from EGNOS geostationary satellites were excluded from the algorithm. Figure 4 presents the results of static positioning including: HPE/VPE — Horizontal/Vertical Position Error, HPL/VPL — Horizontal/Vertical Protection Level and number of satellites used in solution. For static EGNOS positioning very good results were achieved, during the test between 9 and 11 satellites was used for GPS/EGNOS positioning. EGNOS solution was available for 100% of epochs, HPE as well as VPE did not exceed 2 meters with an average of 0.90 m for HPE and 0.77 m for VPE. Also HPL and VPL presented low and acceptable values with an average of 9.57 m for HPL and 12.82 m for VPL.

Numerical values of analyzed statistical parameters are presented in Table 1.

Table 1. Numerical values of static test and flight trials statistical analysis

Statistical parameter	Static test	Flight trials
$HPE_{average}$ [m]	0.90	0.88
$VPE_{average}$ [m]	0.77	1.44

Statistical parameter	Static test	Flight trials
HPE_{RMS} [m]	0.93	0.98
VPE_{RMS} [m]	0.85	1.65
HPE_{max} [m]	1.62	5.23
VPE_{max} [m]	1.98	5.83
HPE_{std}[m]	0.23	0.42
VPE_{std} [m]	0.36	0.81
HPL_{min} [m]	8.78	9.48
VPL_{min} [m]	10.29	19.96
$HPL_{average}$ [m]	9.57	15.37
$VPL_{average}$ [m]	12.82	22.38

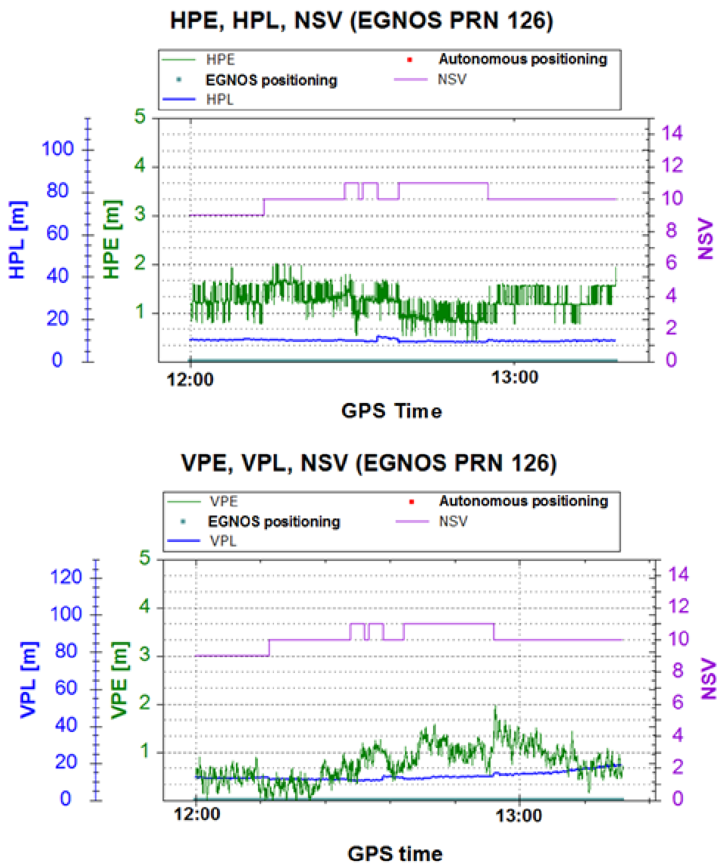

Fig. 4. The results of the static session: HPE/VPE, HPL/VPL and number of satellites used in solution

FLIGHT TRIALS

The second part of practical test was made during a test flight made with Cessna plane taking off at the airport in Bidovce — LZBD and passing a route along eastern border of Slovakia (Fig. 5). In this part of Slovakia the performance of EGNOS could be unsatisfactory due to lack of RIMS stations to the east from there.

Fig. 5. Flight trajectory (red) against Slovakia borders (GoogleEarth)

For data collection dual-frequency receivers: Septentrio and Topcon were used. Collected observations allowed for evaluation of the current quality of GPS/ EGNOS positioning in the area of eastern Slovakia during the flight. Septentrio AsteRx2e was placed on board of the Cessna aircraft and PolaNt_GG antenna was placed in cockpit of the plane (Fig. 6). The location of the antenna was not ideal but the best possible. The other receiver — Topcon HiPer Pro was working in the same location as for static test and it was used as a local base station. Additionally two VRS stations generated out of ASG-EUPOS system were used in calculations.

To perform flight trial with the use of EGNOS, the reference and accurate position of the plane for each second of the flight was necessary. The 'true' trajectory was computed as an average of three independent OTF post processed solutions, determined on the basis of three reference stations (one local station at Bidovce airport and two VRS stations — Fig. 3).

Fig. 6. Cessna plane taking part in the experiment and location of GNSS antenna

Due to redundant observations the determination of OTF accuracy was possible. Standard deviation (S.D.) was computed for each second of the flight for every coordinate – *B*, *L* and *h* (ellipsoidal) using following formulas:

$$S.D.B = \sqrt{\frac{\sum_i (B_{av.} - B_i)^2}{n-1}} \quad S.D.L = \sqrt{\frac{\sum_i (L_{av.} - L_i)^2}{n-1}} \quad S.D.h = \sqrt{\frac{\sum_i (h_{av.} - h_i)^2}{n-1}}. \quad (3)$$

The achieved results are presented in the Figure 7, the average values of standard deviation of reference positioning was: 0.04 m for latitude (*B*), 0.01 m for longitude (*L*) and 0.08 m for height (*h*). This high accuracy allowed for reliable estimation of accuracy achieved with GPS/EGNOS positioning.

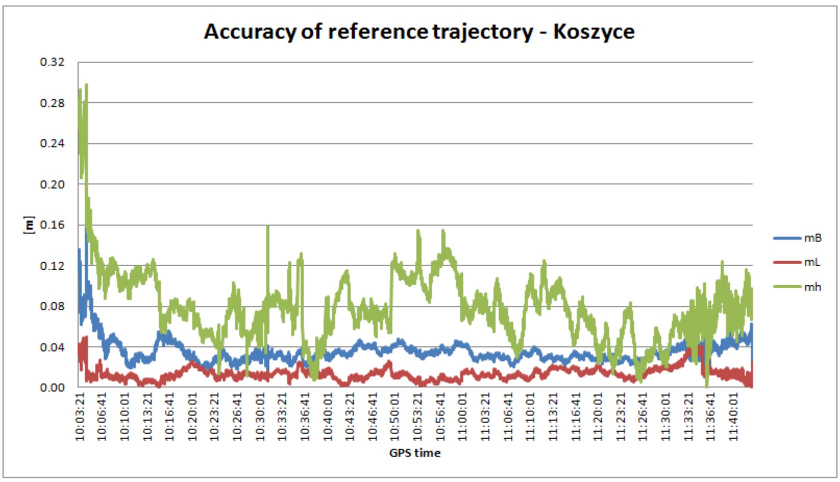

Fig. 7. Standard deviation of reference trajectory for each second of the flight for every coordinate — *B*, *L* and *h*

Having precise reference trajectory it was possible to determine quality of GPS/EGNOS solution. For calculation PP_SBAS_Analyzer software was used in the mode ‘precision-approach’, elevation mask was set to 5 degrees and pseudoranges from EGNOS geostationary satellites were excluded from the algorithm. Figure 8 presents the results of kinematic positioning including: HPE/VPE — Horizontal/Vertical Position Error, HPL/VPL — Horizontal/ Vertical Protection Level and number of satellites used in solution.

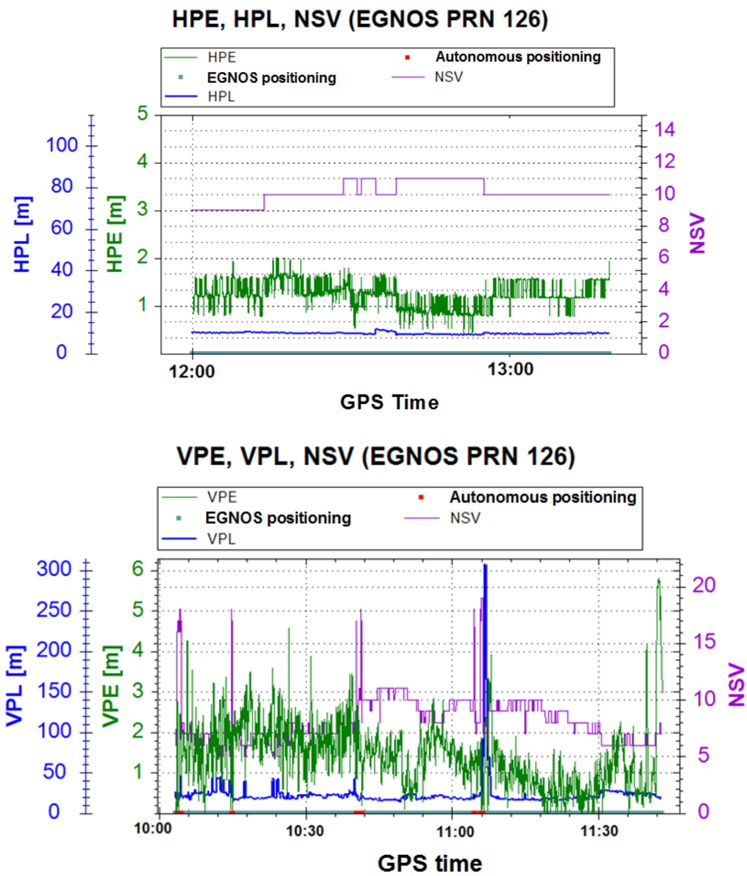

Fig. 8. The results of kinematic test: HPE/VPE, HPL/VPL and number of satellites used in solution

In kinematic experiment the number of observed satellites was changing due to the movement of airplane and access to open sky, varying from 4 to 11 with GPS/EGNOS positioning and reaching 19 in autonomous GPS/GLONASS positioning. EGNOS solution was not available for 100% of epochs, there were 5 gaps of autonomous positioning only, which lasted for few minutes but this was due to location of GNSS antenna and obstructions caused by the body of the airplane. In general HPE did not exceed 2 meters with an average of 0.88 m and VPE did not exceed 6 meters with an average of 1.44 m. However due to obstructions caused by the body of the plane there were few epochs with higher values of HPE/VPE. The values of HPL and VPL during steady flight were low and acceptable with an average of 15.37 m for HPL and 22.38 m for VPL, but again when the sky was obstructed these values reached almost 400 meters at 11:06 GPS time.

CONCLUSIONS

The study on the European EGNOS system has been conducted at the Air Force Academy in Deblin, Technical University in Košice and University of Warmia and Mazury in Olsztyn from the inception of the system. Over 20 years of experience, constant modernizations and improvements of the system led to the certification for the air navigation purposes, which is undoubtedly a milestone for aviation.

Presented preliminary results of examination of EGNOS in eastern Slovakia confirmed the accuracy, availability, integrity and continuity of EGNOS positioning, necessary for aviation applications, in this territory on October 13, 2014. However, there were few gaps in GPS/EGNOS positioning during flight, but they were due to the temporary location of GNSS antenna — in the cockpit of the plane, instead of fuselage of the plane. Completeness of EGNOS in this region was also confirmed with the publication of first PBN approach procedures in Slovakia at Bratislava and Košice airports as of 5 February 2015.

It should be emphasized that EGNOS monitoring should be a permanent process and monitoring stations should be mounted in the area where SBAS procedures take place. Long term monitoring allows for detection of any inaccuracies and can be helpful for EGNOS further improvement and modernization.

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STRESZCZENIE

Pierwsze procedury podejścia do lądowania typu PBN (Performance-Based Navigation) na Słowacji zostały wdrożone na lotniskach w Bratysławie i Koszycach 5 lutego 2015 r. W artykule przedstawiono wyniki wstępnych analiz serwisu Safety-of-Life systemu EGNOS we wschodniej Słowacji, tuż przed oficjalnym wprowadzeniem tych procedur. Badania praktyczne obejmują test statyczny oraz lot testowy wykonany samolotem Cessna z lotniska Bidovce-LZBD (oddalonego zaledwie 16 km od międzynarodowego lotniska w Koszycach) po trasie wzdłuż wschodniej granicy Słowacji. W tym regionie jakość systemu EGNOS może być niezadowalająca z powodu braku stacji monitorujących RIMS na wschód od tego miejsca. Eksperyment przeprowadzono 13 października 2014 r. we współpracy Wyższej Szkoły Oficerskiej Sił Powietrznych w Dęblinie, Wydziału Lotnictwa Politechniki w Koszycach oraz Uniwersytetu Warmińsko-Mazurskiego w Olsztynie.