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NPA GNSS essential step for the lun implementation and the chance for the air regional transport

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ABSTRACT

The general idea of this project is to popularize the usage of European Geostationary Navigation Overlay Service System in Central European countries. The main goal will be achieved by demonstrating key capabilities of the EGNOS System. After that the National Fly Authority Agency certification procedure will be launched, EGNOS will become fully functional and operational airfield domestic system. Project consists of analysis of domestic airfields and Aircraft operator(s) against opportunity of EGNOS installation and utilization of capability for landing purposes, study of demonstrator's technical conception of EGNOS APV implementation connected with blueprint for certification process, on-board and airfield system installation connected with provisional certification and final demonstration of overall system capabilities, followed by on-going tests, system certification and implementation of Safety Case.
Scientific research centers will prepare technical solutions for system installation at airfield and aircraft, with certification projects and procedures as well. This includes two types of certification: technical and fly procedures (landing procedures for aircraft and airfield). Safety of fly and Safety Case are especially taken into consideration.
Currently, differential positioning methods, basing on global satellite navigation systems: GPS, GLONASS and also Galileo in the future, undergo dynamic development.

KEYWORDS: NPA, GNSS, Navigation, EGNOS

1. NPA GNSS essential step for the lun implementation and the chance for the air regional transport

This implementation of GNSS in Poland is „PER ASPERA AD ASTRA". However under the PANSA patronage take action, aiming at the certification of the aviation GNSS application in our country. To distinguish it is possible in this procedure the following phases:

- Arrangements to aviation experiments:
  - › Receiver Septentrio;
  - › SPAN (Synchronized Position Attitude Navigation)
- Active participation in international research and implementation programs:
  - › HEDGE;
  - › EGNOS APV;
  - › NPA GNSS;
  - › CERTIFICATION;
  - › GNSS FUNCTIONING IN AVIATION

Fig. 1. Local Convergence and Implementation Plan Poland 2009 – 2013 and Development Programme network of airports and ground equipment
Source: [own work]

The dynamic development of aviation caused huge development of present techniques and technologies in navigation. The demand appeared on entirely new approach in connection with management the air traffic questions in the aim of solution problems connected with enlargement the capacity and transfer function and the skyway as well as existing the far-reaching European formations the ATM. Therefore document was worked out „The Air Traffic Management Strategy For The Years 2000", which is the aim the creation of uniform aerospace for Europe. Presented strategy delivers also precise hands and presents effective centers, thanks which is possible to deal all problems and effectively cope with challenges by European ATM in XXI century. In received international solutions mention, that initiation global formation ATM/CNS should take into account present techniques and technologies in wide range and simultaneously build it will make possible the modernization of formations in the future.

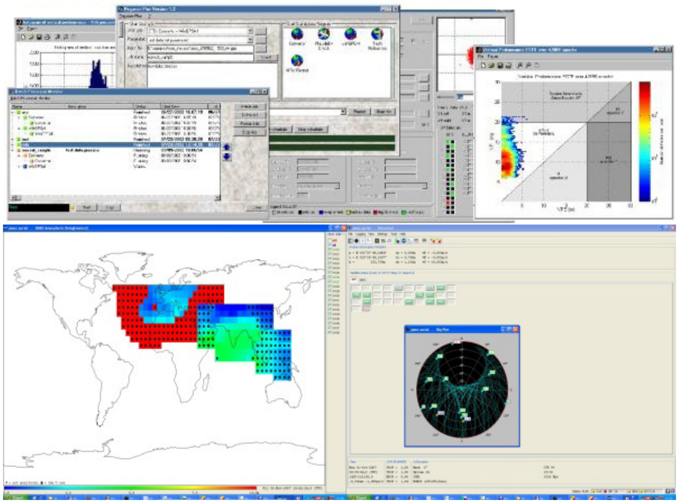


Fig. 2. SBAS system coverage, visualization accuracy EGNOS at current time
Source: [own work]

The implementation of the EGNOS system to APV-I precision approach operations, is conducted according to ICAO requirements in Annex 10 and of other documents: European Convergence and Implementation Plan 2009 – 2013, Local Convergence and Implementation Plan Poland 2009 – 2013, Program Rozwoju Sieci Lotnisk i Lotniczych Urządzeń Naziemnych - admitted to the accomplishment with Resolution of the Council of Ministers Nr 86/2007 (fig. 1).

Definition of usefulness and certification of EGNOS as SBAS (Satellite Based Augmentation System) in aviation requires thorough analyses of accuracy, integrity, continuity and availability of SIS (Signal in Space). Also, the project will try to exploit the excellent accuracy performance of EGNOS to analyse the implementation of GLS (GNSS Landing System) approaches (Cat I-like approached using SBAS, with a decision height of 200 ft). Location of the EGNOS monitoring station, located near Polish - Ukrainian border, being also at the east border of planned EGNOS coverage for ECAC states is very useful for SIS tests in this area.

According to current EGNOS programme schedule, the project activities will be carried out with EGNOS system v2.2, which is the version released for civil aviation certification. Therefore, the project will allow demonstrating the feasibility of the EGNOS certifiable version for civil applications. Planned demonstration and trials will be provided on 2 - 3 Polish airports (central, eastern and western) chosen based on SIS analysis and EGNOS operational coverage in Poland. For creating and testing software and making other documentations we will use ESA standards like ECSS-E-40, ECSS-Q-80B.

1.1. Receiver Septentrio and PEGASUS Program Goals

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

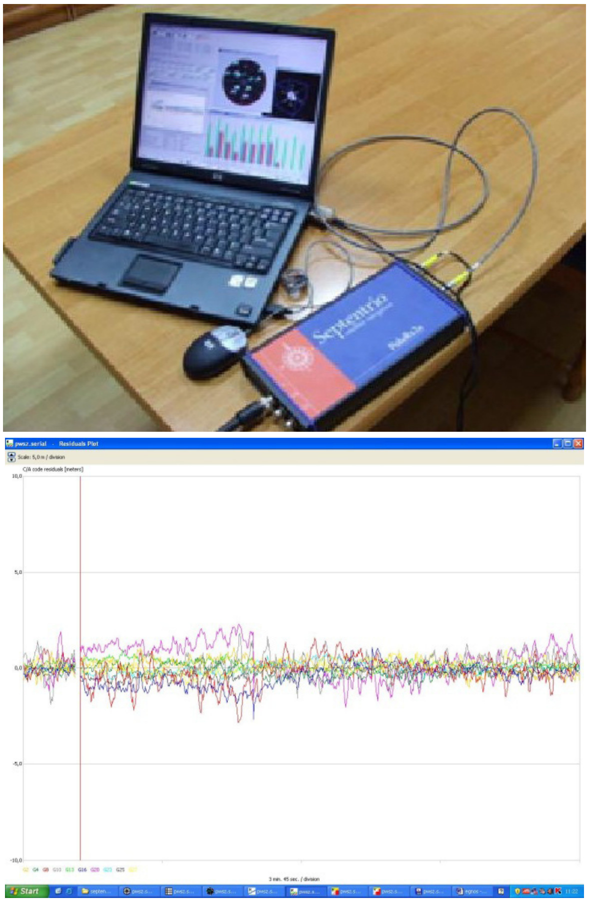


Fig. 3. Workstation configuration Notebook and Septentrio PolaRx2e (EGNOS L1/L2) receiver and Residuals Plot from RxControl
Source: [own work]

systems attributes like accuracy, reliability, and availability simulating MOPS-compliant receivers, computation of trajectory errors, prediction of accuracy and availability with the required integrity and simulation of GBAS Ground Station processing algorithms. Since June 2003 the GBAS Modular Analysis and Research System (MARS) is integrated in PEGASUS in order to support GBAS data processing needs and activities. The GBAS MARS allows to collect and evaluate relevant data and provide required results and is able to assist Air Traffic Service Providers to aid site approval and obtain operational approval of a GBAS installation for supporting CAT-I precision approach conditions at an airport from their respective safety regulation authorities.

1.2. SPAN (Synchronized Position Attitude Navigation)

The Synchronized Position Attitude Navigation (SPAN) system is NovAtel's Global Navigation Satellite System - Inertial Navigation System (GNSS/INS) solution for applications requiring continuous position, velocity and attitude information. Using Inertial Measurement Unit (IMU) data in addition to GNSS, SPAN provides a high rate position, velocity and attitude solution which seamlessly bridges GNSS outages. The tight integration of the IMU to the receiver core improves GNSS performance by enabling faster signal reacquisition and quicker return to fixed integer status after a loss of GNSS signals. Synchronized Position Attitude Navigation.

2. Active participation in international research and implementation programs: HEDGE, EGNOS APV, NPA GNSS

The accomplishment of international programs required adopting the following assumptions:

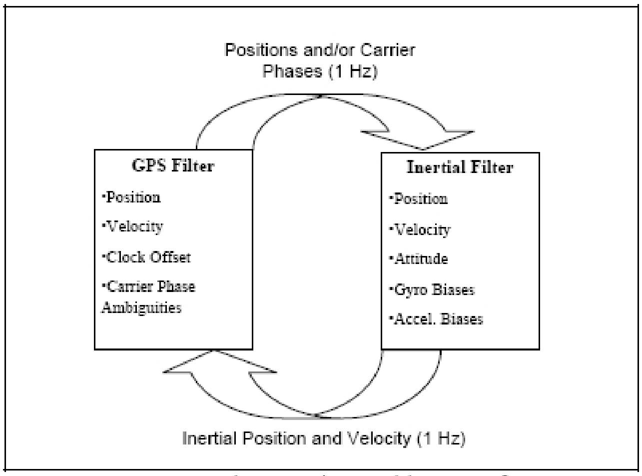


Figure 2 General Integration Architecture of SPAN

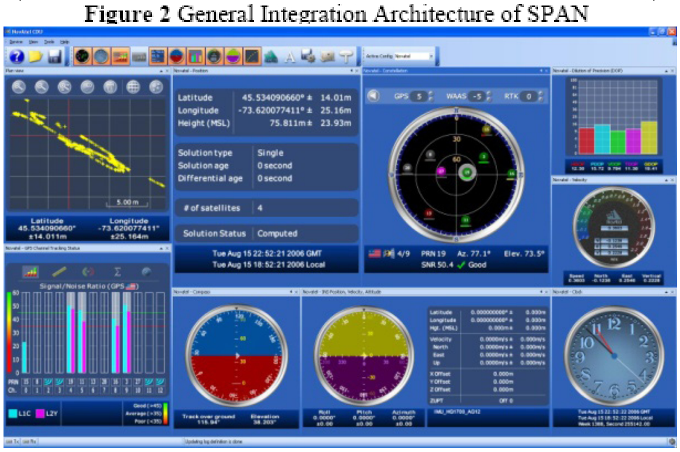


Fig. 1. Genaral Integration Architecture of SPAN and Novatel CDU panel for receiver configuration and monitoring
Source: [own work]

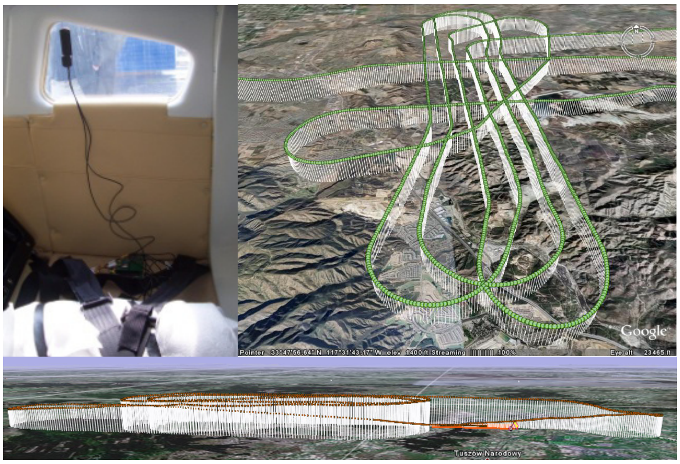


Fig. 5. Visualization postprocesing date(RTK/INS) gathered during the fly over the Mielec airport and GPS/GPRS device for real time monitoring as a second monitoring system on airplane Piper PA-34 Seneca II)
Source: [own work]

- Final Approach of GNSS landing with “Overlines” method;
- Accomplish of the RNAV GNSS Approach Procedures;
- Certification of the GNSS receivers (on board);
- Test flights - checking assumed solutions;
- Operational of EGNOS System;
- Test flights in frames of programs;
- Collecting indispensable materials and drawing up documents, necessary to do the certification;
- Certification of the GNSS approach in Poland.

3. Project HEDGE - work package 5: general aviation EGNOS APV development and demonstration in poland

Helicopters Deploy GNSS in Europe (HEDGE) is Collaborative Project Response to FP7-GALILEO-2007-GSA-1. The project objectives are to achieve the following by the end of the project to:

- develop the helicopter SOAP (SBAS Offshore Approach Procedure) procedure (and necessary avionics) and then to successfully demonstrate it to the user community;
- develop helicopter PINS (Point in Space) procedures for mountain rescue and HEMS (Helicopter Emergency Medical Services), and to then successfully demonstrate them to the user community.
- demonstrate EGNOS (European Geostationary Navigation Overlay Service) APV (approach with vertical guidance) approaches to general aviation in Spain, Poland;

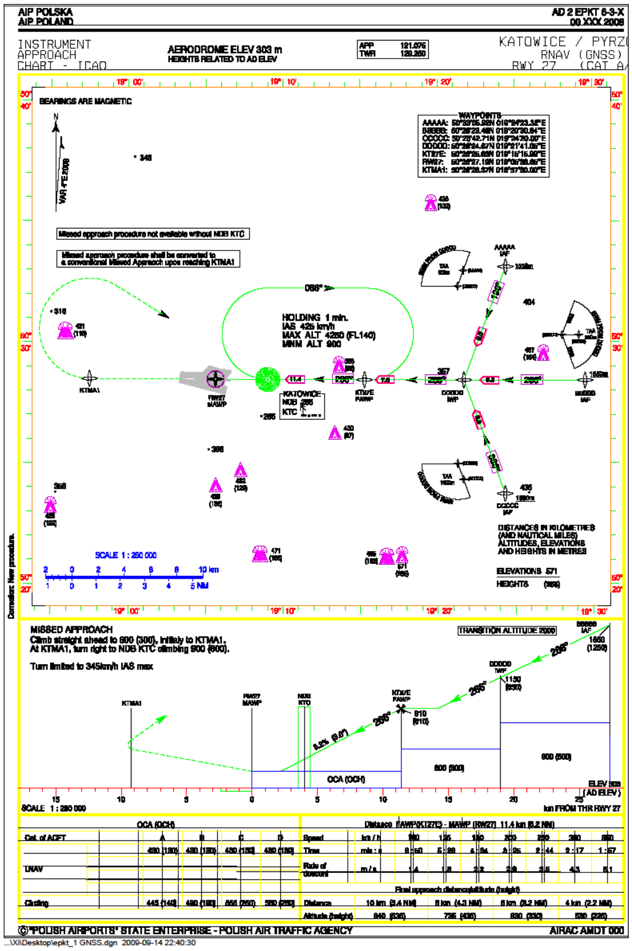


Fig. 6. Example: RNAV GNSS for Katowice – Pyrzowice Airport
Source: [own work]

- (OPTION) To complete EGNOS data gathering that shows the performance of EGNOS.

Coordinator:FP7-GALILEO-2007-GSA-1, for the carrying out of the Helicopters Deploy GNSS in Europe (“HEDGE”) Project, hereinafter referred to as “Effective Date” among: Helios Technology Limited, Pildo Consulting, S. L., REGA, TAF Helicopters S.L., P.P.H.U “ROYAL-STAR”, Aero Club Barcelona-Sabadell, Polish Air Navigation Services Agency (PANSA), Capital High Tech SARL HELILEO,

The new GNS 430 W (already WAAS enabled) receiver in the Seneca airplane is applied during experiments, becouse:

- already WAAS enabled;
- then use an experimental datacard from Garmin to enable EGNOS;
- perform the necessary tests in the laboratory to validate that the receiver is able to work properly with the broadcasted EGNOS SIS at the time the demonstrations will be performed.

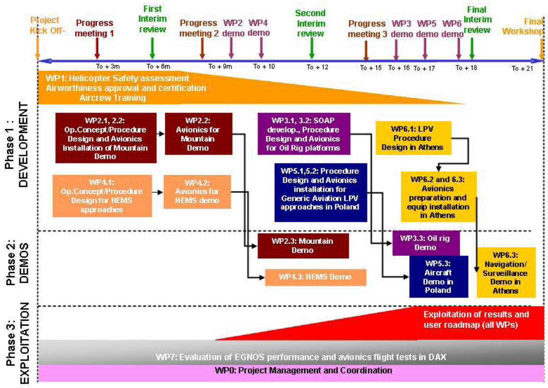


Fig. 7. Project HEDGE
Source: [own work]

4. Protection levels

4.1. General Approach to Protection Levels

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). Errors in the estimation of the aircraft's position is referred to as Navigation System Error NSE which is the difference between the aircraft's true position and its displayed position. 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 the NSE and the FTE is the Total System Error TSE. Since the actual Navigation System Error can not be observed without a high-precision reference system (the NSE is the difference between the actual position of an aircraft and its computed position !), an approach has to be found with which an upper bound can be found for 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 being 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.
- 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 being 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 SBAS protection levels are a function of the satellite constellation and the estimated SBAS performance. Thus, using the SBAS correction data, the protection levels can be determined without using actual pseudorange measurements. The only parameters / items used are:

- the residual error budget as determined for fast, slow, ionospheric, tropospheric and receiver errors
- the satellites received (constellation) and selected (integrity flags) by the receiver in the position solution.

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.

The relevant alert limits, in combination with the required alert limit requirement, are listed in table 1.

In particular, the Integrity Requirements will be used later to derive the protection levels. The corresponding situation in the horizontal plane is depicted in the figure 11.

It should be noted that the main significance using this approach is not the computation of the protection levels and their comparison with the corresponding alert limit. The major interest should be considered to be on the assurance that the computed protection levels represent an upper bound on the NSE with a certain confidence. "Misleading Information" results only, if the NSE is greater than the alert limit and the protection level does not indicate this fact (for a more complete and detailed

Fig. 8. GNS 430 W receiver and Septentrio receiver in the Seneca airplane and Seneca airplane on the Katowice Airport
Source: [own work]

Fig. 9. Route of test flights in Mielec 9.04.2010 and 22.04.2010r. Source: [own work]

description of the "overbounding concept" and problems resulting of it, refer to).

4.2. Protection Levels

Since the SBAS correction information is applied to each individual pseudorange in different ways (according to the criteria shown in the chapters before), the assumption on one single value for the standard deviation for all pseudorange can not be applied. For the calculation of the protection levels using SBAS corrections, the general approach of the weighted least squares is used . For modes other then precision approach, the weights are undefined. For an un-weighted least squares solution, the weighting matrix is a unity diagonal matrix (i.e. the elements on the main diagonal are set to 1). The projection matrix of the position solution is then calculated as:

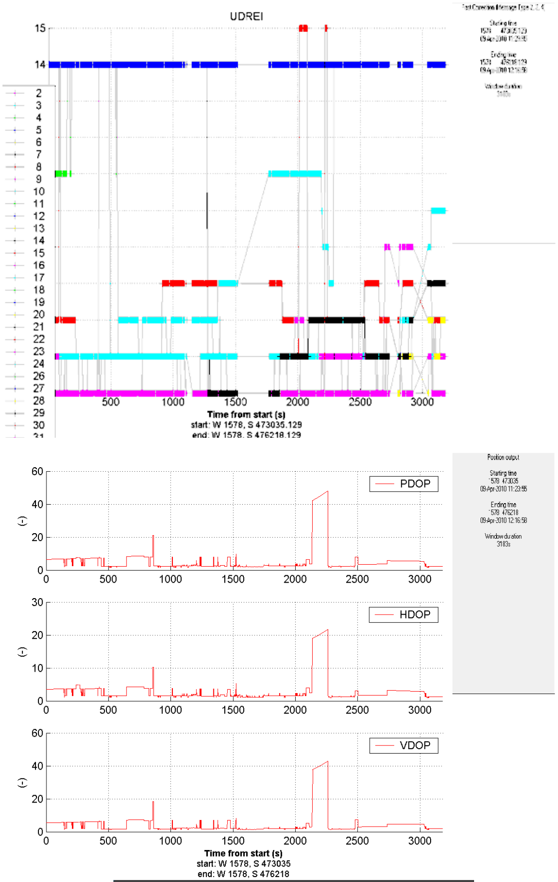
$$S = (H^T W H)^{-1} H^T W = \begin{bmatrix} s_{x1} & s_{x2} & \cdots & s_{xn} \\ s_{y1} & s_{y2} & \cdots & s_{yn} \\ s_{z1} & s_{z2} & \cdots & s_{zn} \\ s_{t1} & s_{t2} & \cdots & s_{tn} \end{bmatrix} \quad (1)$$

The variances of the model distribution that overbound the true error distribution in each direction of the local tangent co-ordinate system are calculated as:

$$\begin{aligned} d_x^2 &= \sum_{i=1}^{N} s_{x,i}^2 \sigma_i^2 \\ d_y^2 &= \sum_{i=1}^{N} s_{y,i}^2 \sigma_i^2 \\ d_{xy} &= \sum_{i=1}^{N} s_{x,i} s_{y,i} \sigma_i^2 \\ d_v^2 &= \sum_{i=1}^{N} s_{z,i}^2 \sigma_i^2 \end{aligned} \quad (2)$$

with d_x^2 variance of the position solution in the east direction
with d_y^2 variance of the position solution in the north direction
with d_{xy}^2 co-variance of the position solution in the east-north direction
with d_v^2 variance of the position solution in the vertical direction

In the horizontal plane, the error distribution will result in an error ellipse. The principal axes of this error ellipse might not be coincident with the north- and east-directions. The intent is to determine the semi-major axis



UDREI i	$UDRE_i$ Meters	$\sigma^2_{i,UDRE}$ Meters²
0	0.75	0.0520
1	1.0	0.0924
2	1.25	0.1444
3	1.75	0.2830
4	2.25	0.4678
5	3.0	0.8315
6	3.75	1.2992
7	4.5	1.8709
8	5.25	2.5465
9	6.0	3.3260
10	7.5	5.1968
11	15.0	20.7870
12	50.0	230.9661
13	150.0	2078.695
14	Not Monitored	Not Monitored
15	Do Not Use	Do Not Use

Fig. 10. Test flights - checking assumed solutions: UDREI (User Differential Range Error Indicator), PDOP, HDOP, VDOP Source: [own work]

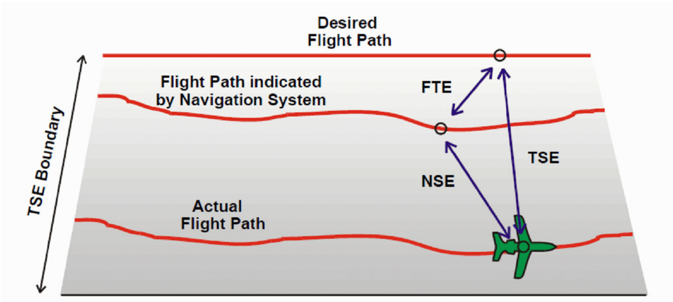


Fig. 11. Navigation System Error, Flight Technical Error and Total System Error
Source: [own work]

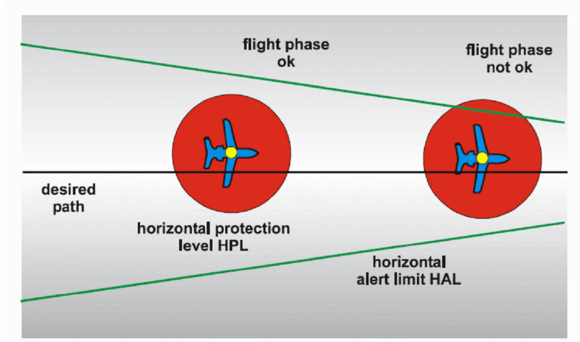


Fig. 12. Horizontal Protection Levels and Horizontal Alert Limit
Source: [own work]

of that error ellipse and use that error variance in order to determine a protection level. The error covariance in the horizontal plane is:

$$P = \begin{bmatrix} d_x^2 & d_{xy} \\ d_{xy} & d_y^2 \end{bmatrix} \tag{3}$$

Mathematically, an eigenvalue problem of that two-dimensional matrix must be solved. A necessary condition to determine the eigenvalues is:

$$\det(P - \lambda I) = 0 \quad \text{or:} \quad \det\begin{bmatrix} d_x^2 - \lambda & d_{xy} \\ d_{xy} & d_y^2 - \lambda \end{bmatrix} = 0 \tag{4}$$

Thus:

$$(d_x^2 - \lambda)\ (d_y^2 - \lambda) - d_{xy}^2 \ = \ 0$$

If this equation is solved for the eigenvalues λ1,2, they are obtained to:

$$\lambda_{1,2} \ = \ \frac{d_x^2 + d_y^2}{2} \ \pm \ \frac{1}{2}\sqrt{(d_x^2 - d_y^2)^2 + 4\,d_{xy}^2} \tag{5}$$

$$\sigma_{major} \ = \ \sqrt{\lambda_1} \ = \ \sqrt{\frac{d_x^2 + d_y^2}{2} \ + \ \sqrt{\left(\frac{d_x^2 - d_y^2}{2}\right)^2 + d_{xy}^2}}$$

with σ_{maj} standard deviation of the horizontal error in the semi-major axis

Taking the root of the larger eigenvalue, the standard deviation of the horizontal position solution in the semi-major axis of the error ellipse is determined.

The horizontal and the vertical protection level are calculated as:

$$\begin{aligned} VPL \ &= \ K_v\ d_v \\ HPL \ &= \ K_h \ \ \sigma_{maj} \end{aligned} \tag{6}$$

Table 1. Protection Levels for Flight Phases

Flight Phase	Integrity Requirements	Horizontal Alert Limit	Vertical Alert Limit	Note
ENR	1-10^{-7} per hour	7400 m 3700 m 1850 m	N/A	different alert limits for domestic and oceanic flight phases
TMA	1-10^{-7} per hour	1850 m	N/A	
NPA	1-10^{-7} per hour	556 m	N/A	
APV-I	1 - 2 x 10^{-7} per approach	40 m	50 m	new flight phase defined in the current SARPs
APV-II	1 - 2 x 10^{-7} per approach	40 m	20 m	new flight phase defined in the current SARPs

with HPL horizontal protection level
VPL vertical protection level

and with K_v = 5.33 multiplication factor
K_h = 6.18 multiplication factor (en-route through non-precision approach
K_h = 6.0 multiplication factor (precision approach) (7)

For the precision approach mode, the values of Kh and Kv were selected to bound the user's position in one dimension with a probability of 2 x 10^{-9} and 10^{-7}, respectively, assuming that the error is characterised by a Gaussian distribution. A Gaussian distribution is used because the aircraft needs to be protected in the vertical and the lateral axes. Only one dimension is used for the HPL, since the along-track tolerance is so much larger than the cross-track tolerance. The worst-case dimension is used. It has been assumed that there is only one independent sample per approach, that half of the total integrity requirement

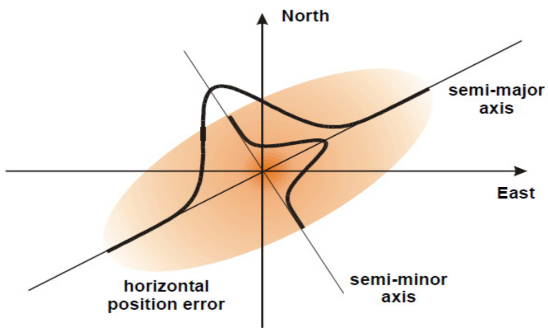


Fig. 13. Horizontal Position Error Ellipse
Source: [own work]

(i.e. 2 x 10-7 per approach) has been allocated to the VPL bounding probability and that the HPL bounding probability has been made negligible. For en-route through non-precision approach modes, the value of Kh was chosen to bound the user's position in two dimensions with a probability of 5 x 10-9 per independent sample, assuming that the error is characterised by a Rayleigh distribution. A Rayleigh distribution is used because the radial error needs to be bounded (both cross-track and along-track errors), using the worst case assumption that the semi-major and semi-minor axes are equal. It has been assumed that there are 10 independent samples per hour, and that half of the total integrity requirement (i.e. 10-7 per hour) has been allocated to the HPL bounding probability.

5. Conclusions

In this article justified the desirability of placing the NPA on Polish airports. Research methods used in the experiments have confirmed that the use of the EGNOS system allows you to safely and continuously carry out the landing maneuver. Presented consortium will be continued its work on the verification of EGNOS for aviation and certification.

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