NPA, GNSS, GPS, EGNOS, EGNOS, Navigation

Andrzej FELLNER*
Silesian University of Technology, Faculty of Transport
Krasińskiego 8, 40-019 Katowice, Poland
Krzysztof BANASZEK
Polish Air Navigation Services Agency, Warsaw, Poland
Wieżowa 8, 02-147 Warszawa, Poland
Paweł TRÓMIŃSKI
Air Force Institute of Technology in Warsaw,
Księcia Bolesława 6, 01-494 Warszawa, Poland
**Corresponding author*. E-mail: andrzej.fellner@polsl.pl

THE SATELLITE BASED AUGMENTATION SYSTEM – EGNOS FOR NON-PRECISION APPROACH GLOBAL NAVIGATION SATELLITE SYSTEM

Summary. First in the Poland tests of the EGNOS SIS (Signal in Space) were conducted on 5th October 2007 on the flight inspection with SPAN (The Synchronized Position Attitude Navigation) technology at the Mielec airfield. This was an introduction to a test campaign of the EGNOS-based satellite navigation system for air traffic. The advanced studies will be performed within the framework of the EGNOS-APV project in 2011. The implementation of the EGNOS system to APV-I precision approach operations, is conducted according to ICAO requirements in Annex 10. 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 [1]. Also, the project will try to exploit the excellent accuracy performance of EGNOS to analyze 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 Rzeszów, 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 programmed 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 [2].

SATELITARNY SYSTEM WSPOMAGAJĄCY – EGNOS DLA NIEPRECYZYJNYCH PODEJŚĆ GLOBALNEGO NAWIGACYJNEGO SYSTEMU SATELITARNEGO

Streszczenie. 5 października 2007 roku, na lotnisku Mielec, podczas wykonywania oblotu technologicznego SPAN (The Synchronized Position Attitude Navigation) przeprowadzone zostały pierwsze w Polsce testy sygnału systemu EGNOS. Było to wprowadzenie do kampanii badania wspomagającego systemu nawigacji satelitarnej – dla ruchu lotniczego. Zaawansowane badania będą wykonywane w ramach projektu EGNOS-APV w 2011 roku. Implementacja systemu EGNOS do wykonywania precyzyjnych podejść operacyjnych przeprowadzana jest zgodnie z wymaganiami

zawartymi w Aneksie 10 ICAO. Zdefiniowanie użyteczności i scertyfikowanie EGNOS jako SBAS (satelitarnego systemu wspomagającego) w lotnictwie, wymagają szczegółowych analiz dokładności, wiarygodności, ciągłości i dostępności sygnału SIS (sygnał w przestrzeni) [1]. Ponadto w projekcie podejmowane będą próby zastosowania zwiększonej dokładności EGNOS podczas analizowania implementacji systemu podejścia do lądowania GLS (System Lądowania GNSS, kategoria I podejścia używająca SBAS, z wysokością decyzji 200 stóp). Lokalizacja lotniczej stacji Rzeszów, monitorującej pracę systemu EGNOS blisko granicy polsko-ukraińskiej, wynika z planowanego pokrycia sygnałem EGNOS obszaru państw ECAC i jest bardzo przydatna podczas testowania SIS w tym terenie. Zgodnie z bieżącym harmonogramem implementacji systemu EGNOS, dalsze działania projektowe będą prowadzone z wersją v2.2, która jest odpowiednio certyfikowana dla lotnictwa cywilnego. W związku z tym projekt umożliwi demonstrację możliwości certyfikowanej wersji systemu EGNOS do cywilnych zastosowań [2].

1. INTRODUCTION

The general idea of this project is to popularize the usage of EGNOS System in Central European countries. The main goal will be achieved by demonstrating key capabilities of the EGNOS System as SBAS APV I – its main role. After that the National Fly Authority Agency certification procedure will be launched, EGNOS will become fully functional and operational airfield domestic system. The Project consists of 4 main phases:

Phase one – Analysis of domestic airfields and Aircraft operator(s) against opportunity of EGNOS installation and utilisation of capability for landing purposes;

Phase two – study of demonstrator’s technical conception of EGNOS APV I implementation connected with blueprint for certification process.

Phase three – on-board and airfield system installation connected with provisional certification

Phase four – Final demonstration of overall system capabilities, followed by on-going tests, system certification and implementation of Safety Case.

The following entities participate in this project: scientific research centers, government agencies, aircraft operator and local small airfield, which guarantees general outlook analysis, clearly constructed user requirements with correct technical solutions which are in compliance with Polish and European air traffic regulations.

Government agency will keep an eye on realizing a thorough airfield and aircrafts operators inspection used by research centers for analysis. Additionally government agency will be the supervisor for preparation and certification of the airfield and aircraft.

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. Aircraft operator involved in a project will perform the EGNOS system installation on the aircraft and on the airfield, using blueprint for technical solution developed in the second phase of the project, and as result of that in next phases of project will perform test and certification flights. Additionally aircraft operator is allowed to train new and current pilots, which will fully realize plan for preparing all the pilots to be familiarized with EGNOS System, and if so, this system will be widely and commonly used in aviation/air force.

All demonstration, testing and certification flights will be in participation of scientific research center and government agency, which will guarantee the test procedure correctness in accordance to flight safety regulations and rules for new equipment on board aircrafts.

The following article provides a quick overview of the most important performance characteristics as obtained during the observed period of 168 hours at EGNOS Rzeszów. Smoothing was set to 100 seconds.

2. SIGNAL IN SPACE ANALYSIS

This First Glance Report is generated with Pegasus 4.2 and presents the following performance characteristics (Table 1 and Table 2):

- Sample validity: Valid samples are all the samples that are present in the data and are not considered to be affected due to logging or processing tool problems
- Accuracy statistics: calculated for horizontal and vertical positioning errors separately.
    - For the measured accuracy, the samples are taken directly from the horizontal and vertical errors as computed by PEGASUS.
    - For the scaled accuracy, every sample is scaled with a ratio of AL/PL before taking the 95th percentile.
- User Availability percentiles for the different PA operations: determined by dividing the number of samples that are available for an operation by the total number of valid samples Number of discontinuity events within the period: the total number of discontinuity events for a given operation.
- Number of Integrity events within the period: the total number of integrity events. The Misleading Information (MI) events are determined based on samples with XPE>XPL. The Hazardous MI (HMI) are counted according to XPE>XAL>XPL for each operation.
- All values that exceeds a certain required threshold are presented in red.
- For more information refer to the FGA Performance algorithms document.

Table 1

SIS Analyze EGNOS CHELM

Site	[ANALYZE] EGNOS CHELM 7 days							Date	27/11/2008	
Location	Lat:	51.130		Lon:	23.480			Alt:	254.70	
Receiver	Septentrio PolaRx 2			Software	Pegasus 4.2300150			PRN	120	
Data set	Duration	Start	Stop	Expected	Total	SBAS Msg		Valid	Valid(%)	
1 Hz	168h00	00:00	23:59	604800	604788	604285		604428	**99.94%**	
Results per operation										
	Operation	**APV-I**			**APV-II**			**CAT-I**		
	HAL/VAL	40 / 50			40 / 20			40 / 12		
Accuracy (m)										
		Meas.	Scaled	Req.	Meas.	Scaled	Req.	Meas.	Scaled	Req.
HNSE(95%)		**1.71**	6.92	16	1.72	7.03	16	1.72	7.72	16
VNSE(95%)		**1.69**	5.46	20	1.63	2.23	8	1.53	1.60	4
Availability (%)										
Valid EGNOS Solutions	603370	**597696**			510339			62104		
Minimum Required		99%			99%			na		
Availability		**98.886%**			**84.433%**			**10.275%**		
Continuity										
Events		**345**			**3120**			**7838**		
Integrity										
	MI	HMI APV-I			HMI APV-II			HMI CAT-I		
Total	**0**	0			0			0		
Horizontal	**0**	0			0			0		
Vertical	**0**	0			0			0		

Table 2

HPL, VPL and APV-I statistics

Protection level statistics					
	99%	95%	50%	mean	std deviation
HPL	**34.81**	22.99	10.24	11.89	5.21
VPL	**35.66**	24.43	15.40	16.39	4.67
APV-I Position error statistics					
	Samples	**Mean**	**RMS**	95%	std deviation
HPE	**597696**	1.10	1.16	1.71	0.35
VPE	**597696**	0.76	0.92	1.69	0.51

Signal In Space Analysis consist of:

- Message Distribution by time - Fig. 1.

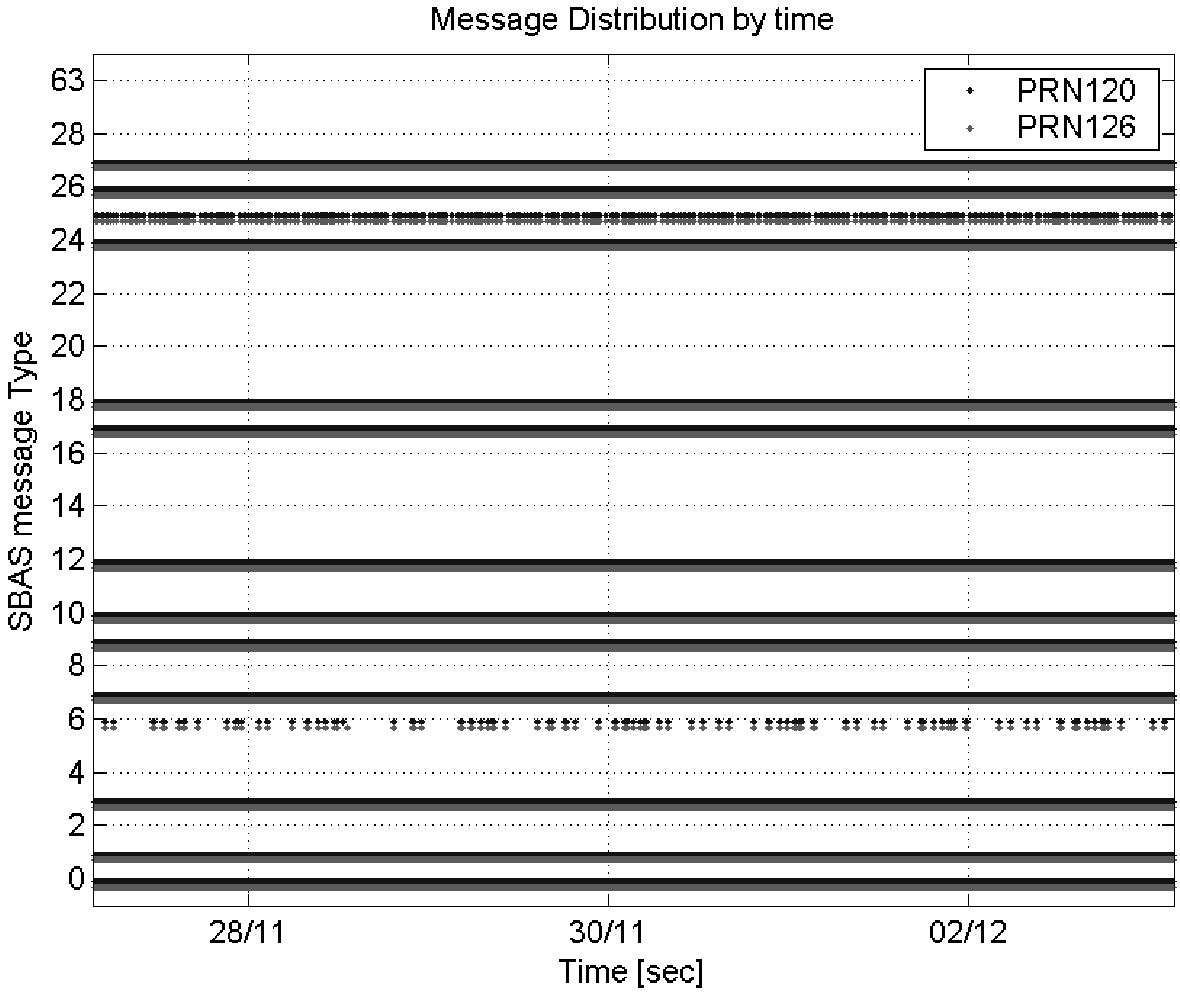

Fig. 1. Message Distribution by time
Rys. 1. Komunikat dystrybuowany w czasie

➢ Message type counter - (Table 3)

Table 3

Message type counter

.	PRN 120		PRN 126	
SBAS MT	**number**	**%**	**number**	**%**
MT 0	150905	24.97	150839	24.97
MT 1	9396	1.55	9393	1.56
MT 2	0	0.00	0	0.00
MT 3	150865	24.97	150806	24.97
MT 4	0	0.00	0	0.00
MT 5	0	0.00	0	0.00
MT 6	590	0.10	585	0.10
MT 7	9397	1.56	9392	1.55
MT 9	9396	1.55	9393	1.56
MT 10	9396	1.55	9393	1.56
MT 12	3764	0.62	3762	0.62
MT 17	3764	0.62	3763	0.62
MT 18	18819	3.11	18814	3.11
MT 24	150869	24.97	150807	24.97
MT 25	550	0.09	550	0.09
MT 26	82811	13.70	82772	13.70
MT 27	3763	0.62	3763	0.62
MT 28	0	0.00	0	0.00
MT 62	0	0.00	0	0.00
MT 63	0	0.00	0	0.00
Total	604285	100.00	604032	100.00

➢ Message Type 6 Analysis

This figure shows the number of occurrences for consecutive MT6 broadcasts - Table 4 (1, 2, 3, 4 or more repetitions). A normal alert consists of four consecutive MT6 messages, while single occurences indicate CPF switch-overs.

Table 4

Message type 6 repetitions

Message Type 6 repetitions					
	single	double	3 x	4 x	> 5x
PRN 120	1	0	1	145	1
PRN 126	1	0	1	145	0

Position Solution Analysis consist of:

Position errors and Protection levels (Fig. 2 and Fig.3)

All plots have fixed scales that represent nominal behavior. When the performance does not fit properly within these scales further detailed investigations are needed.

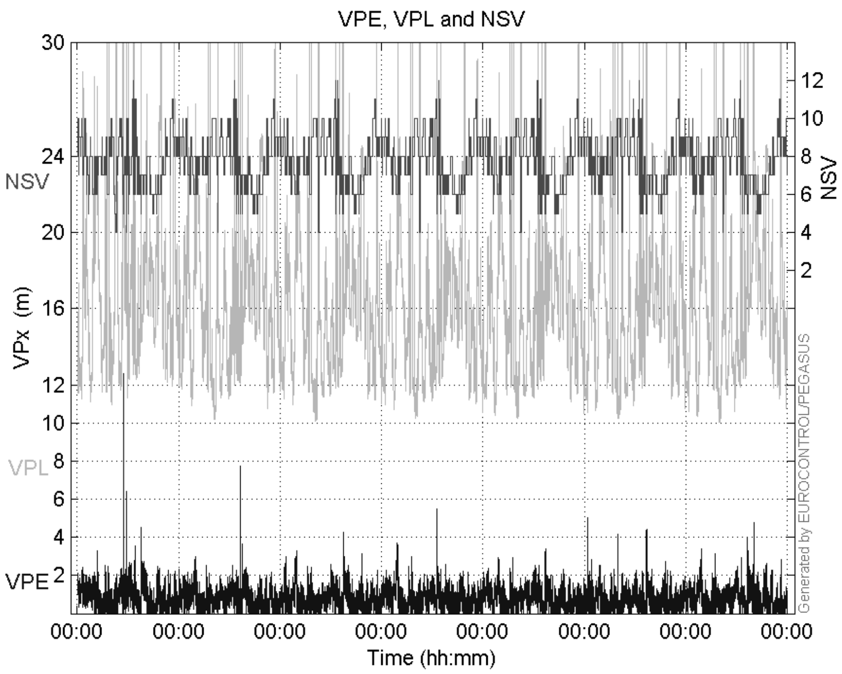

Fig. 2. Vertical Error, Protection Level and NSV over time
Rys. 2. Pionowy błąd, ochronny poziom w czasie

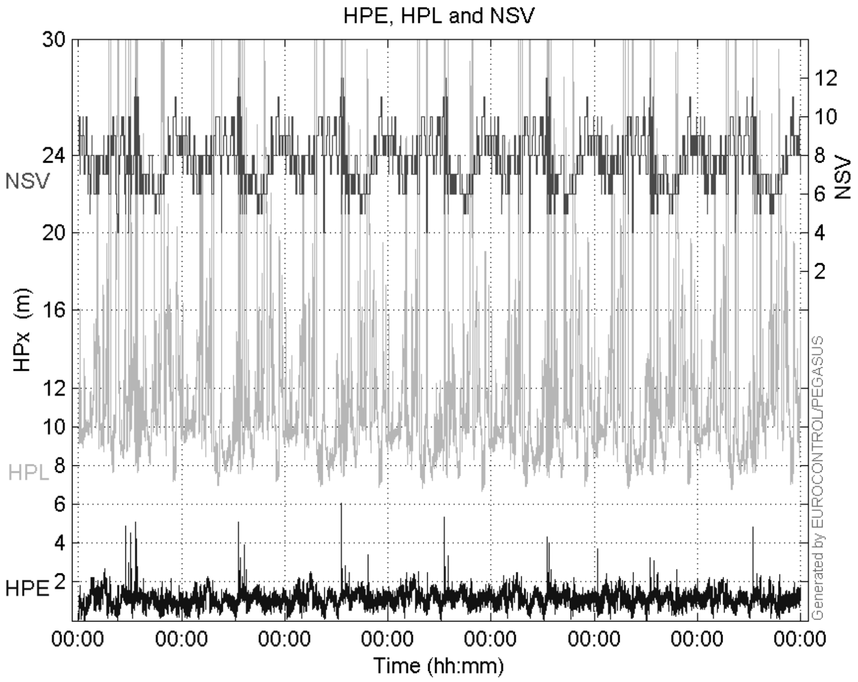

Fig. 3. Horizontal Error, Protection Level and NSV over time
Rys. 3. Poziomy błąd, ochronny poziom w czasie

- Scatter plot of horizontal deviation from reference position – Fig. 4.

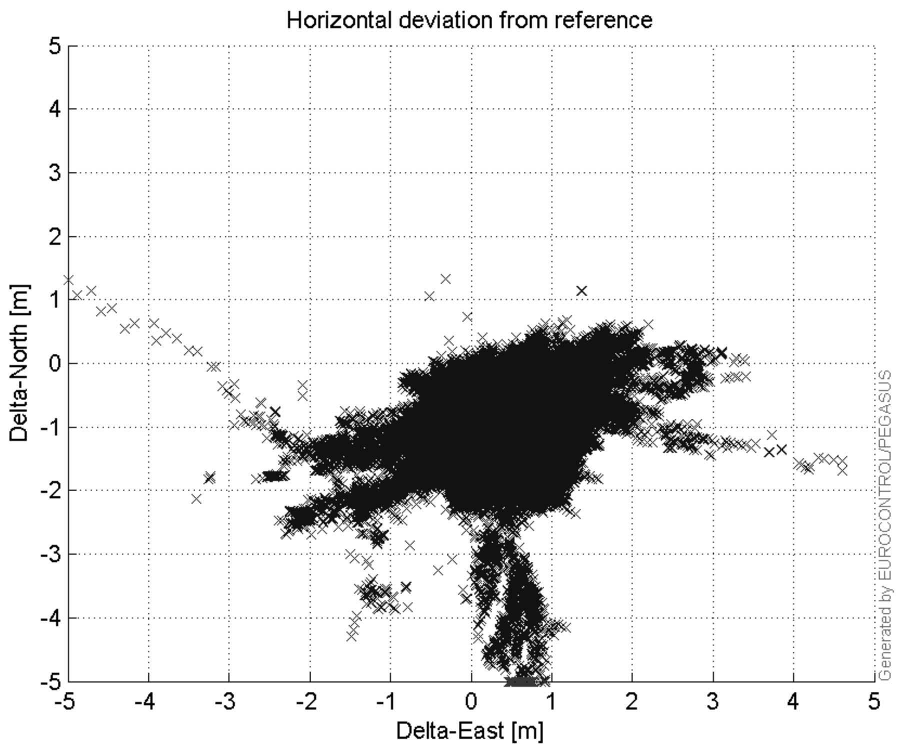

Fig. 4. Scatter plot of horizontal deviation from reference position
Rys. 4. Wykres punktowy powierzchni poziomej odchyleń od pozycji odniesienia

➢ Horizontal Stanford graphs - Fig. 5.

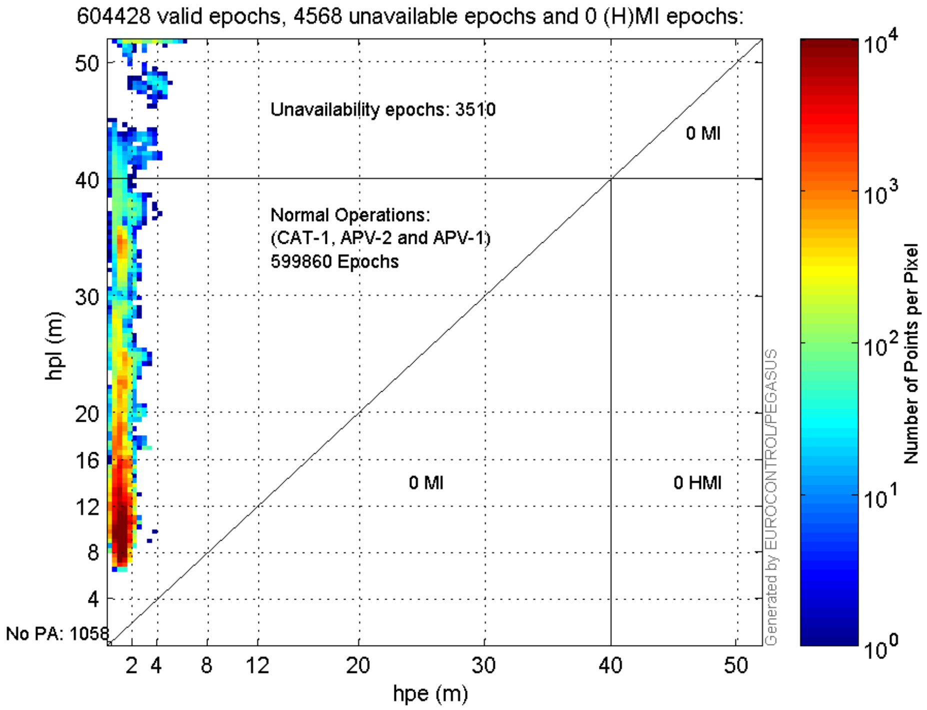

Fig. 5. Horizontal Stanford graph
Rys. 5. Poziomy wykres Stanforda

➢ Vertical Stanford graphs – Fig. 6.

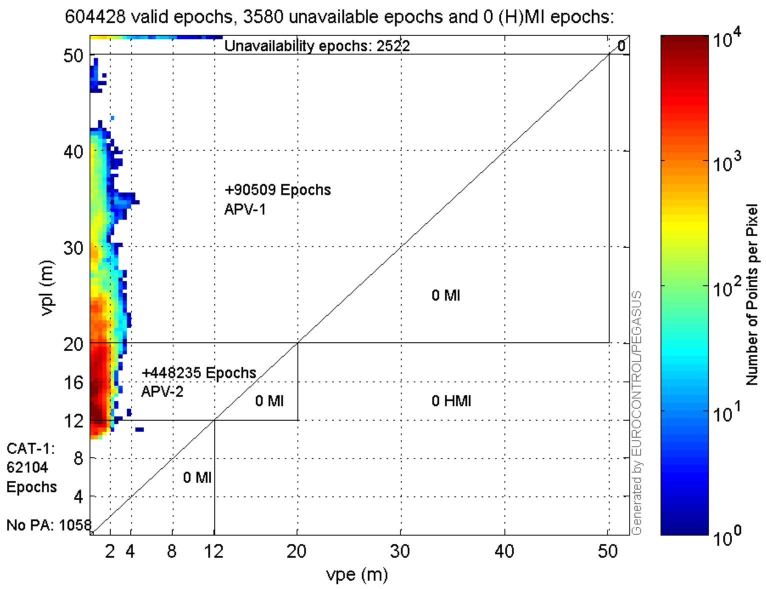

Fig. 6. Vertical Stanford graphs
Rys. 6. Pionowy wykres Stanforda

APV-I Statistics consist of:

➢ Horizontal position error distributions (epochs when APV-I available) - Fig. 7.

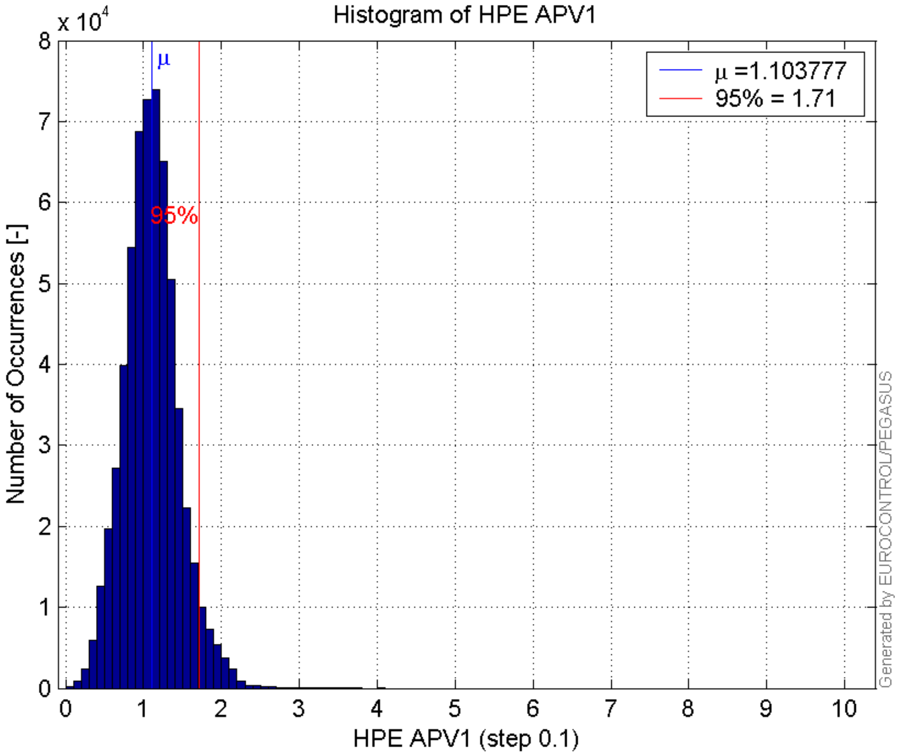

Fig. 7. Horizontal position error distributions (epochs when APV-I available)
Rys. 7. Poziomy błąd dystrybucji położenia (epoki, kiedy APV-I są dostępne)

- Vertical position error distributions (epochs when APV-I available) - Fig. 8.

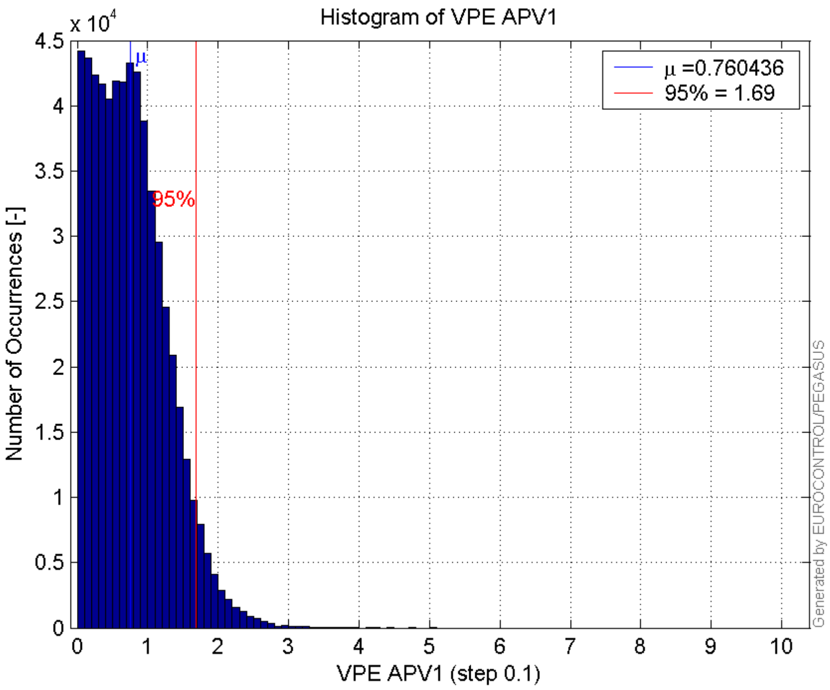

Fig. 8. Vertical position error distributions (epochs when APV-I available)
Rys. 8. Pionowy błąd dystrybucji położenia (epoki, kiedy APV-I są dostępne)

➢ Vertical protection level distributions (epochs when APV-I available) - Fig. 9.

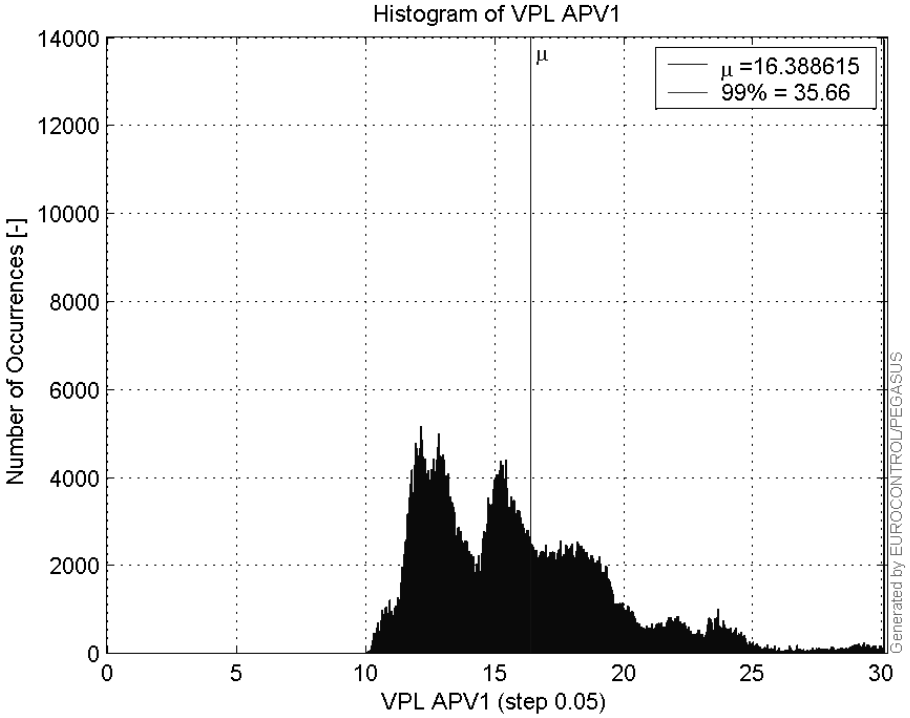

Fig. 9. Vertical protection level distributions (epochs when APV-I available)
Rys. 9. Pionowa dystrybucja poziomu ochronnego (epoki, gdy APV-I są dostępne)

➢Horizontal Vertical protection level distributions (epochs when APV-I available) - Fig. 10.

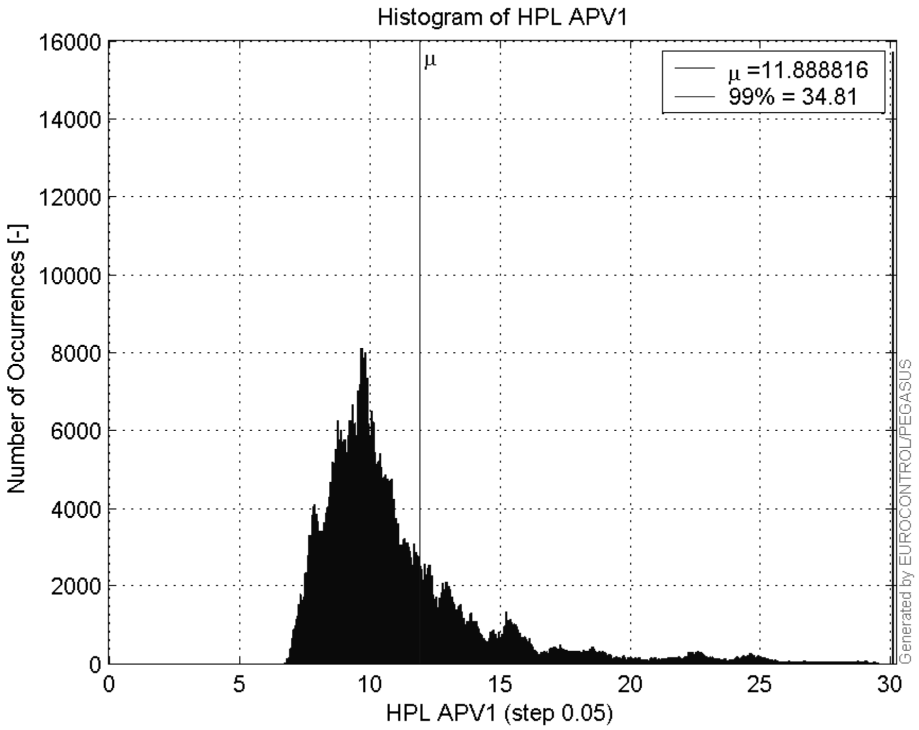

Fig. 10. Horizontal protection level distributions (epochs when APV-I available)
Rys. 10. Horyzontalna dystrybucja poziomu ochronnego (epoki, gdy APV-I są dostępne)

➢ Horizontal Safety Index distributions (epochs when APV-I available) - Fig. 11.

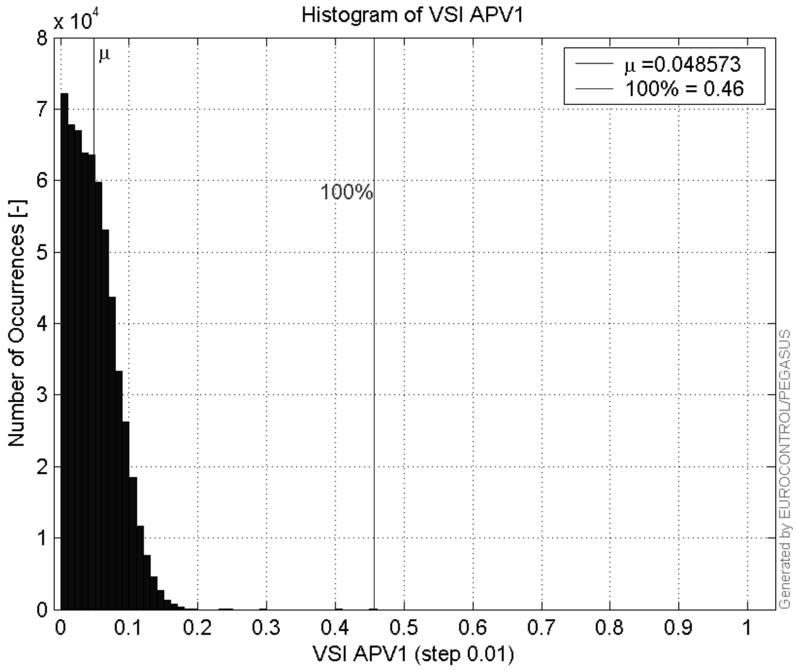

Fig. 11. Horizontal Safety Index distributions (epochs when APV-I available)
Rys. 11. Pozioma dystrybucja indeksu bezpieczeństwa (epoki, kiedy APV-I są dostępne)

➢ Vertical Safety Index distributions (epochs when APV-I available) - Fig. 12.

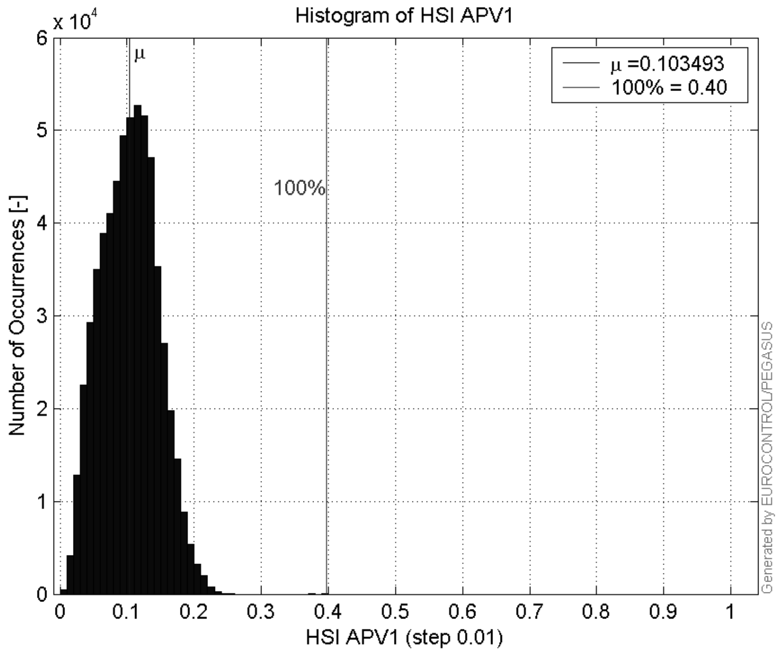

Fig. 12. Vertical Safety Index distributions (epochs when APV-I available)
Rys. 12. Pionowa dystrybucja indeksu bezpieczeństwa (epoki, kiedy APV-I są dostępne)

Integrity.

In case of a (potential) Misleading Information situation, this section will provide a list of all the epochs where there was an xPE/xPL ratio of more than 1 (real MI) or more than 0.75 (near MI).

Integrity events – Table 5.

There are no Integrity events in the data. The maximum Horizontal PL/PE ratio is 0.397273 and the maximum Vertical PL/PE ratio is 0.455981

The following table represents the most extreme epochs: Highest xPE/xPL ratio, Lowest xPL values and Highest xPE values.

Table 5

Highest xPE/xPL ratio, Lowest xPL values and Highest xPE values

extremes							
	Epoch	HPE	HPL	HPE/HPL	VPE	VPL	VPE/VPL
max normHor	175329	3.59359	9.04564	0.39727	1.51378	10.8631	0.13935
max normVer	175331	0.16034	8.86431	0.01809	5.03754	11.0477	0.45598
max HPE	565906	6.07277	60.2411	0.10081	-1.57755	35.1706	0.04485
max VPE	385129	4.89637	52.9584	0.09246	-12.6208	140.124	0.09007
min HPL	78769	1.22757	6.67681	0.18386	0.71793	11.5757	0.06202
min VPL	287957	0.97835	6.78061	0.14429	0.06461	10.0249	0.00645

Cumulative Density Function – Fig. 13.

The Cumulative Density Function (CDF) gives a good indication of the quality of the data in terms of over-bounding. Especially the trend towards lower probabilities becomes clear. The graphs should be read as follows:

- The Red dashed line indicates the ideal trend
- The vertical axis indicates the probabilities, the more data is available, the lower the graphs continues
- The horizontal axis indicates the quality of over-bounding.
- The data points are strictly not allowed to exceed the red-dashed line.
  - However at the start they normally tend to exceed it, and this is acceptable as long as this is only for a small area at the beginning
- The steeper the trend of the data-points, the better.
  - A clear downward trend gives confidence that the over-bounding is sufficient.
  - A clear trend towards exceeding the reference (red-dashed) line is an indication of non over-bounding.
  - In case the trend is parallel and close to the reference, further investigation such as EVT is recommended.
  - A change(s) of the trend suggests that multiple system modes are present in the data. For detailed analysis these should be separated.

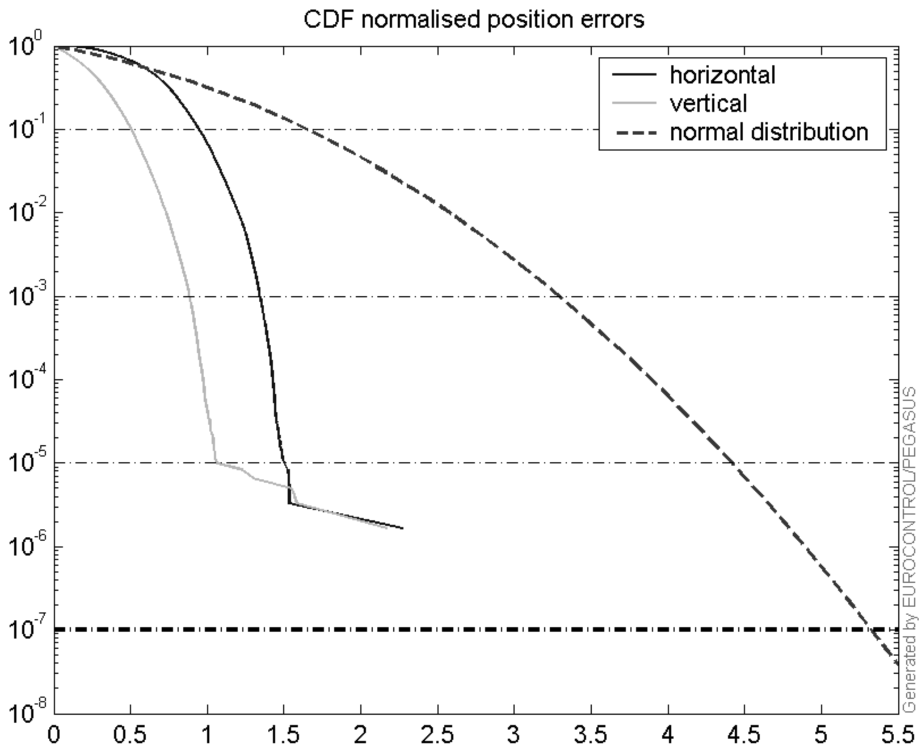

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Fig. 13. Horizontal and Vertical Position over-bounding in CDF
Rys. 13. Poziome i pionowe położenie nad obwiednią w CDF

Continuity – Table 6.

This section will provide a list of all the discontinuity events. In case there are more than 20 discontinuity events the tables are filtered to a maximum table length of 20. In case there still too many independent events, the table will not be displayed and further investigation is recommended.

Table 6

Discontinuity in detail

Discontinuity events					
	Valid	APV-1	APV-2	CAT-1	APV-35m
All	10	345	3120	7838	745
Long	9	40	173	257	49
Independent	7	27	103	67	27
P(disc.)	0.00017	0.00068	0.00303	0.01618	0.00069
P(slide)	0.00021	0.00206	0.01723	-9.35643	0.00371

The following table presents the discontinuity performance in more detail.

- All discontinuities regardless of duration (same as in first glance)
- Long discontinuities lasting 3 or more seconds
- Independent discontinuities, lasting 3 or more seconds and after continuously available period of 15 or more seconds
- P(disc.): Continuity Risk determined by multiplying the continuity risk per epoch with 15 seconds
- P(slide): Continuity Risk determined with sliding window of 15 seconds

Discontinuity events for Position Solution – Table 7.

Table 7

The following table presents all Position discontinuity events

Position discontinuity events			
#	Epoch	duration	stable period
1	379453	34	33493
2	387656	219	8169
3	387879	25	4
4	416940	160	29036
5	484425	171	67325
6	484600	84	4
7	70570	160	28709
8	109514	1	38784
9	201129	44	4466
10	242862	160	41689

3. SUMMARY

Currently using the EGNOS to precision approaches is not possible on the eastern border the system. Inside area such parameters as accuracy, continuity and availability are on the far more better level, what is a good forecast to development of an EGNOS system.

Area Navigation (RNAV) can be defined as a method of navigation that permits aircraft operation on any desired course within the coverage of station-referenced navigation signals or within the limits of a self contained system capability, or a combination of these [3].

RNAV was developed to provide more lateral freedom and thus more complete use of available airspace. This method of navigation does not require a track directly to or from any specific radio navigation aid, and has three principal applications [4]:

1. A route structure can be organized between any given departure and arrival point to reduce flight distance and traffic separation;

2. Aircraft can be flown into terminal areas on varied pre-programmed arrival and departure paths to expedite traffic flow;
3. Instrument approaches can be developed and certified at certain airports, without local instrument landing aids at that airport.

Focusing on the last point, RNAV approaches can have several descent minima depending on the kind of RNAV approach to be flown [5]:

- RNAV (GNSS) NPA: an approach without vertical guidance flown to the LNAV MDA/H
- APV Baro: an approach with barometric vertical guidance flown to the LNAV/VNAV DA/H.
- APV SBAS: An approach with geometric vertical and lateral guidance flown to the LPV DA/H

The 36th ICAO Assembly in 2007 passed a resolution encouraging States to implement approach procedures with vertical guidance (Baro-VNAV and/or SBAS) for all instrument runway ends [6], either as the primary approach or as a back-up for precision approaches by 2016.

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Received 15.10.2011; accepted in revised form 26.02.2012