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AIRBORNE MEASUREMENT SYSTEM DURING VALIDATION OF EGNOS/GNSS ESSENTIAL PARAMETERS IN LANDING

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Abstract

The air transport requires certificate of ground and deck devices, systems and adequate procedures. However applied geodetic techniques and measuring technologies depend on taken undertakings. If one should precisely put standard ground systems and the navigational assistance are overbalancing static geodetic techniques and measuring technologies. However operational activity, depending on the phase of the flight a real requires applying geodetic techniques and measuring „technologies time". As part of conducted air tests they made the validation of four fundamental parameters (accuracy, credibility, availability, continuity) of satellite EGNOS, GNSS signals, made as part of European projects: "Support to the EGNOS APV Operational Implementation – APV MIELEC", air tests enabled to draw right procedures up and to apply satellite signals in the air transport. Details will be presented in the following article.

Keywords: Flight Validation, RNAV, EGNOS/GNSS, LPV

1. Introduction

The purpose of this article is to show evidence of the work carried out as part of the flight validation activities of one RNAV approach Instrument Flight Procedures (IFP), down to LPV minima, at Katowice airport [3]. It is a deliverable of the TEN-T funded programme "Support to the EGNOS APV Operational Implementation – APV MIELEC" [4].

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, within the limits of a self-contained system capability or a combination of these [10].

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:

- A route structure can be organized between any given departure and arrival point to reduce flight distance and traffic separation;
- Aircraft can be flown into terminal areas on varied pre-programmed arrival and departure paths to expedite traffic flow;
- 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 [9]:

- RNAV NPA - approach without vertical guidance (flown LNAV MDA/H);
- APV Baro - approach with barometric vertical guidance (LNAV/VNAV DA/H);
- APV SBAS - approach with geometric vertical and lateral guidance (LPV DA/H).

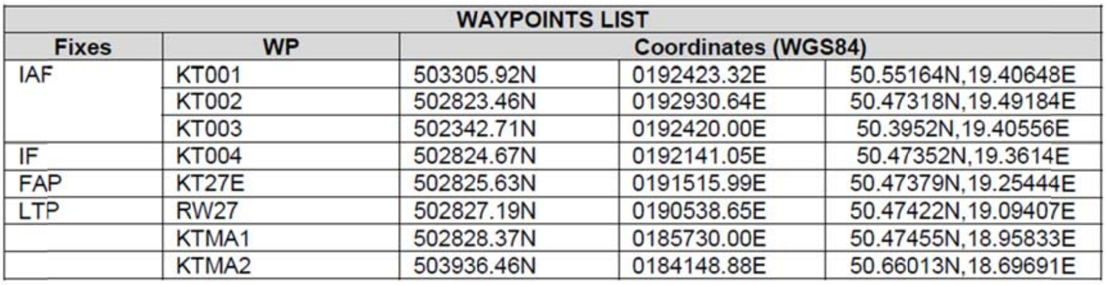
The 36th ICAO Assembly in 2007 passed a resolution encouraging States to implement approach procedures with vertical guidance (Baro-VNAV, SBAS) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 [11].

APV SBAS is supported by satellite based augmentation systems such as WAAS [7] in the USA [6] and EGNOS in Europe to provide lateral and vertical guidance is equivalent to an ILS localizer and the vertical guidance is provided against a geometrical path in space rather than a barometric altitude. The use of the EGNOS, presents a feasible solution to APV approaches: navigation system specifically designed for approach operations, high accuracy and integrity, requires no infrastructure on the aerodromes themselves, supports autopilot coupling, standalone avionics possible thereby minimising retrofit costs [5].

2. Procedure presentation and ground validation

Before the accession to the ground and air validation, executing the procedure of the RNAV GNSS approach [12] was necessary (Fig.1). it was also necessary to prepare: List of waypoints (Table 1), Path Terminators (Table 2), Final Approach Segment (FAS) Data Block (Table 3).

Table 1. List of waypoints



WAYPOINTS LIST				
Fixes	**WP**	**Coordinates (WGS84)**		
IAF	KT001	503305.92N	0192423.32E	50.55164N,19.40648E
	KT002	502823.46N	0192930.64E	50.47318N,19.49184E
	KT003	502342.71N	0192420.00E	50.3952N,19.40556E
IF	KT004	502824.67N	0192141.05E	50.47352N,19.3614E
FAP	KT27E	502825.63N	0191515.99E	50.47379N,19.25444E
LTP	RW27	502827.19N	0190538.65E	50.47422N,19.09407E
	KTMA1	502828.37N	0185730.00E	50.47455N,18.95833E
	KTMA2	503936.46N	0184148.88E	50.66013N,18.69691E

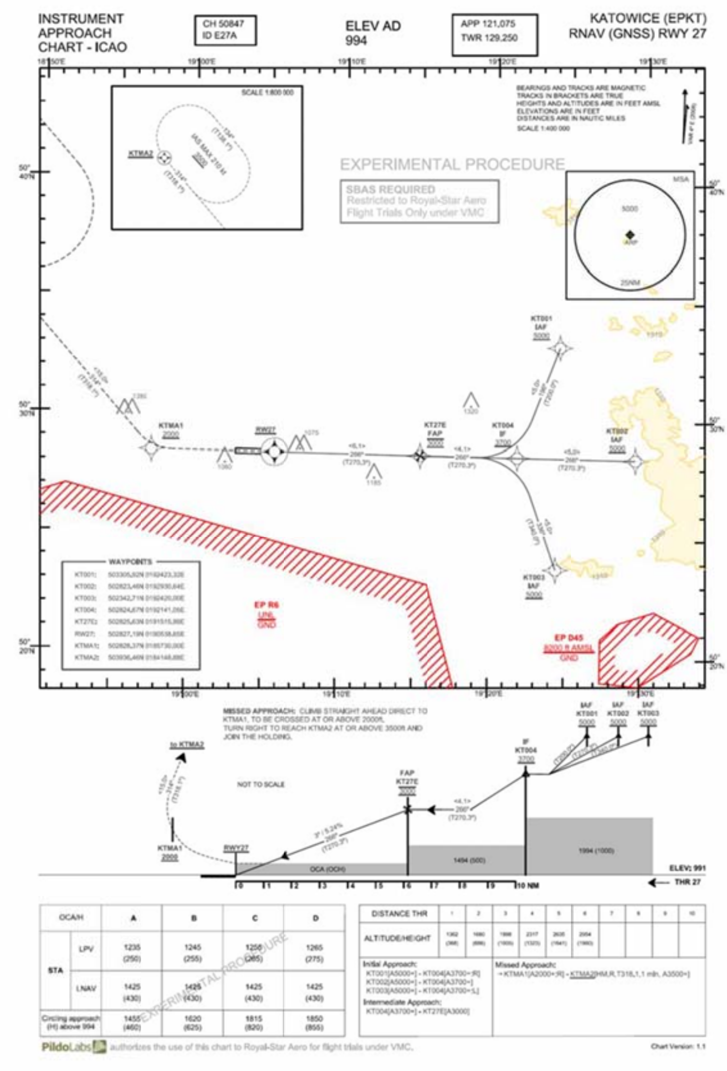


Fig. 1. Procedure chart

Table 2. Path Terminators

APPROACH / MISSED APPROACH FROM IAF KT001			
Formal Description	**Short description**	**Expected Path Terminator**	**Flyover required**
KT001 at or above 5000ft	KT001[A5000+]	IF	N
To KT004 at or above 3700ft, turn right	KT004[A3700+;R]	TF	N
To KT27E at 3000ft	KT27E[A3000]	TF	N
To RW27	RW27[A1041+]	TF	Y
MISSED APPROACH			
Direct to KTMA1 at or above 2000ft, turn right	→ KTMA1[A2000+;R]	DF	N
To KTMA2{HM,R,T318.1, 1min} at or above 3500ft	KTMA2[R]	TF	Y

APPROACH / MISSED APPROACH FROM IAF KT002			
Formal Description	**Short description**	**Expected Path Terminator**	**Flyover required**
KT002 at or above 5000ft	KT002[A5000+]	IF	N
To KT004 at or above 3700ft	KT004[A3700+]	TF	N
To KT27E at 3000ft	KT27E[A3000]	TF	N
To RWY27	RWY27[A1041+]	TF	Y
MISSED APPROACH			
Direct to KTMA1 at or above 2000ft, turn right	→ KTMA1[A2000+;R]	DF	N
To KTMA2{HM,R,T318.1, 1min} at or above 3500ft	KTMA2[R]	TF	Y

Table 3. FAS Datablock input data

ref	Field	Value	Remarks
A	Operation type	0	[0] straigh-in approach including offset.
B	SBAS provider ID	1	[1] EGNOS
C	Airport identifier	EPKT	
D	RWY	RW27	
E	Approach performance designator	0	[0] LPV
F	Route indicator		No other RNAV procedures
G	Reference path data selector	0	Field reserved for GBAS
H	Reference path identifier	E27A	
I	LTP/FTP latitude	502827.1900N	
J	LTP/FTP longitude	0190538.6500E	
K	LTP/FTP height	+03436 (343.6m)	FTP Height = Elevation + Geoid height Geoid = 40.4 m (AIP)
L	FPAP latitude	502827.5000N	
M	FPAP longitude	0190316.7100E	
N	Threshold crossing height (TCH)	15	
O	TCH units	M	
P	Glide path angle	03.00	3.00° / 5.24%
Q	Course width at threshold	105	
R	Length offset	0	FPAP at opposite rwy end
S	Horizontal alert limit	40	
T	Vertical alert limit	50	
U	CRC	E0D87AF8	
V	ICAO code	EP	
W	Orthometric height	+03032 (303.2m)	Height AMSL threshold 27

A ground validation was next action. The review of the IFP design package has been performed together with PANSA and Pildo. The main outcomes are:

- It has been confirmed the application of the criteria specified in PANS-OPS [4];
- It has been confirmed the data accuracy and integrity;
- The Terrain maps used (DTM from SRTM with 90 m accuracy);
- The controlled obstacles around the airport were provided by the airport.

The reviewers involved realised that one of the obstacles (ID#79) was not well referenced. This entailed a substantial reduction of the LPV minima value. The charts were corrected accordingly prior to the flight trials. There is a slight deviation of the criteria concerning the position where the FPAP has been located. In Katowice the ILS localizer (LOC) is located more than 305 meters from THR09. Thus the position of the FPAP should be the one specified in the figure 2. The codification performed considered that the localizer was located at 305 m. Therefore the FPAP was coded in THR09 (runway end) postion, being the length offset nil. However, it is not an important issue operationally speaking. The horizontal deviations that the pilot obtains are not exactly the same that the ones that would be obtained flying the existing ILS procedure. Figure 3. shows this small difference.

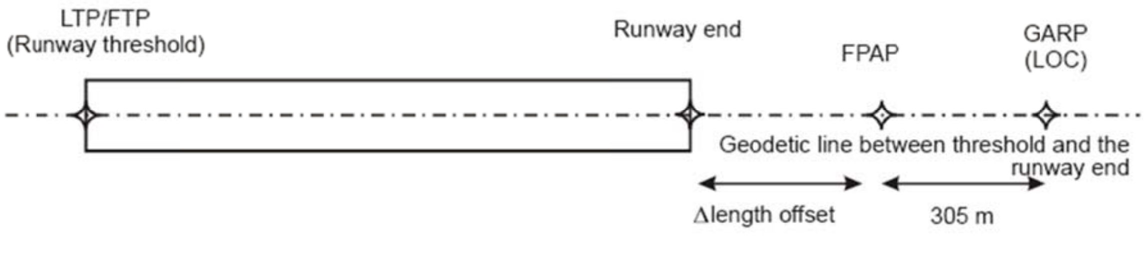


Fig. 2. FPAP location, ILS localizier more than 305 m from the runway end

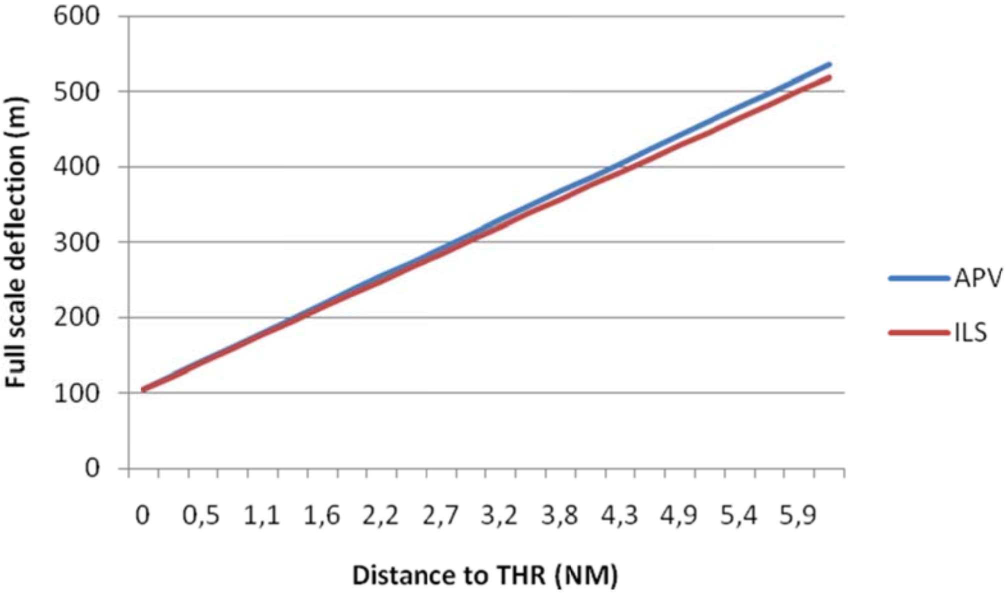


Fig. 3 Difference between the Full Scale Deflection of the ILS with respect to the APV

Pre-flight validation was next action. A Jeppesen coding screenshot is provided in order to validate the coding of the database used in the aircraft. Furthermore, it is provided two screenshots with the results of the CRC generation and Final Approach Segment Data block:

- One using the online application developed by EUROCONTROL
- Another using the in-house tool developed by Pildo Labs in accordance with DO-229D.

3. Flight validation

The following guidelines were taken into consideration for conducting the flight validation activities:

- The validation was carried out in daylight hours under VMC conditions;
- The Missed Approach segment was flown;
- The Final Approach Segment has to be flown ½ scale down, at least once;
- All segments of the approach were flown at least once (segments common to the LNAV approaches were already flown during the LNAV validation flights);
- A test database containing the RNAV IFP was used;
- There was one pilot acting as FVP, and one observer assisting the FVP in the validation process observing the ‘out of cockpit’ environment;
- The aircraft used during the flight validation had the appropriate performance capabilities for which the IFP was designed.

The FV was conducted with a Piper Seneca II aircraft. The aircraft is equipped with the appropriate RNAV equipment for conducting LPV operations: a Garmin GNS 430W connected with other required avionics (antenna, CDI/VDI). The complete set allows flying during all phases of flight, from en-route to precision approach down to LPV minima. The IFP to be validated, designed by Pildo and PANSA, was coded inside a test database produced by Jeppesen and Garmin. The pilots inserted the FV plan inside the FMS-like Garmin device and conducted the trials in the relevant navigation mode using the GPS/SBAS guidance. Guidance during the entire flight, including aircraft positioning, was provided by the CDI/VDI fed by the GNS 430W.

Before the flight trials, the local APV-1 availability in the area was simulated using a predictive RAIM algorithm developed by Pildo Labs. The analysis was performed at the ARP, considering also the following conditions:

- No digital terrain model was used to simulate the local conditions of the area (useful in some environments to take into account the masking caused by a mountainous environment);
- The GPS almanac was downloaded from the U.S. Coast Guard Navigation Center website;
- The simulation was carried out for a 12 hours dataset (from 9:00h to 21:00h), with samples every 5 minutes.

The obtained result is of a 100% APV-1 availability at the threshold coordinates. The estimated horizontal and vertical errors were also estimated (Fig. 4). These simulations ensured that the EGNOS would enable an APV-1 level of service at Katowice during the whole day.

The data analysis focuses on the data recorded during the flights. The next figures show the trajectories flown during the approaches (Fig. 5). The approaches are drawn jointly with the tested paths (yellow lines).

The following figures present the flight trajectories of the demonstrations together with the waypoints and runway threshold (Fig. 6, 7). It can be seen how the aircraft successfully accomplished the operations up to the OCA/H values, when either a missed approach or a landing was conducted. In the profile views, the next reference altitudes have been plotted:

- 5000 ft, which is the minimum altitude to fly the initial segments of both approaches;
- 1235 ft, which is the CAT a LPV minima (OCA) of the procedures;
- 991 ft, which is the elevation of RWY 27 THR

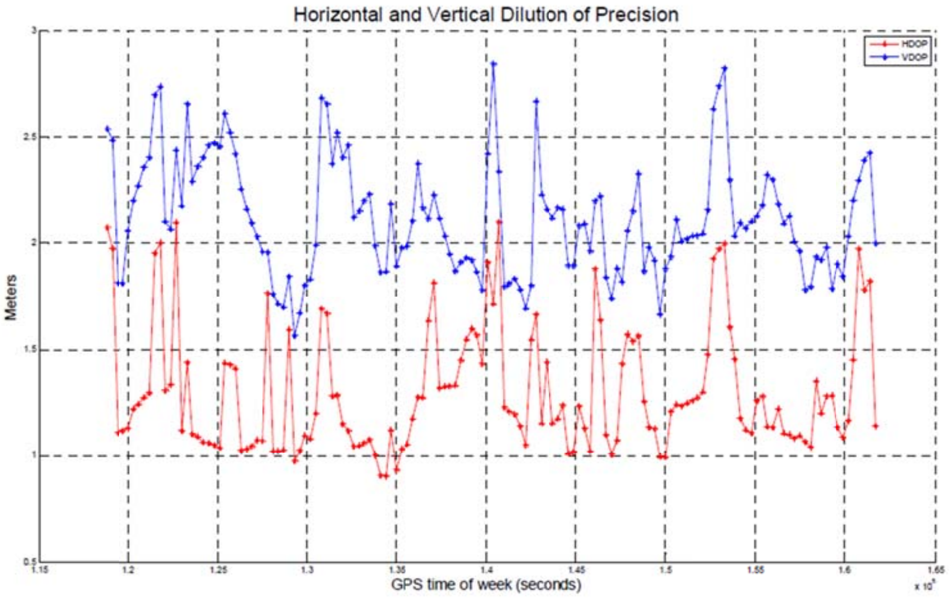


Fig. 4. DOP for Katowice ARP

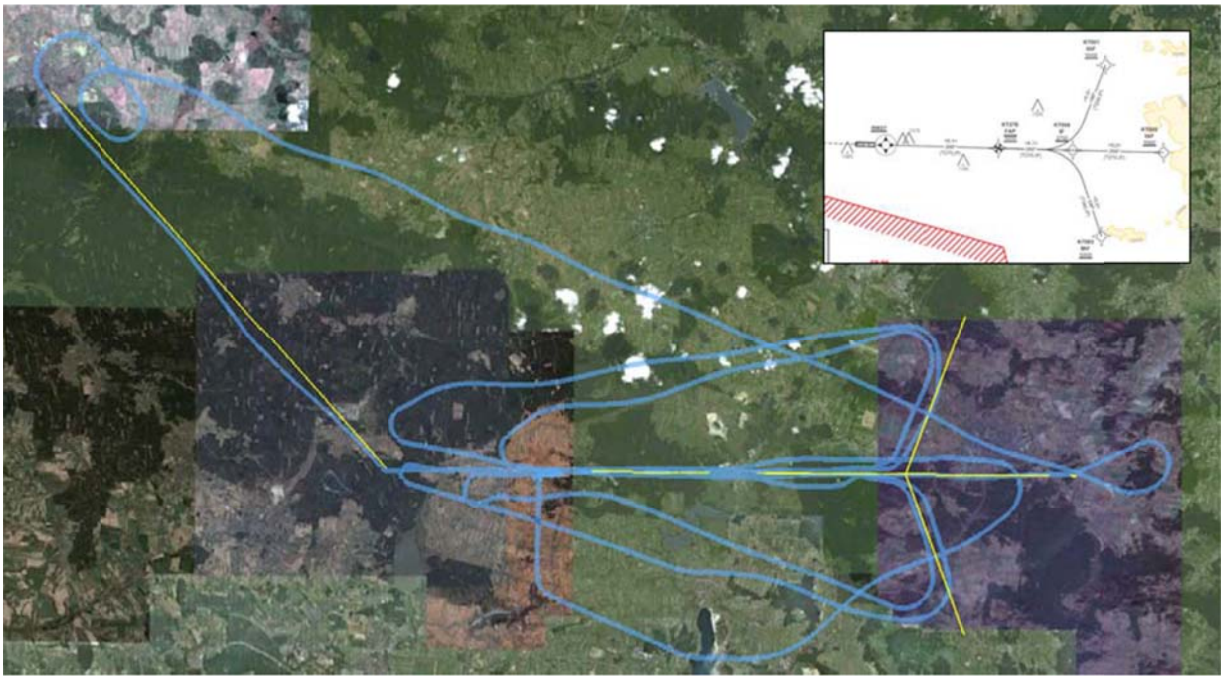


Fig. 5. Plan view of the flight demonstrations

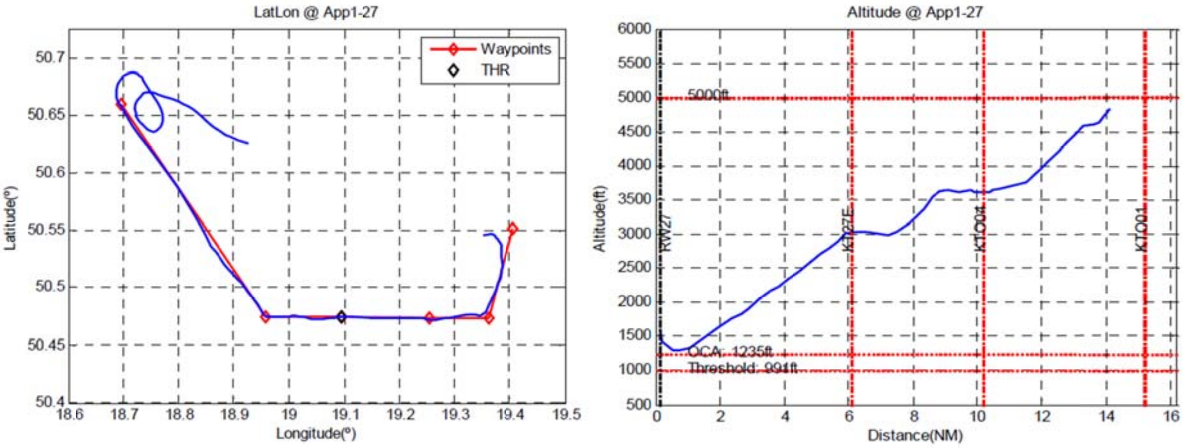


Fig. 6. Approach 1: plan view of A/C flight path (left), A/C altitude profile (right)

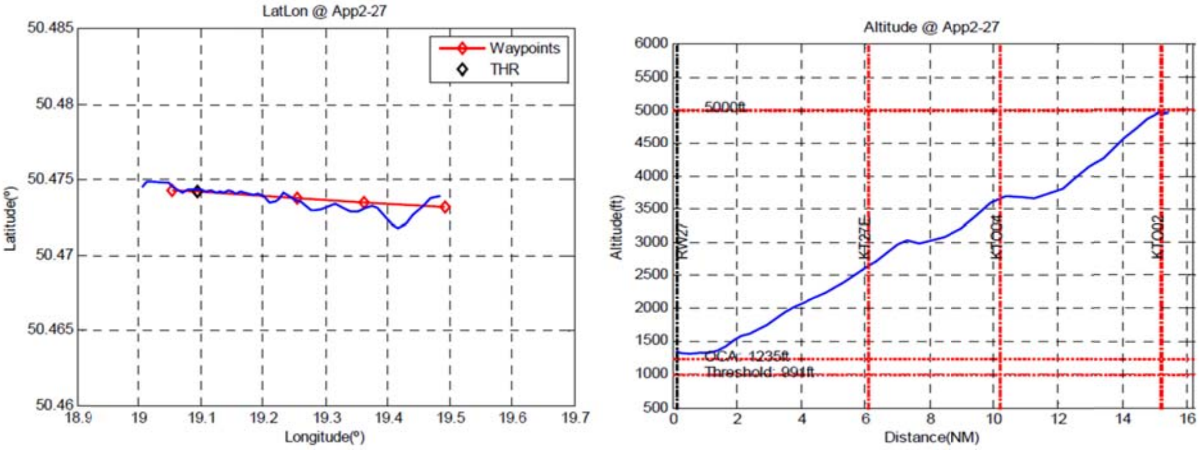


Fig.7. Approach 2: plan view of A/C flight path (left), A/C altitude profile (right)

A question about flight deviations is essential. To have a clearer picture of the deviations presented to the pilot during the approaches, the horizontal and vertical deviations have been computed with respect to the desired flight path. The results are presented in the figure 8. The distances in the vertical axis represent the horizontal or vertical Flight Technical Error (FTE) in meters. The FTE is provided as guidance information to the pilot during the flight, while the NSE and TSE can only be determined using truth reference after post-processing the data. Figures located in the left show the deviations of the a/c during the intermediate and final approach segments, while the figures located in the right side offer a zoom of the deviations during the FAS. The FSD (Full Scale Deflection) of the CDI/VDI is also plotted in the figures (cyan color) when contained in the figure limits, both in the horizontal and the vertical domain. These curves indicate the value of the deviations that the aircraft would have had with respect to the approach path if the CDI/VDI needles had been totally deflected. The curves have been calculated using in-house developed tools, in accordance to MOPS RTCA DO-229D [8]. As can be seen, the FSDs are not constant, and they change between linear and angular along the approach, following the requirements laid down in the MOPS.

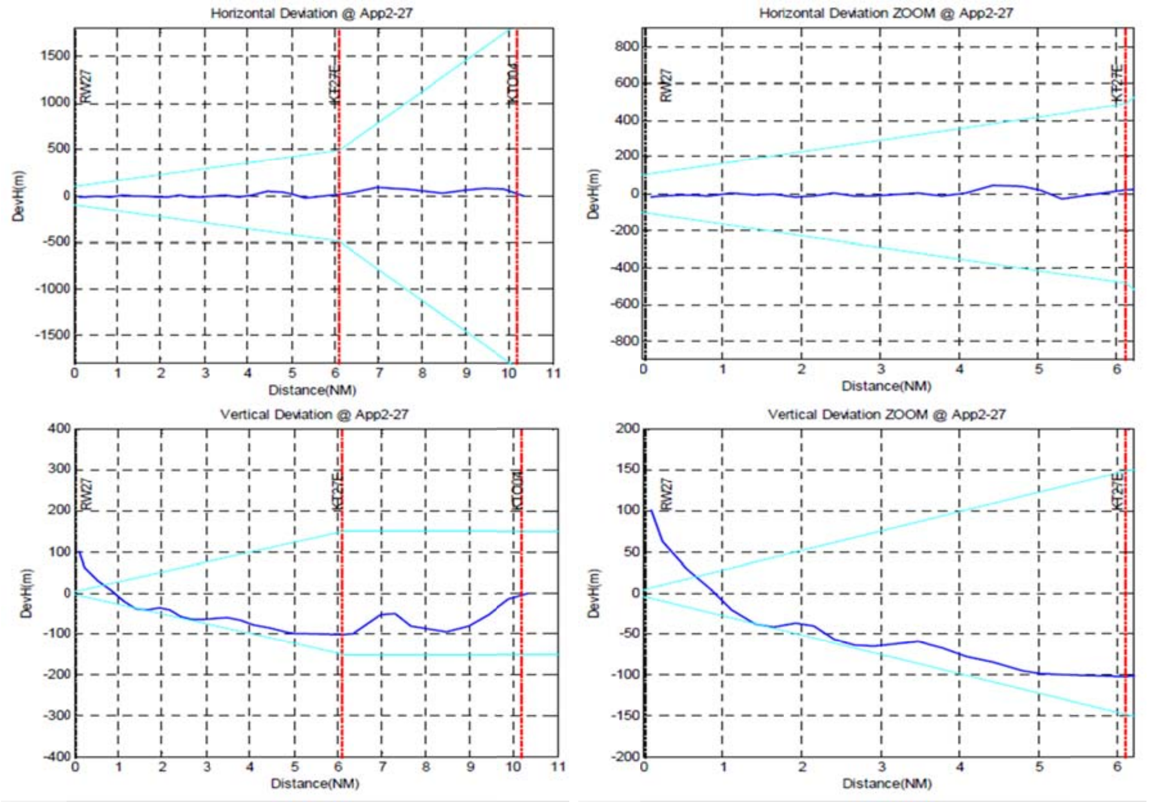


Fig. 8. Approach 2: horizontal and vertical deviations

4. Conclusions

The LPV flight procedures for Katowice provide tangible operational benefits for the airport operators in case of ILS inactive. The EGNOS system was capable of providing excellent aircraft guidance, appreciated by the pilots. The main outcomes of the validation of the new GNSS procedure are as follows:

- The EGNOS availability performance APV-I was fully achieved during all the approaches;
- The coding of the procedure for SBAS is satisfactory;
- The horizontal and vertical sensibility of the CDI was successfully tested;
- The procedure is safe from the obstacle clearance point of view (it has been flown ½ scale down the nominal glide path without identifying potential obstacles);
- No significant obstacles were found when overflying the surroundings of the airport either;
- The flyability of the procedure was correct.

The ground and flight validation performed are successful. As a result of conducted research, in April 2013 was placed twenty one of procedures for airports in AIP POLAND.

References

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[3] EASA - Helicopters Deploy GNSS in Europe (HEDGE) project documentation,

[4] EGNOS Introduction in European Eastern Region MIELEC project documentation,

[5] FAA - AC 20-129: Airworthiness Approval for Vertical Navigation (VNAV) Systems for Use in the U.S. National Airspace System (NAS) and Alaska;

[6] FAA - AC 20-105: Approval Guidance for RNP Operations and Barometric Vertical Navigation in the U.S. National Airspace System;

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[8] FAA - TSO C146A: Stand-Alone Airborne Navigation Equipment Using the Global Positioning System Augmented by the Wide Area Augmentation System (WAAS);

[9] ICAO Annex 10,

[10] ICAO Doc 8168 – PANS-OPS,

[11] ICAO Doc 9613 – PBN Manual,

[12] ICAO Doc 9905 – RNP AR Procedure Design Manual

Acronyms and Abbreviations

A/C - Aircraft
AD - Aerodrome or Airport
AGL- Above Ground Level
AIP - Aeronautical Information Publication
APV - Approach with Vertical guidance
ARP - Aerodrome Reference Point
CDI - Course Display Indicator
CRC - Cyclic Redundancy Check
DA/DH - Decision Altitud/ decision Height
DF - Direct to Fix
DOP - Dilution of Precision
DTM - Digital Terrain Model
EGNOS - European Geostationary Navigation Overlay System
EPKT - ICAO code for Katowice International airport
ESSP - European Satellite Service Provider
FAP - Final Approach Fix
FAS - Final Approach Segment
FPAP - Flight Path Alignment Point
FSD - Full Scale Deflection
FTE - Flight Technical Error
FVP - Flight Validation Pilot
GNSS - Global Navigation Satellite System
GPS - Global Positioning System
IAF - Initial Approach Fix
ICAO - International Civil Aviation Organisation
ID - Identifier
IF - Intermediate Fix (Initial Fix for Path terminators)
IFP - Instrument Flight Procedure
IFR - Instrumental Flight Rules
ILS - Instrumental Landing System
LNAV/VNAV - Lateral/Vertical Navigation
LPV - Localizer Performance with Vertical guidance
LTP - Landing Threshold Point
MA - Missed Approach
MOPS - Minimum Operational Performance Specifications
NM - Nautical Miles
NPA - Non Precision Approach
OCA/H - Obstacle Clearance Altitude/ Height
PANSA - Polish Air Navigation Services Agency
RAIM Receiver Autonomous Integrity Monitoring
RNAV - Area Navigation
RWY - Runway
SBAS - Satellite Based Augmentation System
SIS - Signal in space
TCH - Threshold Crossing Height
TF - Track to Fix
THR - Threshold
VDI - Vertical Display Indicator

VFR - Visual Flight Rules
VMC - Visual Meteorological Conditions
WAAS - Wide Area Augmentation System
WGS - World Geodesic System
WP – Waypoint
LOC - Localiser (azimuth guidance portion of ILS)
MDA - Minimum Decision Altitude
MDH - Minimum Decision Height
LNAV - Lateral Navigation
VNAV - Vertical Navigation
NSE - Navigation System Error
RTCA - Requirements and Technical Concepts for Aviation
TEN-T - Trans-European Networks - Transport
TSE - Total System Error

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