SBAS Flight Trials in European Eastern countries where EGNOS is still not available

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BIOGRAPHY

Jesús Cegarra has a MSc in Aeronautical Engineering from the Polytechnic University of Madrid. He finished his degree at Imperial College in London. He has an experience of more than 10 years in space control operations and aeronautical systems engineering. He currently works in the GNSS department of GMV and he is involved in EGNOS user segment applications. He acted as the coordinator of the EEGS2 project.

Javier Escartin received the MSc degree in Aerospace Engineering from the Polytechnic University of Valencia in 2011, carrying out his Final Master’s Project at the City University London. He has worked as a project engineer at GMV Aerospace and Defence since 2011 in the fields of GNSS Aeronautical Systems and Air Traffic Management systems research and development.

Javier Ostolaza finished the Master in Space Technology at Polytechnic University of Madrid in 2012. He got his MSc. degree in Telecommunications Engineering in 2007 at University of Cantabria. He has been working at GMV within the GNSS Business Unit, since 2008, where along these years he has got an extensive experience in GNSS demonstrators such as magicSBAS and SPEED contributing to their real-time and communication algorithms and integrating the emerging network of NTRIP stations to magicSBAS. He has also collaborated in the adaptation of the magicSBAS algorithms to cover different service areas (South America, South Africa, Australia and New Zealand, Korea) adapting also some GMV performance analysis tools such as teresa, magicGEMINI and eclayr.

Marta Krywanis has a MSc in Geodesy and Satellite Navigation by the University of Warmia and Mazury. She has been working in satellite navigation for more than 5 five years. She started working in the Polish Space Research Centre coordinating EGNOS and Galileo activities. Currently she works in the European GNSS Agency as Market Innovation Officer. She is the technical officer of the EEGS2 project.

Hans de With did his studies in the Catholic University of Leuven in Commercial Engineering. He did also a Master in Business Administration by INSEAD. He has more than 15 year of experience. He worked as Project Officer for FP7 projects including leading evaluation and selection of proposals in the European GNSS Agency. Currently he works as GNSS expert and strategy consultant. He is the reviewer of the EEGS2 project.

ABSTRACT

Taking into account the widespread availability of aRea NAVigation (RNAV) capabilities onboard the aircraft and in particular the increasing use of GNSS systems, navigation is moving from conventional towards RNAV. RNAV is a method of navigation which permits aircraft operations on any desired flight path within the coverage of referenced navigation aids, prescribed limits of self-contained aids or within a combination of both. The RNAV method covers not just en route and terminal area but also approach, where RNP approach procedures are described by a series of waypoints, legs and altitude constraints stored in the onboard navigation database. Initially, RNAV procedures were used for en-route and terminal area navigation and for non-precision approaches, using lateral guidance only. Nowadays, with the availability of SBAS integrity services, GNSS provides alternative and more precise navigation means flying RNP approach procedures (APV SBAS to LPV minima).

On the 2nd of March 2011 the EGNOS Safety-of-Life Service (SoL) was officially declared operational for aviation. Now, there are more than 40 APV SBAS procedures published in almost 40 airports in France, Switzerland, Germany, Italy and the Bailiwick of Guernsey. Also, by the end of 2011, the use of EGNOS for flying existing RNP approach procedures in Germany (82 APV Baro procedures in 38 airports) was approved meaning that they could be flown with EGNOS (for the vertical guidance too). EGNOS-based approach procedures implementation is now ramping up in Europe, with more than 100 APV SBAS procedures planned to be published along 2013.
However, EGNOS service is still not available all over Europe. One of the main objectives of the EEGS2 [2] project (EGNOS Extension to Eastern Europe: Applications) funded by the 7th Framework Programme of the European Commission (FP7/2007-2013) under the grant agreement number 287179 and reviewed by the European GNSS Agency (GSA) is to demonstrate through flight trials the benefits of EGNOS in areas of Eastern Europe where EGNOS is not yet available and prepare the civil aviation authorities and navigation service providers of those areas for the future usage of EGNOS. Not only through the flight trials will the countries where EGNOS has not yet coverage familiarize with EGNOS procedures but also pilots will be able to really understand and feel the EGNOS performances and advantages.

These flight trials will contribute to the adoption of SBAS systems in countries where the EGNOS signal is not yet available. The International Civil Aviation Organization (ICAO), in its Assembly meeting (36th Assembly meeting on 18th – 28th September 2007) strongly recommended the implementation of LPV approach procedures, for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016, with intermediate milestones of 30% by 2010 and 70% by 2014.

For that purpose a system in order to conduct those flight trials has been developed. This system has been designed to be a plug and play device. It is composed of two different sub-systems. The first one, on ground, is capable of broadcasting the magicSBAS [3] signal in the airfield and the surrounding area, and the second one, located onboard, which consists of an easily transportable rack plus a wirelessly operated tablet providing guidance to the pilot. This onboard system only needs a GPS antenna as the system works autonomously with rechargeable batteries.

**magicSBAS** is a state-of-the-art operational SBAS testbed developed by GMV to offer non-safety critical SBAS augmentation to any interested region. The algorithms implemented in **magicSBAS** have been fully developed by GMV and are the result of more than 15 years of experience in the development of EGNOS and other SBAS programs. The **magicSBAS** algorithms, originally designed to mimic EGNOS performances over the ECAC service area, have been further optimized and tuned to provide the best performances in other regions of the world (South America, South Africa, Russian Federation, etc.) and to extend EGNOS performances to Eastern and Southern Europe.

On ground, a mobile base station receives the **magicSBAS** EGNOS-like signal through an internet connection, which is then broadcasted by a radio modem transmitter in a free UHF band.

The signal is received onboard the aircraft through the radio modem receiver installed in the rack. Then, the GPS signal and the **magicSBAS** EGNOS-like signal are transmitted to the tablet device via Wi-Fi. The tablet contains an application SW including real-time data processing and graphical plots for monitoring and providing guidance to the pilot through a CDI/VDI display.

The benefits and main features of the application are:

- A Plug and Play Modular System which allows easy transportation, configuration and installation both on ground and onboard.
- The possibility of flying any LPV procedures defined in the airfield in places where a SBAS signal is not available. Vertical Guidance to the pilot via a CDI/VDI through a touch screen tablet device located in the cockpit without cabling.
- Power supply autonomy since the systems onboard work with rechargeable batteries;
- Real-Time, Standalone & Autonomous data processing.
- Processing of GPS + **magicSBAS** or any available SBAS signal.
- Easy comparison of **magicSBAS** and SBAS performances.

This paper will present the architecture of the system, the preparation of the flights trials and the results obtained during the different flights throughout Europe.

**INTRODUCTION**

The International Civil Aviation Organization (ICAO), in its Assembly meeting (36th Assembly meeting on 18th – 28th September 2007) strongly recommended the implementation of LPV approach procedures, for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016, with intermediate milestones of 30% by 2010 and 70% by 2014.

In Europe those recommendations are driven by the ATM Master Plan and the SESAR programme. In this context Eurocontrol has the mandate to develop a draft interoperability implementing rule on performance based navigation that will define navigation requirements and identify the functionalities required in en-route and terminal airspace, including arrival, departure, and also approach.

Apart from this mandate other initiatives are needed at European level in other to implement the PBN concept. Those initiatives cover better understanding of PBN and RNP APCH, global approval of GPS usage, ICAO provisions, guidance for implementation and the supporting groups like the ICAO PBN Task Force and the Eurocontrol RAISG. Also there are some implementation projects funded by Eurocontrol, EC and GSA.
In line with those initiatives the EEGS2 project has been focused in demonstrating and showing in the Eastern Countries of Europe the following issues:

- The performances of an SBAS system from the point of view of the aeronautical users.
- The steps that the ANSP has to follow in order to design, approve and certify an LPV procedure.

The following paragraphs will review the status of EGNOS in the Eastern European countries, the LPV procedures and the work done in the scope of this project in order to conduct the flight trials.

**LPV PROCEDURES**

Localizer performance with vertical guidance (LPV) are the highest precision GPS (EGNOS/WAAS enabled) aviation instrument approach procedures. Those procedures provide horizontal and vertical guidance with SBAS to the pilot to LPV minima. This height depends on the obstacles during the approach which can be up to 250 feet. The main advantage from the point of view of the ANSP is that it is not required any navaid in the airport and from the point of view of the pilot the procedure does not depend on the temperature as it happens with APV Baro procedures.

In USA more than 3000 LPV procedures have been designed and approved and in Europe there are 63 procedures implemented and 374 planned. It is expected to have 393 implemented by the end of 2016.

**EGNOS IN EASTERN EUROPEAN COUNTRIES**

The coverage of the EGNOS signal in the European Eastern Countries is improving but still is not enough for the implementation of LPV procedures. The figure below presents the availability of APV I procedures in Europe during June 2013.

![Figure 1- EGNOS Availability in June 2013 (courtesy of the ESSP)](image)

The figure shows that the availability of EGNOS does not reach some countries in the Eastern part of Europe. During the first phase of the project [1] it was demonstrated that by using *magicSBAS* tool with one additional station located in East-Ukraine and some improvements in the ionospheric algorithms the Eastern and Southern Countries of Europe would have enough availability as can be observed in the following figure:

![Figure 2 - magicSBAS improved availability](image)

**FLIGHT TRIALS**

The idea of the flight trials was to use the signal generated by *magicSBAS* in order to conduct the trials. This signal currently covers all the eastern European countries and allows us to use an EGNOS-like signal in the target area.

For that purpose it was proposed to send that message in the surroundings of the airport via radiofrequency link. The message would be read at the airport through internet and sent via radiofrequency signal through a radio modem. There was also the possibility of reading the message via 3G, but this option was discarded from the beginning as the 3G coverage is not good at altitudes higher than 500 meters. However this option, as it will be shown, demonstrated to be a good choice in some particular flights.

**SYSTEM ARCHITECTURE**

In order to perform the flight trials the architecture showed in the figure below was proposed. This system is called *magicLPV* [5].
The main drivers of this architecture were the following:

- Easy installation inside the aircraft avoiding recertification issues. For this reason the GPS and the radiofrequency antennas were installed inside the cabin.

- Avoid cables in the cockpit. For this purpose the Wi-Fi option was selected. The tablet can also be installed with a support attached to the window.

- Electrically autonomous. The rack has its own battery; therefore it is not necessary to connect the equipment to the electrical system of the aircraft.

As it can be observed in the figure above, the system can be divided in two parts, the on-ground and airborne segments both communicated by a radio link. The system on ground broadcasts the $\text{magicSBAS}$ messages which are received onboard and processed.

The $\text{magicSBAS}$ server, located at GMV premises in Madrid, generates the SBAS correction messages based on the information available from GPS satellites and EGNOS ground station’s network covering the Eastern part of Europe. In the airfield, a ground base station establishes a connection to the $\text{magicSBAS}$ server and broadcasts the messages through the transmitter radio modem. This signal is received by the onboard radio modem simultaneously with the GPS signal obtained by the GPS/GNSS receiver. Both signals, $\text{magicSBAS}$ messages and GPS, are then processed by the onboard software.

The overall architecture of the system allows several configuration alternatives, some of which have been used throughout the project. For instance, if there is good 3G internet connectivity, the $\text{magicSBAS}$ messages could be received directly from the servers in the tablet onboard and the system can work without radio link. It is also possible to use directly the EGNOS signal, instead $\text{magicSBAS}$ signal, in those countries where the signal is available.

**SYSTEM ONBOARD**

The $\text{magicLPV}$ system is composed of a rack box and a tablet PC.

The rack box, which is electrically autonomous, is composed of the following equipment:

- Ublox EVK-6T receiver.
- Radio Modem Microhard Systems IPn920 869 MHz.
- Wireless Access Point
- HP tablet PC

The rack also has two external antennas; one for the radio modem and one for the GPS receiver. Its compact design allows great flexibility in the installation and, depending on the aircraft, the rack can be installed in the cockpit or in the rear cabin.

Although it is not included in the onboard system, in all the trials GNSS L1/L2 receivers have been used to compute precise reference trajectories for post-processing analysis purposes.
ONGROUND BASE STATION

The magicLPV system on ground is composed of a base station including a client/server computer, an emitter radio modem plus the associated antenna and an internet connection. With this base station it is possible to broadcast the magicSBAS messages along the airfield.

![Figure 6 – Airfield installation schema](image)

TESTING PHASE

All the components of the system have been carefully tested before the flight campaign. The testing activities were divided in two phases. During the first phase, called static phase, all the components were tested separately, in the second phase the components were tested as a part of the whole system. The first phase was devoted to test the navigation software, radio communications, GPS performances and wireless communications. Finally the whole system was tested statically, with GPS and radio antennas in GMV offices. In the second phase the whole system was dynamically tested throughout road and flight trials. Coverage of the radio link and GPS performances were fully tested during this phase. The next paragraphs presents briefly the main tests performed.

Static software tests

The software tools used during the project were extensively tested and their performances thoroughly validated. A validation campaign was carried out at GMV premises installing the GPS antenna on the roof of the building. Those tests covered correct reception and decoding of SBAS correction messages, GPS messages and computation of navigation performances such a Position, Velocity, GPS geometry or Protection Levels.

Static components test

Tests were done to evaluate the correct operation of the individual equipment that compounds the magicLPV system. Specifically, the radio modems were carefully tested to ensure the proper communication through the radio link, which was considered one of the system’s critical point.

Static system tests

The magicLPV system developed and all the possible configurations were statically tested and the performances were carefully checked and analyzed. Also long duration tests were performed in order to check the robustness of the system. Those tests covered the following:

- Reception of SBAS correction messages from magicSBAS through radio link.
- Reception of correction messages from magicSBAS through 3G internet connection.
- Reception of SBAS correction messages from EGNOS through GEO satellites.
- Operation of the system during 24 hours.

Dynamic system tests, Road Trials

Once the software tools, components and systems were tested, a dynamic test campaign was carried out to study the performances of the overall system with dynamic scenarios.

Those system tests were basically focused on:

- Analysis of performances with 3G connection in a car.
- Analysis of the radio link coverage.

For the tests of the radio link configuration, the magicLPV system was installed in a car and the base station on the roof of GMV premises. The car was moving around the GMV building to check the coverage of the signal.

![Figure 7 – Road Trials](image)

Dynamic system tests, Flight Trials

As part of the test campaign in Spain, several flight trials were performed to test the magicLPV system. Those trials were focused on testing the following aspects:

- Navigation Performances
- Radio link performances and coverage
- 3G performance and coverage
- LPV guidance to the pilot
The main lessons learnt during this phase were the following:

- The radio frequency antenna should be attached to the radio modem since the usage of cables significantly mitigates the signal.
- It is fundamental to have always line of sight in order to receive the radio frequency signal correctly.
- The antenna should be at 3-5 m from ground to avoid the ground effect.
- The procedures were able to be flown and the pilot was able to do some approaches in a non-instrumental airfield.

FLIGHT TESTS IN EASTERN EUROPEAN COUNTRIES

During the second quarter of 2013 a flight test campaign covering Moldova, Poland, Romania and Ukraine was carried out.

The main motivation of the flight trials was, as explained, the demonstration of the SBAS performances and capabilities. For that purpose in some cases the flights consisted in flight data collection to be later post processed, like in the Moldavian flights, and in other cases those capabilities were demonstrated providing guidance to the pilot during the final approach. For this purpose for the flights in Romania, Ukraine and Poland the ILS procedures were firstly uploaded in the Tablet PC and an ILS look-like guidance was provided to the pilot. The picture below shows the guidance provided during the Ukrainian flight.

Below are presented chronologically the trials performed.

Moldova, April 2013

A total of 12 flight trials were performed among the main four Moldovan airports: Chişinău, Mărculeşti, Bălţi and Cahul. The radio link solution was selected in all the flights and the aircraft used was an R-40F Festival ultra-light aircraft.

Several trajectories were flown in each airport, testing the coverage of the radio link and the performances of the overall system, emphasizing the tests on the final approach segment where the system provides guidance based on the SBAS solution with ILS look-alike procedures. During each flight test, several final approaches were performed by means of touch-and-go maneuvers.

Romania, May 2013

A total of 3 flight trials were carried out in Romania, all of them in the International Airport of “Delta Dunarii” in Tulcea. The aircraft used was a Hawker Beechcraft C90GTx King Air.

Three system configurations were tested:

- Using the radio link solution.
• Receiving the message through 3G internet connection on-board.
• Using the EGNOS geostationary satellites.

It has to be highlighted that the Tulcea Airport is equipped with ILS system in the runway end RWY-34 which allowed the pilots to follow the instrumental procedures based on ILS while the magicLPV system provided LPV guidance based on SBAS corrections in parallel.

As in all the flight test campaign, the trials were focused on the final approach procedures, flying successive touch-and-go manoeuvres.

**Figure 11 – Installation and Configuration of the system in Romania**

**Ukraine, June 2013**

The flight trials in Ukraine consisted on two flights performed in the Kharkov North Airport with the XA.3-30 ultra-light aircraft.

The 3G solution was used throughout the trials as it was not allowed to transmit radio-frequency signals in the surroundings of the airport according to Ukrainian laws. The performances of the system were very good, providing guidance based on magicSBAS during the several approaches flown.

**Poland, June 2013**

A total of 5 flight trials were carried out during the Polish test campaign. These trials were carried out in Dęblin Military Air Base. The tests were performed using different configurations, with magicSBAS and EGNOS messages. When using the radio link solution the flights were focused on the final approaches in Dęblin Airport.

Two of the flights were performed based on EGNOS signal, and in order to test the availability of the system in the easternmost part of Poland, routes were flown from Dęblin to locations close to the Belarusian and Ukrainian borders respectively.

**RESULTS**

The results of the flights can be divided in two different aspects: on one hand the performances showed by the SBAS system in the post processing analysis and on the other hand the capability of providing horizontal and vertical guidance in real time during the final approaches performed.

This section will be focused on the flights conducted in Moldova, Ukraine and Poland. The flights in Moldova and Ukraine are very interesting flights as EGNOS has not full coverage in those areas and all the flights were carried out with magicSBAS signal. The polish flight will show the capability of the system of providing guidance during the approaches and differences with the ILS guidance.

**Moldovan Results**

As it has been previously explained, 12 flight trials were carried out in Moldova. All the flights used the radio frequency solution with the magicSBAS message. For each flight the position of the radio antenna was precisely selected in order to have line of sight with the aircraft during the whole flight. The aircraft selected for the flights was an ultra-light aircraft that flew around 300 m height. That made that the coverage and reception of signal during all the flights was very good. The following figure shows the aircraft used for the flights.
The rack was installed behind the pilot with the radio antenna close to the window in order to optimize the reception of the radio signal. Also an L1/L2 Trimble receiver was mounted on-board for precise trajectory computation and analysis of the errors in flight. The figures below show the installation of the radio antenna in one of the airports and the rack inside the aircraft.

Figure 13 – R-40F Festival Aircraft

Cahul

The airport of Cahul is located in the South of Moldova, next to the Romanian border and not far from the Black Sea.

Figure 14 – Installation of the radio antenna and the rack in the aircraft

Detailed results of two flights are presented and then a summary of the flights in Moldova.

Figure 15 – Cahul in Moldova and Trajectory flown

Four flights were undertaken during the 23rd of April 2013. The following figures show the results of the flight.

Figure 16 – PL coverage with altitude

Four approaches to the airport were done. The figure shows the coverage of Protection Levels during the approaches. The blue line means that Protection Levels were available during the flight. As it can be observed there was whole coverage during 3 out of four approaches.
The figures above show the evolution of Dilution of Precision and Protection Levels through the flight trial. Note that the Protection Levels were the ones computed on-board using the magicSBAS signal transmitted by radio frequency signals during the flight.

As it is shown in the figures the navigation error is very noisy and even in a couple of points the error is higher than the protection level. This issue, that could be considered an integrity error, is in fact a navigation error due the position of the antennas inside the aircraft. That position inside the aircraft made that visibility of satellites and the reception of the signal was worse than expected. The type of antenna used for the trials was similar to the one used for road applications, that made also that the quality of the data was not the best one for aircraft navigation.
Despite the position and the type of antenna, the navigation errors show a good accuracy with mean of 1.6 m and standard deviation of 1.17 m for horizontal error and mean of 2.6 m and standard deviation of 2.04 m for vertical error.

Finally the Stanford diagram shows two points were errors are higher than Protection Levels and also some points where the horizontal Protection Levels are higher than the alarm limit for an LPV approach.

**Balti**

The airport of Balti is located in the north of Moldova. This flight was very interesting because the radio antenna was installed at Balti airport but the aircraft took off from Marculesti airport 30 km far from Balti.
Four approaches were flown for that flight trial. The plot shows that there was full coverage of Protection Levels during the flight over Balti airport. As the flight took off from an airport 30 km far from Balti, the radio link with good coverage was established once the aircraft approached to the Balti airport.

The pictures above show the evolution of Dilution of Precision and Protection Levels during the flight. The plots show a typical evolution of DOP and PL except some peaks when the radio signal is lost. Those peaks are navigation errors due to behaviour of the algorithms when the signal is lost.

Those figures show the evolution of the vertical and horizontal errors in the whole flight. Precise trajectory were computed with PPP algorithms \textit{(magicPPP)} obtaining less than 10 cm of error in the trajectory.

As it is shown in the figures the navigation error is again very noisy and there are some epochs where the navigation error is higher than the Protection Levels. In this case this is also due to the type of the antenna and its position within the aircraft but also to the errors described with the loss of signal when the aircraft is flying back to Marculesti airport.
The navigation errors show again a good accuracy with a mean of 2.93 m and standard deviation of 1.88 m for horizontal error and a mean of 4.10 m and standard deviation of 4.40 m for vertical error.

Finally the Stanford diagram shows some epochs where errors are higher than protection level. The Protection Levels are always below the Alarm Limit with full availability for LPV procedures.

In summary, the results of the flights done in Moldova are shown in the table below.

### Table 1 Results of the Moldovan Flight trials

<table>
<thead>
<tr>
<th>Flight Name</th>
<th>HPL HPE&gt; HPL</th>
<th>HPE&gt; HPL (%)</th>
<th>VPL VPE&gt; VPL</th>
<th>VPE&gt; VPL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balti</td>
<td>1038 3</td>
<td>0.29</td>
<td>1038 4</td>
<td>0.39</td>
</tr>
<tr>
<td>Balti</td>
<td>1047 10</td>
<td>0.96</td>
<td>1047 4</td>
<td>0.38</td>
</tr>
<tr>
<td>Cahul</td>
<td>1481 2</td>
<td>0.14</td>
<td>1481 2</td>
<td>0.14</td>
</tr>
<tr>
<td>Cahul</td>
<td>1074 20</td>
<td>1.86</td>
<td>1074 15</td>
<td>1.40</td>
</tr>
<tr>
<td>Cahul</td>
<td>1083 1</td>
<td>0.09</td>
<td>1083 43</td>
<td>3.97</td>
</tr>
<tr>
<td>Cahul</td>
<td>596 2</td>
<td>0.34</td>
<td>596 3</td>
<td>0.50</td>
</tr>
<tr>
<td>Chisinau</td>
<td>1897 7</td>
<td>0.37</td>
<td>1897 9</td>
<td>0.47</td>
</tr>
<tr>
<td>Chisinau</td>
<td>1526 14</td>
<td>0.92</td>
<td>1526 60</td>
<td>3.93</td>
</tr>
<tr>
<td>Chisinau</td>
<td>3876 87</td>
<td>2.24</td>
<td>3876 206</td>
<td>5.31</td>
</tr>
<tr>
<td>Chisinau</td>
<td>2189 50</td>
<td>2.28</td>
<td>2189 269</td>
<td>12.29</td>
</tr>
<tr>
<td>All Flights</td>
<td>15807 196</td>
<td>1.24</td>
<td>15807 615</td>
<td>3.89</td>
</tr>
</tbody>
</table>

The table above shows the number of computed PLs for each flight and the number of navigation errors higher than protection level. As it is shown in few epochs the navigation error is higher than the protection level, due to, as explained before, the location and type of antenna. In total more than 7 hour of data in flight were recorded.
Table 2 Results of the Moldovan Flight trials

<table>
<thead>
<tr>
<th>Flight Name</th>
<th>Mean HNE (m)</th>
<th>Std HNE (m)</th>
<th>Mean VNE (m)</th>
<th>Std VNE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balti</td>
<td>2.93</td>
<td>1.88</td>
<td>4.10</td>
<td>4.40</td>
</tr>
<tr>
<td>Balti</td>
<td>3.37</td>
<td>1.99</td>
<td>2.48</td>
<td>3.08</td>
</tr>
<tr>
<td>Cahul</td>
<td>1.58</td>
<td>1.17</td>
<td>2.60</td>
<td>2.04</td>
</tr>
<tr>
<td>Cahul</td>
<td>1.65</td>
<td>1.62</td>
<td>2.46</td>
<td>2.29</td>
</tr>
<tr>
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<td>3.59</td>
<td>2.86</td>
</tr>
<tr>
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<td>Chisinau</td>
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<td>AllFlights</td>
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<td>2.47</td>
<td>4.01</td>
<td>4.56</td>
</tr>
</tbody>
</table>

The table above presents the mean horizontal and vertical errors and their standard deviations. As it can be observed the mean and the standard deviation for the horizontal error are less than 2.5 m. For the vertical error the mean is 4 m while the standard deviation is 4.6 m.

**Ukrainian Results**

The flight performed in Ukraine took place in Kharkov, next to the Russian border. The main differences with the flights in Moldova were the following ones:

- The GPS antenna used for the flight trials was installed outside the aircraft.
- The radio frequency option was not used as it was not allowed by Ukrainian laws; therefore 3G link was used for the reading of the magicSBAS messages.
- The tablet was installed in the cabin to provide guidance to the pilot.

The aircraft selected for the flight was an Ukrainian ultralight called XA3-30 which can be observed in the figure below:

![Figure 35 – Aircraft XA3-30](image)

The following figures show how the installation of the tablet, GPS antenna and equipment was carried out in the aircraft.

![Figure 36 – Installation of the equipment](image)

Two flight trials were performed. The first one was performed in order to check that all the systems were working properly. The second one consisted of five approaches to the runway where the pilot followed the guidance provided by the system. Previously, the ILS procedure associated to the runway end was loaded in the tablet. Therefore the pilot was following part of the ILS procedure using GPS + magicSBAS signal.
The flight was conducted during the 5th of June 2013. As it shown in the vertical profile there was coverage of Protection Levels during the whole flight trial. The 3G internet coverage was very good as the area was very populated and the aircraft was flying very low, around 75 m height from the airport.
Those figures show the evolution of the vertical and horizontal errors in the whole flight trial. Precise trajectory was computed with PPP algorithms (*magicPPP*) obtaining less than 10 cm of error in the trajectory.

As it is shown in the figures the navigation errors are always below the Protection Levels and much lower than the ones obtained during the Moldovan flight trials. Even, it can be observed a clear improvement in the accuracy when the corrections start to be applied by the receiver. The main reasons of those good performances are on one hand the antenna outside the aircraft and on the other hand the type of antenna, which was a geodetic Novatel antenna.

The navigation errors in this flight show excellent navigation error performances with a mean value of 1 m for horizontal and 1.2 m for vertical accuracy with standard deviations of 0.5 m and 1.7 m for the horizontal and vertical components respectively.
The Stanford diagrams also show very good performances with all the errors below the Protection Levels and full availability of the service for the LPV procedure.

**Polish Results**

The flights done in Poland took place in the Polish Air Force Academy in Dęblin, 100 Km far from Warsaw.

Five different flights were performed during three days. The most interesting flight that is going to be analysed in this section was the final one where the pilots did four approaches, three with ILS and the final one with SBAS. The picture below shows the tablet inside the cabin of Cessna.

The ILS procedure was previously loaded. The picture below shows the vertical profile and the horizontal profile of the procedure and the flight with ILS and SBAS.
The pictures show a similar behaviour with the horizontal profile as both systems provide a similar guidance in the horizontal plane. However in the vertical plane the ILS flight is always above the procedure around 40 m. The results in terms of errors of those flights were the following:

Table 3 Flight Technical Errors in Polish Flights

<table>
<thead>
<tr>
<th></th>
<th>Mean HTE (m)</th>
<th>Std HTE (m)</th>
<th>Mean VTE (m)</th>
<th>Std VTE (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILS</td>
<td>24.1</td>
<td>7.8</td>
<td>40.8</td>
<td>8.2</td>
</tr>
<tr>
<td>SBAS</td>
<td>13.5</td>
<td>9.1</td>
<td>13.8</td>
<td>7.5</td>
</tr>
</tbody>
</table>

In order to finalise this section it has to be mentioned that the pilots flew the procedures along the trial phases in Spain, Ukraine and Poland. In all the cases they were very satisfied with the guidance provided by the software and they realised that the procedure was in fact very similar to the one provided by the ILS.

CONCLUSIONS

In the scope of the EEGS2 project the magicLPV system has been developed. This system allows flying LPV procedures using the magicSBAS signal; therefore LPV procedures can be flown in areas where SBAS is not available (considering there is a network of ground stations to deliver GNSS data to be used as inputs in magicSBAS).

For this system the radio frequency link in the surroundings of the airport is used. The main drivers during the development of the system have been:

- Easy installation in the aircraft avoiding recertification issues. For that reason the GPS antenna and the radiofrequency antenna were normally installed inside the cabin.
- Avoid cables in the cockpit. For this reason the Wi-Fi option was selected. The tablet can be easily installed with a support attached to the window.
- Electrical autonomy. The rack has its own battery; therefore it is not necessary to connect the equipment to the electrical system of the aircraft.

During the first test phase it was concluded that the radio antennas should be attached to the radio modem as long cables considerably mitigate the signal. It is also fundamental to have line of sight between both radio modems, the one on ground and the one onboard, during the flights.

With the flights conducted in Eastern European countries the main lessons learnt were:

- The GPS antennas outside the aircraft provide a much better navigation solution.
- Radio antennas outside the aircraft also provide better coverage. In case of pressurized aircrafts, like the Beechcraft aircraft used in the Romanian trials the reception of signal is very poor.
- Also the reception of signal at high altitudes is not very good when the aircraft is flying higher than 1000 ft and the antennas are inside.

If the system is to be installed in a pressurized aircraft, antennas must be installed outside the aircraft, therefore recertification is needed and maybe a more powerful radio modem should be used for the trials. Also the transmission of the message could be done through satellite link providing in that case full coverage of the signal and more stability to the solution.

As a general conclusion, magicLPV is currently capable of providing LPV guidance with magicSBAS signal and very good navigation performances when an ultra-light aircraft is used and the altitude is lower than 1000 ft. With EGNOS signal the system works at every altitude.

Therefore magicLPV together with magicSBAS is a very powerful platform to demonstrate the performances of an SBAS system in places where SBAS is still not available or is not providing the expected performances.

ACKNOWLEDGEMENTS

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### ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ANSP</td>
<td>Air Navigation Service Provider</td>
</tr>
<tr>
<td>APCH</td>
<td>Approach</td>
</tr>
<tr>
<td>APV</td>
<td>Approach with Vertical Guidance</td>
</tr>
<tr>
<td>APV Baro</td>
<td>Vertically guided RNAV approach with VNAV functionality using barometric inputs. RNAV approach supported by satellite based augmentation systems to provide lateral and vertical guidance. The lateral guidance is equivalent to an ILS localizer and the vertical guidance is provided against a geometrical path.</td>
</tr>
<tr>
<td>APV SBAS</td>
<td>RNAV approach supported by satellite based augmentation systems to provide lateral and vertical guidance.</td>
</tr>
<tr>
<td>CDI/VDI</td>
<td>Course Deviation Indicator/Vertical Deviation Indicator</td>
</tr>
<tr>
<td>DOP</td>
<td>Dilution of Precision</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
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<td>EEGS2</td>
<td>EGNOS Extension to Eastern Europe</td>
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<td>EGNOS</td>
<td>European Geostationary Navigation Overlay Service</td>
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<td>FP7</td>
<td>Seventh Framework Programme</td>
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<td>GNSS</td>
<td>Global Navigation Satellite Systems</td>
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<td>GPS</td>
<td>Global Positioning System</td>
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<td>GSA</td>
<td>European GNSS Agency</td>
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<tr>
<td>HPE</td>
<td>Horizontal Positioning Error</td>
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<td>HPL</td>
<td>Horizontal Protection Level</td>
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<tr>
<td>ICAO</td>
<td>International Civil Aviation Organization</td>
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<tr>
<td>ILS</td>
<td>Instrumental Landing System</td>
</tr>
<tr>
<td>L1/L2</td>
<td>GPS Frequency Bands</td>
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<tr>
<td>LPV</td>
<td>Localizer Performance with Vertical Guidance</td>
</tr>
<tr>
<td>PBN</td>
<td>Performance Based Navigation</td>
</tr>
<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>PL</td>
<td>Protection Level</td>
</tr>
<tr>
<td>PPP</td>
<td>Precise Point Positioning</td>
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<tr>
<td>RAISG</td>
<td>RNAV Approach Implementation Support Group</td>
</tr>
<tr>
<td>RNAV</td>
<td>Area Navigation</td>
</tr>
<tr>
<td>RNP</td>
<td>Required Navigation Performance</td>
</tr>
<tr>
<td>SBAS</td>
<td>Satellite Based Augmentation System</td>
</tr>
<tr>
<td>SISNet</td>
<td>Signal In Space through internet</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
</tr>
<tr>
<td>VPE</td>
<td>Vertical Positioning Error</td>
</tr>
<tr>
<td>VPL</td>
<td>Vertical Protection Level</td>
</tr>
<tr>
<td>WAAS</td>
<td>Wide Area Augmentation System</td>
</tr>
</tbody>
</table>

### REFERENCES

[2] EGNOS Extension to Eastern Europe EEGS project website: [www.eegs-project.eu](http://www.eegs-project.eu)
EEGS2 project website: [www.eegs2-project.eu](http://www.eegs2-project.eu)