Flight Inspecting Ground Based Augmentation Systems (GBAS)

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ABSTRACT

The civil air traffic has increased tremendously during the last decade and a break of this steady rise is not foreseeable. The capacities on the main hubs are exhausted due to geographic restraints or through separation minima caused by the instrument landing procedures. The discrepancy between the escalating traffic and the limitations at the airports initiates the search for other applicable navigation systems.

Ground based augmentation systems are one of those newer navigation systems, which should help the global traffic solving those conflicts. Nearly all new multimode receivers installed in the cockpits of the commercial air transport have the capability to perform A/C's GBAS approaches. Those navigation devices are certified and the standards are almost set. The ground segment for GBAS is still "on the way". Till this day no ground station is fully operational and certified for commercial air transport. Several ground systems are installed in the United States, some are installed elsewhere. Those ground systems have been flight inspected with sophisticated flight inspection systems with GBAS capability to show that the systems fulfill their dedicated specification.

This paper summarizes results and experiences regarding the flight inspection of ground based augmentation systems. Several trials have been flown either on test sides or at ground stations waiting on their approval to go into service. Is there a necessity to upgrade the current flight inspection systems for GBAS? Is GBAS a real alternative against the well known instrument landing systems?

INTRODUCTION

GBAS flight trails have been performed in the past on several airports on which different GBAS ground station were installed. All of those ground stations were prototypes and revisions of those. No GBAS ground stations has been commissioned so far. The first unit shall be commissioned according to the announcement in 2009. This long developing phase has certainly more than just one reason; but defining the rules to flight inspecting these ground stations, defining the procedures to flight inspect them and developing the body structure of flight inspection systems for GBAS inspection are some of those reasons.

This paper elucidate some trails in Europe during the last two years, displays their highlights and summarizes their findings. These trials of course were performed on research bases with an experimental aircraft which is not one by one comparable to commercial flights with a suitable equipped flight inspection aircraft. The requirements for flight inspection systems in the future for GBAS calibration are explained and explored. Examples from flight inspection systems, which are capable to perform those inspections, are shown .

GBAS ACTIVITIES AT TU BRAUNSCHWEIG

The Institute of Flight Guidance (IFF) of the TU Braunschweig operates two research aircraft for testing, measuring, and surveying purposes. One of them is a DORNIER DO 128-6 (see figure 1), which is equipped with a variety navigation systems (HONEYWELL LASERNAV, several GPS receivers, etc.) and has air data sensors mounted on a nose boom (standard) and at wing tip stations (optional).

The aircraft features sophisticated measuring and recording systems that can be utilized for a vast range of research projects. The crew comprises two pilots, a flight engineer and a maximum of two test system engineers for the respective payload. It has been used for numerous measuring campaigns in the last 15 years.

Figure 1: Research Aircraft of the TU Braunschweig

The Rockwell Collins MMR GLU-925-330 (owned by EUROCONTROL and currently under tests at the Institute of Flight Guidance) supports the use of the ILS and GBAS guidance systems. This equipment has been installed into the research aircraft and connected via an ARINC429 interface to the onboard data gathering and recording system. During the flight trials the respective ARINC labels have been decoded (for flight guidance and monitoring of proper work of the MMR) and recorded (for detailed offline data evaluation).

For the flight trials an additional ILS / LOC-antenna has been installed. With this additional antenna it is possible to receive the VDB data of a GBAS ground station without getting into problems with the standard ILS installation and certification of the aircraft. Furthermore an experimental display has been installed (see figure 3). With this display the experimental pilot is able to follow the deviations generated by the MMR.

Figure 2. Cockpit of Research Aircraft with experimental CDTI

Data evaluation

For data evaluation the navigation system error (NSE) had been calculated. This is the difference between the actual flight path and the navigation system output. The NSE is calculated in the three directions “North”, “East” and “Down”. Then the total NSE gets calculated with the root-sum-square. Further errors of interest are the Flight Technical Error (FTE), which is the difference between the desired flight path and the path of the navigation system, and the Total System Error (TSE), that is the addition of those two errors.

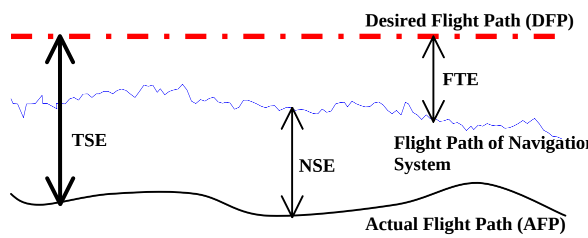

Figure 3. Error profiles

For a better understanding and easier interpretation they will often be transformed into the cross track (to the left and to the right of the flight track), along track (not of very much interest) and vertical (up and down direction, tilted with the glide path angle) direction.

An important step to calculate the NSE is the determination of the Actual Flight Path. The TU Braunschweig has used own GPS reference receivers (NovAtel OEM3 and OEMV) on ground of the airport, where flight trials took place. These GPS reference receivers have been used in conjunction with the two onboard receivers and COTS GPS surveying software to process reference tracks. Aboard the aircraft the standard GPS receiver is also a NovAtel Millennium OEM3, which has been run for redundancy purposes, whereas the receiver designated to be used has been an OEM4 linked to the same antenna the MMR uses. The antenna for the OEM3, however, is placed 57 cm beside the other antenna. The reference station has been surveyed by using a SAPOS generated Virtual Reference Station so that its position can be assumed to be well known. To evaluate the quality of the phase solutions both reference tracks have been processed and the solutions for each time slice have been compared so that the slant range between the antennae has been calculated. For a flight on January, 23rd 2006 this can be seen on Figure 4. Ideally this should be a straight line at about 57 cm, which it obviously is not.

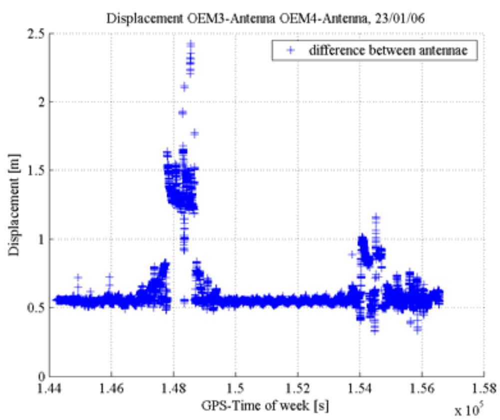

Figure 4: Slant range between GPS antennae, Jan. 23rd

The differences can be explained by the fact that the OEM4 uses more satellites than the OEM3 and that during manoeuvres satellites are shaded, thus altering the constellation and so the ambiguity search has to be re-initialised. This example demonstrates the importance of a well known and reliable truth reference track.

Flight Trials

Like mentioned before several flight trials had been performed using the research aircraft of the Institute of Flight Guidance. During these flight trial campaign, different locations with different GBAS ground station installations had been covered.

Table 1: locations of flight trials

Airport	GBAS Ground Station
Egelsbach (near Frankfurt)	Honeywell SLS-3000 Beta LAAS
Toulouse-Blagnac	Thales ATM AS615
Bremen	Honeywell SLS-3000 Beta LAAS PSP
Braunschweig	NPPF Spectr LCCS-A-2000

With the recorded data extensive data assessments of the performed flight trials had been made. One example will be shown in this paper.

In September 2006 flight trials at Toulouse-Blagnac airport (south part of France) have been executed [2]. Previous flight trials at Egelsbach ([1], see Table 1) had some limitations due to the airspace structure of Frankfurt International. This made it impossible to fly at altitudes above 1.500 ft, which gave only a short final approach segment. At Toulouse it was possible to fly the complete approach out of 3.000 ft. DSNA, the French Air Navigation Service Provider, has installed at Toulouse Blagnac airport an experimental GBAS ground station that is currently used by Airbus for GLS certification on its fleet of aircraft. With the cooperative work of Air Traffic Controllers it was possible to fly visual right hand traffic pattern most of the time with final legs of 6 to 15 NM. Figure 5 shows the overall 48 approaches, flown on 3 consecutive days.

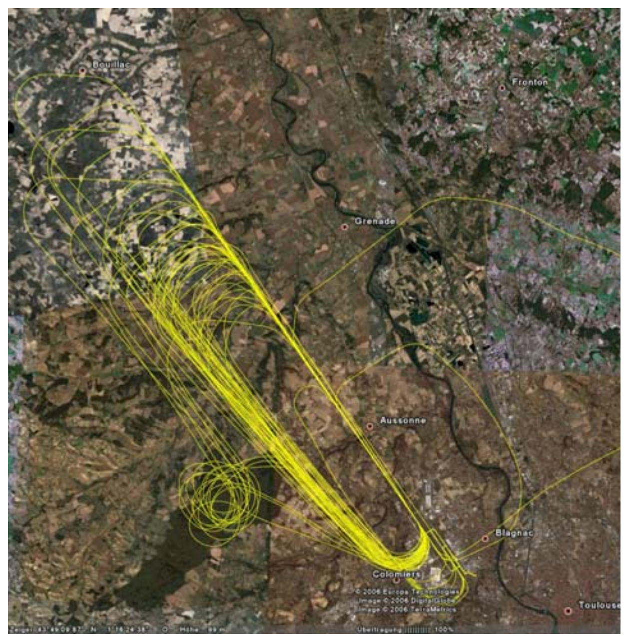

Figure 5. Flight Pattern, Toulouse

The circles in the south-west were holding circles due to other inbound traffic. During the trials one approach had been flown to the Runway 14L, the other 47 had been flown to runway 14R. The majority of the approaches had been flown with a centered localizer indication, with the exception of four approaches, where a constant deviation offset (i.e. angular offset) had been flown. Again like during the Egelsbach trials, from the pilots' point of view it was an easy to fly procedure with no visible differences to an ILS approach.

The evaluation of the recorded data has been done in the framework of GIFTaS, as mentioned before. As an example the calculated NSE of the approaches will be shown here.

Figure 6 and Figure 7 are showing the computed Navigation System Error in the vertical track direction. Figure 6 shows the NSE against the Distance to Threshold, i.e. the approaches started at approximately 18 km Distance to Threshold. There is no dependency of the NSE and the Distance visible. Figure 7 shows the Histogram of all chosen approaches. It can be seen that the NSE vertical track is always below the absolute of 2 metres.

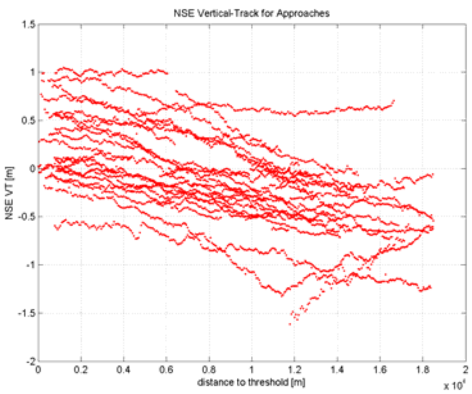

Figure 6. NSE vertical track versus distance to threshold

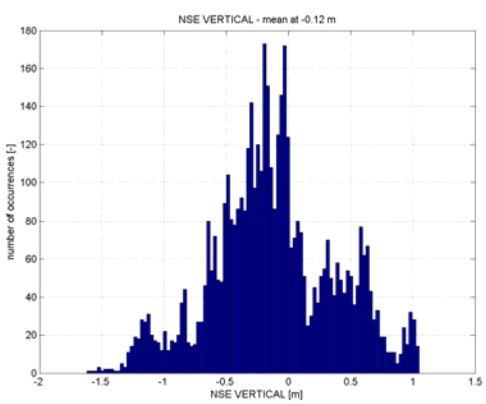

Figure 7 Histogram of NSE vertical track

The GIFTaS Toulouse report has not been published yet, as it is under review by EUROCONTROL. After the review process the report can be purchased via EUROCONTROL. Inside this report the complete evaluation of performance parameters (on-ground and airborne) can be found.

In May 2007 the IFF has performed the initial in-flight evaluation of the GBAS ground station located in Bremen. These flights have been performed under contract with DFS GmbH, the German Air Navigation Service Provider. The flight program of these flights can be found in Table 2.

Table 2. flight program according to ICAO Doc. 8071

Maneuver	Distance to Threshold or GBAS VDB antenna	Altitude
Arc (+/- 35° to both sides of the centerline)	15 NM	1.500 ft
Level run (Heading towards the Threshold)	21 NM until 2.5 NM	2.000 ft
	23 NM until 13 NM	10.000 ft
360° Orbit	23 NM	2.000 ft
Standard GLS approach Runway 09	n/a	Starting at 3.000 ft
Standard GLS approach Runway 27		

The program had been developed in accordance to the ICAO Doc. 8071, Vol. II. It had been flown twice on different days and different times to cover the influence of different constellations. The intention of the flight trials were to validate, that the VDB field strength inside the coverage volume is within the specified limits and that there are no interference issues through out the approach procedure (including the missed approach segment). An additional check had verified that the data contents of the VDB transmission are as expected and within the specified data rates. The limits of the field strength [4] and data update rate [4] can be found in Table 3.

Table 3. Limitations

Description	upper limit	lower limit
Field strength	111 dBµV/m (equal to 0,35 V/m)	46,6 dBµV/m (equal to 215 µV/m)
Message Type 1	For each measurement type: all measurement blocks once per slot (i.e. every 0.0625s)	For each measurement type: all measurement blocks once per frame (i.e. every 0.5s)
Message Type 2	Once per frame (i.e., every 0.5s)	Once per 20 consecutive frames (i.e., every 10s)
Message Type 4	All FAS blocks once per 20 consecutive frames (i.e. every 10s)	All FAS blocks once per frame (i.e. every 0.5s)

As an example of the results Figure 8 shows the measured field strength (in blue) of the Arc-Maneuver (+/-35° to both sides of the centerline at a Distance of 15 NM to the Thresholds). In red the lower limit of the field strength is displayed. Beneath some violations in the upper right quadrant, which had been caused by a shadowing effect during a procedure turn, the field strength is at all positions within the specified range.

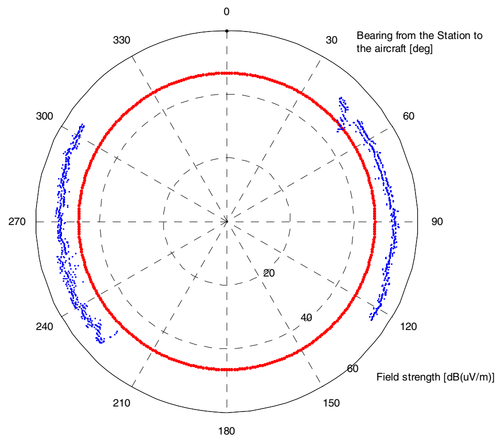

Figure 8. Field strength of +/-35°-Arc

In total it had been shown that the Bremen GBAS installation is working as expected.

Requirements of a Flight Inspection System for GBAS calibration

The research flight trails, the ICAO documentation and regulation and the experience from flight inspection systems already equipped with GBAS capability has constituted the requirements and recommendations for flight inspection mentioned in this paper.

From the flight trails previously completed, it has been found necessary that the flying pilot have a visualization of the GBAS signal. This is obtainable through a cockpit which is equipped with a modern multi mode receiver, which you will find in the avionic of nearly all new large aeroplanes. But unfortunately most flight inspection aircraft - also new ones - are equipped with neither such an avionic nor with such a multi mode receiver. Therefore either the avionic has to be upgraded or the flight inspection system has to be coupled to the cockpit displays to visualize the GBAS data. This can be achieved either through a separate display or through the EFIS itself interfaced to the flight inspection system. Otherwise the pilot is not able to follow the GBAS approach and to deliver its necessary impression of fly-ability. To obtain an accurate flight track and thus the desired positions for the measurement, a flight guidance on the EFIS or the separate display from the flight inspection system is recommended.

To assure the continuity of the GBAS signal the message types 1, 2, and 4 have to be decoded, analyzed, displayed, and recorded by the flight inspection system. The recording will prove the necessity of availability for the flight track during inspection. Interference of the VDB signal has to be investigated with a capable spectrum analyzer connected to a suitable antenna. This can be achieved with an automatic spectrum analyzer program, which displays and records the spectrum in parallel to the GBAS data. If interference is observed, this can be analyzed in detail during replay, or even in multiple replays from different approaches on this particular airfield. Therefore, it is very important that the GBAS data and the spectrum are recorded simultaneously in one common recording file. Otherwise an exact and detailed investigation in the office is difficult, due to the fact that the data has to be time synchronized.

The space segment of these approach techniques has to be checked during flight inspection as well. All satellites and their individual information especially their signal to noise ratio, has to be displayed and recorded to assure the mandatory availability. Interference from the ground should be examined with a downward looking GPS antenna or with another there for suitable antenna connected to the spectrum analyzer input. Airborne interference can be investigated with the GPS receiver in combination with the spectrum analyzer. The necessary synchronized recording of the GPS data and the spectrum data is applicable here as well.

Some effort has to be spent to confirm the correct coverage of the VDB signal according to the published tolerances. The field strength tolerances according to ICAO of 3dB are only achievable with a calibrated antenna and the compensation of the antenna characteristic by the flight inspection software.

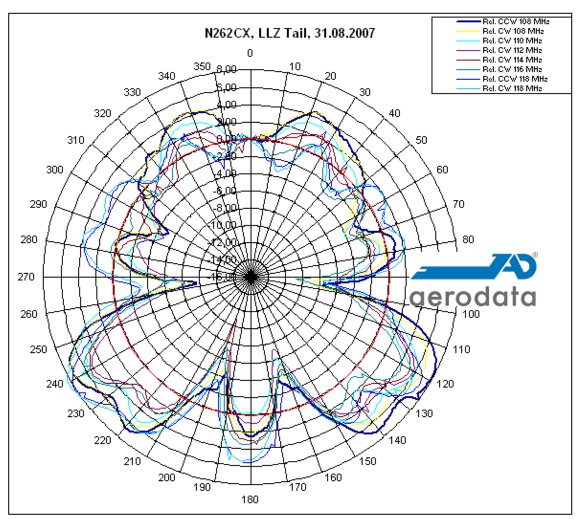

Figure 9. Antenna calibration diagram

The flight trails in the past detected that the measurements with GBAS receivers are not as accurate as with a spectrum analyzer. Therefore a connection of the spectrum analyzer to the GBAS antenna and the accurate measurement of the internal signal loss are recommended.

The flight inspection system of course has to be equipped with a GBAS device to receive and decode the message types of the GBAS data. The receiver has to be tuned to the appropriate function on the dedicated frequency of the ground station.

Examples of GBAS Flight Inspection Systems

The Telerad VDB receiver has been used in flight inspection systems for years and is well known in the flight inspection community. It is basically used to decode the dedicated message types. It also allows field strength measurements through it AGC output.

Figure 10. Telerad VDB Receiver

The Rockwell Collins MMR GLU 925/930 has been flying in some flight inspection systems since last year. Upgrades and new MMR's are being developed by the manufacturer. The uncertified 930 is a special version which provides additional useful AGC information.

Figure 11. Rockwell Collins GLU 930

A few systems have been equipped with the necessary GBAS hard- and software as mentioned above for a couple of years. A screenshot of the GBAS capable AeroFIS© software is shown below. Exemplarily, the alphanumeric page of the decoded message type 4 (FAS) is displayed. The used transmission of the VDB signal is originated from an experimental installation of a GBAS ground station at the Institute of Flight Guidance.

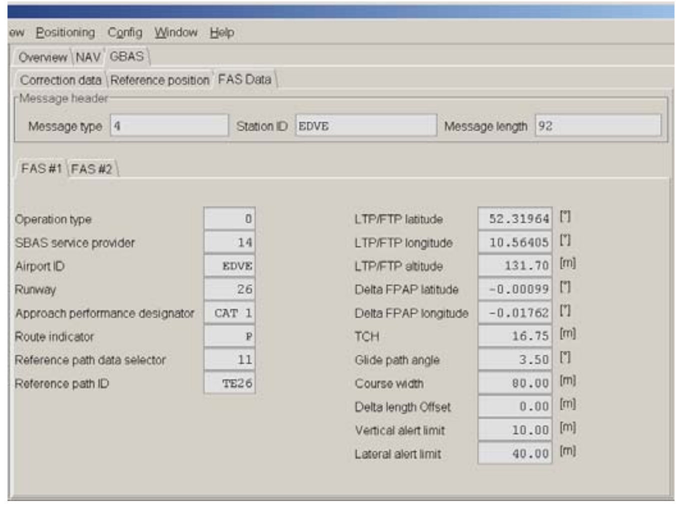

Figure 12. FAS Data Viewer in AeroFIS©

The calibration of GBAS ground stations with an AeroFIS© equipped aircraft is feasible and performable without additional enhancements.

CONCLUSIONS

GBAS is a suitable technique for performing ILS look-a-like approaches for the therefore equipped aircraft. The accuracies are on all trails according to their requirements although some anomalies have been found at certain prototype ground stations. Those were corrected on the newer revisions.

Flight inspection of GBAS ground stations can be performed with an aircraft which is equipped with a flight inspection system with the following implemented enhancements:

- GBAS receiver
- GBAS flight guidance in the cockpit by primary equipment or from the flight inspection system
- Suitable spectrum analyzer for GPS and VDB
- Calibrated VDB antenna system.

These mandatory main aspects have to be controlled and managed by a capable software, which has to be very sensitive regarding the parallel recording of these necessary signal data.

OUTLOOK

In general GBAS is indeed a good alternative to help the economy to lessen the increasing aircraft traffic. Its behavior is stable and easily flyable. Only one station can support an airport with several runways. But this system also has a disadvantage. The system is more vulnerable against RF jamming than ILS, because it consists of only one transmitter. In addition, and this is even more critical, the main navigation source (GNSS) is not controlled by the airport operator and is very sensitive against jamming. One single emitter can cause that the whole infrastructure is inoperative. Out of these drawbacks GBAS probably will not replace ILS in the near future. However, it may be growing to an alternative, on the background that the GNSS sector is increasing and due to the fact becoming more and more autonomous. An important step ahead into the “GBAS direction” will be the necessity to finalize the ground stations segment, and in parallel to this finalization the start of the development of the stand alone GBAS receiver for the avionic of business and smaller aircraft.

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