

[EN-005] GBAS CAT II/III concepts for flexible approach procedures (EIWAC 2010)

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Abstract: Satellite based Navigation Systems (Global Navigation Satellite System GNSS) will become a major element in the navigation infrastructure of the future. In addition to classical en-route and terminal navigation, where GNSS is increasingly used, approach and landing procedures are being developed and implemented based on GNSS. To meet the requirements of integrity, accuracy, continuity and availability for precision approach and landing operations, augmentation systems are needed. Currently there are two augmentation systems for these periods of flight available: Ground Based Augmentation Systems (GBAS) and Space Based Augmentation Systems (SBAS). This paper will focus on GBAS research projects conducted by the Technische Universität (TU) Braunschweig, Institute of Flight Guidance (IFF), and the German Aerospace Center (DLR) Braunschweig, Institute of Flight Guidance (FL). While TU Braunschweig is working mainly in the domain of navigation technology (both ground and airborne) DLR (namely Robert Geister) is concentrating on the procedure design and implementation of special approach procedures.

In December 2008 DLR has installed an experimental GBAS ground station, manufactured by Thales ATM GmbH. The station has a production-line software status but will not be used for operational approach procedures inbound Braunschweig airport. Therefore experimental procedures can be implemented easily.

Furthermore a Galileo Test Environment called “aviationGATE” is currently under development by TU Braunschweig, using a total of 9 ground located transmitters to cover an area of up to 5,500 square-kilometres. A concept has been designed which includes among others the implementation of an aircraft positioning module and an aviationGATE correction message uplink module. With the coverage area including the airport as well as the already implemented GPS and GBAS approaches this test bed will serve as an ideal environment for tests of GBAS CAT II/III dual constellation concepts. This paper will describe the setup of the GBAS research infrastructure at the Research Airport Braunschweig-Wolfsburg. Furthermore an initial set of GBAS approaches with different glide path angles will be discussed.

Keywords: GBAS CAT II/III, approach procedures, airborne augmentation

1. BIOGRAPHY

Thomas Feuerle received his Diploma (Dipl.-Ing.) in mechanical engineering in 1997. He joined the Institute of Flight Guidance (IFF) of the Technische Universität Braunschweig in May 1997 as a technical pilot of the research aircraft Dornier Do 128-6. He has been involved in the recent GBAS activities at the Institute. Besides the GBAS hardware installation and the adoption of the real-time software onboard the aircraft he flew most of the GBAS experimental approaches with the Dornier. He is also responsible for the GBAS data evaluations as well as for the development of GBAS software tools at the Institute. Since 2005 he is team leader of the ATM team at

the IFF. In April 2010 he finished his PhD-Thesis called “GPS- and Ionosphere Monitoring with Low-Cost GPS Receivers”.

Mark Bitter holds a Dipl.-Ing. in mechanical engineering and is employed as a research engineer at the Technische Universität Braunschweig, Institute of Flight Guidance since 2003. He is member of the flight metrology department and as flight test engineer of the research aircraft Dornier Do 128-6 he is responsible for hardware development, adaption, installation and operation of experimental equipment onboard the aircraft.

Prof. Peter Hecker joined the Institute of Flight Guidance of the German Aerospace Center DLR 1989 as research scientist. Initial focus of his scientific work was in the

field of automated situation assessment for flight guidance, where he was responsible for several research projects. From 2000 until 2005 Prof. Hecker was head of the DLR Department "Pilot Assistance". Since April 2005 he is director of the Institute of Flight Guidance of the Technische Universität Braunschweig. He is managing research activities in the areas of air/ground co-operative air traffic management, airborne measurement technologies and services, satellite navigation, human factors in aviation and safety in air transport systems.

Robert Geister graduated from the Technical University of Hamburg Harburg as a Dipl. Engineer in Computer Science Engineering in 2005. Since then he is employed in the Institute of Flight Guidance of the German Aerospace Centre in Braunschweig. He graduated from the National Test Pilot School's short course (Mojave, CA) as a flight test engineer in 2009. At the German Aerospace Centre he is currently working there in the areas of flight testing, software development, and operational procedures based on GBAS.

2. INTRODUCTION

In contrast to area navigation (RNAV) based on GNSS, precision approach and landing operations need additional augmentation to meet the requirements of integrity, accuracy, continuity and availability. Ground Based Augmentation Systems (GBAS) are designed to support precision approach operations at airports. They offer more flexibility than the well approved Instrument Landing System ILS as they can provide desired flight path information for approaches, landings, missed approaches and flight paths through the terminal area. The GBAS ground station receives the signal in space and determines the ranging source errors based on measurements from multiple ground reference receivers. These errors are broadcasted via VHF Data Broadcast (VDB) to the aircraft in the coverage area and used on-board for correcting the ranging sources. Additionally, the signal integrity is monitored and parameters are computed which are needed for the determination of the availability of the signal in space for a desired level of service. The VDB message link also includes information on the Final Approach Segment (FAS).

Ground Based Augmentation Systems that provide approaches equivalent to ILS CAT-I operations are almost certified for operational usage. Future GNSS Landing System (GLS) CAT-II/III operations have to meet more severe requirements of integrity, accuracy, continuity and availability. On ICAO level the requirements for these systems are currently under development.

The IFF has been conducting a lot of research on this topic and several ground and flight tests have been performed in the past. Ongoing activities are covering on-board

equipment as well as components for a GBAS ground station. One attempt that has been pursued to increase the performance of a GLS with respect to the high CAT-II/III requirements is to implement independent monitors and additional augmentation systems, one of them being an aircraft based augmentation utilizing an Inertial Reference System (IRS). The inertial part of an integrated system is able to assure the continuity of the GLS for a certain time span. In contrast to stand-alone GNSS navigation, the GBAS corrected pseudoranges have to be smoothed and cannot be used for the navigation solution immediately after acquisition. Thus, GBAS operations are relatively vulnerable to shadowing. Concerning integrity aspects, integration with inertial navigation using Aircraft Autonomous Integrity Monitoring (AAIM) can achieve a higher ability to detect GNSS faulty measurements which are caused on user level like rare ionospheric events and thus cannot be augmented by the GBAS ground station. Within the German UniTaS IV project, founded by the Federal Ministry of Economics and Technology (BMWi) and administered by the Agency of Astronautics of the DLR, an experimental on-board equipment has been developed and different levels of integration of GBAS and inertial navigation system with respect to accuracy, continuity in case of GNSS outage and on-board integrity monitoring have been evaluated.

Until now, the evaluation of the developed integrated GBAS/INS system and the on-board integrity monitoring has been based on artificial errors that were introduced on recorded flight trial data in post-processing. The introduction and use of a Galileo test environment that will be explained below will open up new possibilities for research under real-time conditions. It will enable various options to concretely manipulate signals emitted and test its impact on the whole system as well as it will serve as an ideal environment for tests of GBAS CAT II/III dual-constellation concepts.

A Galileo test bed called aviationGATE is being set up at the Braunschweig Research Airport to enable aviation related technologies to be developed and tested in a realistic scenario. The aviationGATE is being built by the IFF as part of the already mentioned project UniTaS IV. Measuring 5,500 square kilometers in extent and up to 100 kilometers across, aviationGATE is unique and enables aircraft to receive Galileo signals during their entire approach to Braunschweig Research Airport.

A total of nine dual frequency pseudolites (PSL) provide the complete test bed with signals. While five of the nine PSLs are located on the area of the airport, the remaining four PSLs are arranged on elevated positions with a distance of up to 70 km to the airport. This subdivision into an inner and an outer ring ensures that signals can be received in the entire area with a minimum coverage of five PSLs. The aviationGATE uses the E1 and E5 frequency bands with both messages (I-NAV, F-NAV) on

E5. Each signal can be adapted, changed to vary or freely define its navigation message, to change its synchronization in relation to GPS, to other PSLs or to the other signal emitted on the same PSL. In particular, there is the possibility to generate offsets between E1 and E5 as needed for test purposes. This can be done relying on the timing equipment used in each PSL, but also can be monitored by two reference stations at different positions. At the current state, the inner ring of the aviationGATE is fully operational, while the outer ring is not able to send synchronized signals, yet.

For the intended purpose as a test environment for dual-constellation GBAS concepts, the aviationGATE has to be further developed (see chapter 4). During GLONASS/GPS dual-constellation data gathering campaigns and interoperability trials performed 2007 [1] in Braunschweig and 2009 [2] in Moscow, different experiences have been gained and will be taken into account. Existing components of the ground segment as well as components of the user segment will be modified and extended. Firstly, ranging source errors of each PSL signal have to be determined and broadcasted. As the VDB data link of the GBAS ground station at the Braunschweig Research Airport cannot be adapted directly, a concept for transmission of the increase in correction data via VHF data link in relation to a single constellation will be necessary. Secondly, the experimental GBAS/INS on-board equipment will be extended to receive aviationGATE pseudorange and correction data. Also the GBAS/INS navigation algorithms and the calculation of the hybrid protection levels will be adapted.

The before mentioned interoperability trials have been initiated by EUROCONTROL due to the fact that the technical complexity of satellite-based systems is such that different interpretations of standards cannot be excluded. In principle, equipment interoperability is guaranteed by the development and validation of the ICAO SARPS and complemented by industry standards, such as RTCA and EUROCAE MOPS, ICD's and ARINC standards. These should be detected and clarified as quickly as possible.

2.1 Interoperability Trials Braunschweig

Testing the Russian GBAS system presented different challenges from those encountered previously. Both the Western European and the US systems are the fruit of a long development history based on a US initiative and have thus many shared requirements, including the use of EUROCAE and RTCA MOPS (Minimum Operational Performance Specifications). The Russian system covers the use not only of GPS, but also of GLONASS – which for GBAS is included in ICAO Annex 10, but not in the different MOPS. The design was started independently, using MOPS only where Annex 10 needed completion to define functionality.



Fig. 1: GBAS ground station and monitor installation

Fig. 1 provides an impression of the ground system installation of the LCCS-A-2000 station combined with an independent GBAS ground monitor (developed by the Institute of Flight Guidance, TU Braunschweig).

The first set of trials showed no ability to decode other system's signals. The investigation revealed that Annex 10 defines navigation data to be modulated "in a mathematically positive sense" onto the signal – a wording that was interpreted differently in Russia. In the MOPS, different, unambiguous wording had been used and as consequence an update to Annex 10 has been proposed and accepted to clarify the modulation.

Other results include the necessity to adapt processes of frequency coordination between European states, as the digital, timeslot based GBAS system allows several stations in close proximity (in this case Bremen and Braunschweig – Fig. 2) to transmit on the same frequency. This is possible, as each station will only use 2-3 of the 8 available timeslots and the standards foresee appropriate distinction mechanisms. In these times in Germany only one frequency was available for GBAS use. However, depending on topography, altitude and antenna installation, practical reception ranges are 200-250NM. The transmission areas of the three stations in Germany thus

show a clear overlap and ICAO has defined a 500NM coordination radius [1].

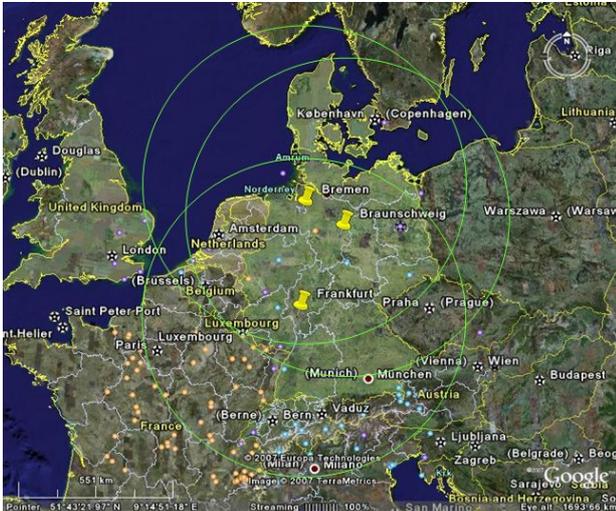


Fig. 2: Location of GBAS stations in Germany (note the 500 NM frequency coordination radius)

2.2 Moscow Trials

Based on the broad experience of GBAS related projects at TU Braunschweig a mobile measurement equipment setup had been developed. As it can be seen in Fig. 3 an adapter for the connection of a Rockwell-Collins Multi-Mode-Receiver to a laptop with ARINC PC Card had been worked out. With the laptop all online parameters of the Multi-Mode-Receiver (like channel number) can be changed. For the MMR specific hardwired configuration of parameters, a connector-integrated switch board had been implemented. With this special feature it is easy to operate with different versions of the MMR GLU 925, like the version -430 (Airbus) or -330 (Boeing). Additionally, a VDB receiver (manufactured by the French company Telerad) had been repackaged. The purpose of this rebuild was that all parts of the mobile GBAS measurement equipment will fit into one or maximum two small pieces of luggage which can be taken into the cabin of a commercial airliner. To assure the proper working of the Telerad VDB Receiver, cabling between the MMR and the receiver is also provided to support using a PPS (Pulse-Per-Second) input coming from the built-in GPS receiver of the MMR and synchronizing the timing of the VDB receiver.

The first measurement campaign with this portable measurement equipment took place in April 2009 in Moscow.

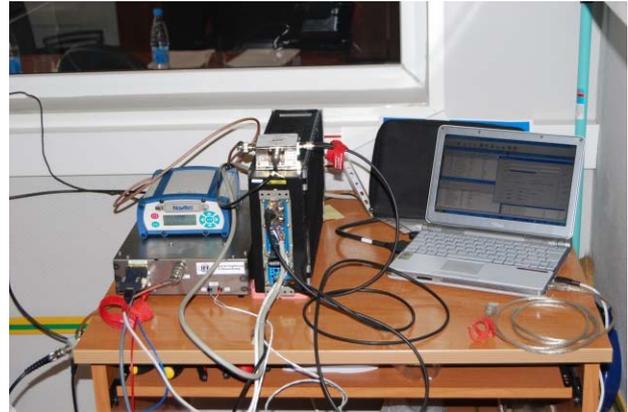


Fig. 3: Mobile GBAS test equipment

A detailed evaluation of the test can be found in [2].

The evaluation and the fact that the data was received by all systems tested without anomalies have shown that the technical standards are robust. The trials have also served to address operational aspects and open discussions took place with the many actors involved in operational use of such a multi-constellation system. The elements to be considered range from ownership and training considerations for operators of a fleet using mixed equipment, and for ground system operators to the necessity of validation of GPS and GLONASS performance and notably integrity separately during the procedure development process. Also addressed was the ATC impact of providing consistent service to a mixed fleet equipped without GBAS, with only GPS or with multi-constellation systems and the phraseology necessary to unambiguously describe the requested service.

The focus at the Institute of Flight Guidance has now been turned to more complex integrated systems and the validation of future modifications and extensions of GBAS standards, such as GAST-D and the future multi-constellation, multi-frequency GBAS system designs.

3. AIRBORNE EQUIPMENT

As part of the project UniTaS IV, a concept for an integrated GBAS/INS system has been developed that finally resulted in the realization of an experimental on-board system. Centerpiece of this system – next to the inertial measurement unit (IMU) – is the GBAS/INS integration unit designed by Funkwerk Avionics GmbH (see Fig. 4). It incorporates GNSS receiver, VDB receiver, GBAS computer and integration computer. The INS data is fed to the system externally via serial interface.



Fig. 4: GBAS/INS integration unit (Funkwerk Avionics)

The GNSS receiver provides pseudoranges and carrier phase measurements while the VDB receiver provides pseudorange- and range-rate corrections that the GBAS computer first decodes and then adapts to the smoothed pseudoranges. Afterwards, the integration computer applies the GBAS navigation algorithms on GBAS data and inertial data and calculates the hybrid protection levels for the integrity monitoring function.

A short introduction to the general principle of hybridization and integrity monitoring will be given in the following two chapters. More detailed information can be found in **Fehler! Verweisquelle konnte nicht gefunden werden.**

3.1 Hybridization

The hybridization of the GBAS with the inertial part is done within a full-state (or total-state) KALMAN Filter. This means that the position, velocity and attitude information is directly calculated by the filter instead of estimating the errors in position, velocity and attitude.

The state vector of the system contains position, velocity, attitude and heading as well as the estimation of the sensor bias, i.e. the accelerometer bias and the gyro bias, and in addition, the estimation of the receiver clock errors (e.g. by estimating the clock bias). The navigation solution is obtained by solving the navigation equations of the inertial part directly within the propagation step of the KALMAN Filter. Thereby, the differential equations for the attitude, the velocity and the position are solved. As it is depicted in Fig. 5, the inertial and the GNSS information are fed into the navigation filter. The inertial data can be optionally complemented by barometric data.

Within the measurement update step of the KALMAN Filter, the GBAS-corrected pseudoranges are used to aid the inertial part. For the smoothing of the pseudorange ρ^i the carrier phase measurement Φ^i is used as defined in [6]. According to GAST D requirements, two solutions are calculated with a smoothing time constant of 100 seconds and 30 seconds respectively.

If the pseudorange-corrections (PRC) and range-rate corrections (RRC) are valid, they are applied to the smoothed pseudoranges as well as satellite clock

correction, the time difference between the current time and the time of applicability of the corrections and tropospheric correction.

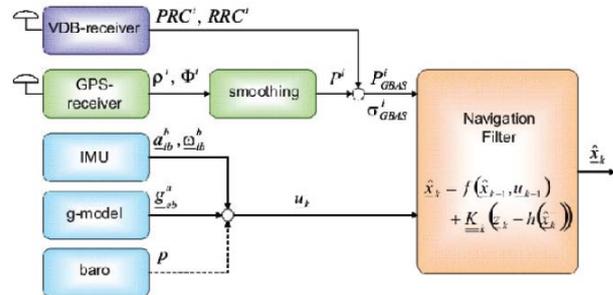


Fig. 5: Hybridization of GBAS with INS

During the update of the KALMAN Filter, the system state is corrected by the differences between the GBAS corrected pseudoranges and the estimated pseudoranges.

3.2 Integrity Monitoring

Beside the ability of coasting during temporary signal loss, inertial measurement units provide the augmentation of the differential corrected GNSS signal on user level. Locally disturbed ranging sources can either be excluded from the hybridized navigation solution or be accounted by the calculation of the protection levels [7].

The principle structure of the implemented integrity monitoring is depicted in Fig. 6. The basis for the fault detection and the fault exclusion functions is a mixture between the techniques proposed in [7] and [8].

The GNSS, INS and optionally the barometric data (Air Data Reference, ADR) are fed into the system. Depending on the service availability, the GNSS data can be either sole GPS or SBAS/GBAS corrected raw data. One main filter (MF) uses all (n) available GNSS ranging sources, while a bank of n-1 sub-filters (SF_i) is operated in parallel. Each sub-filter is excluding one ranging source. Fault detection is either performed by monitoring the main filter's residuals comparable to the method proposed in [8] or by monitoring the solution separations in the horizontal and vertical domain between the main filter and the sub-filters. If a fault is detected, the healthy subfilter – the one that is excluding the faulty ranging source – is used to reset the whole system. The fault-free protection levels are extracted from the main filter's error covariances. The missed-detection protection levels are derived from main filter and sub-filter characteristics. As for the sole GBAS protection levels, the maximum of either fault-free or missed-detection protection levels is taken for horizontal or vertical protection level information. Additional filter

banks are used for monitoring newly acquired ranging sources before they are used for navigation. Also, excluded ranging sources are further monitored in separated filter banks.

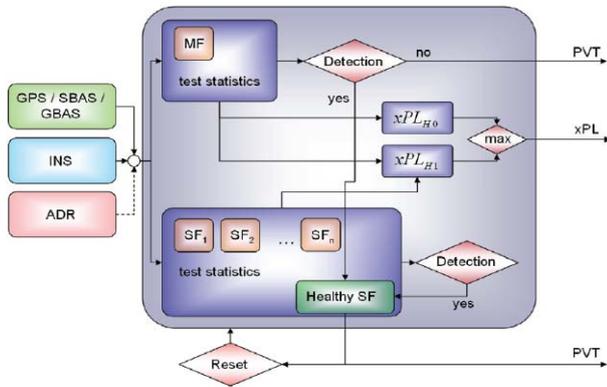


Fig. 6: Hybrid integrity monitoring

4. Expansion of aviationGATE Towards a Test Bed for Dual-Constellation GBAS Research

As mentioned before, the aviationGATE will be further developed to be used as an environment for dual-constellation GBAS research and research on GBAS system concepts (like GAST-D, for example). The main modification of the aviationGATE is the implementation of the GBAS component using the Galileo signals of the pseudolites. The basic idea to conduct dual-constellation research is to have one space-based constellation (GPS) combined with the aviationGATE constellation. The reason behind this is the hypothesis that all PSLs are able to send navigation signals. Ranging source errors can easily be inserted on any PSL signal which then has to be determined on board the approaching aircraft. Two different modes are planned:

1. a dedicated ranging source will be disturbed and the respecting error will be transmitted (i.e. detected) by the ground station to the approaching aircraft
2. a dedicated ranging source will be disturbed and the respecting error will not be transmitted (i.e. an undetected error on ground side)

With these two different modes on ground station side the airborne equipment can be tested whether it will apply the transmitted corrections in an adequate way or whether the on-board monitors (like the before mentioned hybrid integrity monitoring) are able to detect the inserted errors. So far, this testing had been done offline with error simulations fed into a navigation system. With the intended expansion, additional hardware-in-the-loop-tests are planned.

Furthermore, there are thoughts to use only the aviationGATE components to evaluate parts of currently discussed GAST-D concepts. In this approach, airborne monitor schemes, for example, can be evaluated when inserting errors on one of the ranging sources of the aviationGATE while the ground segment still transmits correction data as before.

A depiction of the layout principles of the dual-constellation test bed at the research airport of Braunschweig can be found in Fig. 7. The chosen approach consists of the ground and user segment, the aviationGATE PSLs and the GPS constellation. The aviationGATE PSLs will be controlled by the ground segment. In the control station of the aviationGATE pseudorange and range-rate corrections for the PSL signals will be generated. Another module will receive the GPS GBAS corrections, coming from the GBAS station at Braunschweig Research Airport. These GPS and aviationGATE corrections will be merged and uplinked via a special data link to the user segment on board of an aircraft. The approach of using not a conventional VDB data link has the drawback that no statement about the appropriateness for dual-constellation GBAS of a VDB as described in the standards can be made. But it gives us flexibility in terms of research and allowance of data transmission, because an already available telemetry will be used.

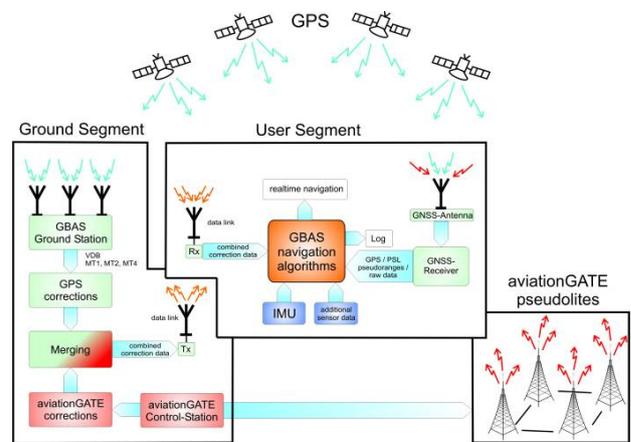


Fig. 7: System concept of a test bed for dual-constellation GBAS research

The user segment on board of an aircraft will receive three different kinds of data:

- GPS satellite signals
- aviationGATE pseudolite signals
- combined correction data

The received data blocks will be combined in the proprietary experimental GBAS software. Different integrity monitoring approaches are already implemented (see e.g. the hybrid integrity monitoring) which are

calculating a navigation solution as well as hybrid protection levels. Due to its modular composition additional concepts will follow.

5. APPROACH PROCEDURES

As the international air traffic becomes more and more complex (a growth of 2.3% from 2006 to 2007, 57% from 1997 to 2007 [11]) there is a growing demand for new operational procedures. Especially quiet and fuel efficient approaches are desired. GBAS provides more flexibility than current precision landing systems. Therefore, it is identified as a potential key technology for providing different approach procedures tailored for unique demands at a special location. Particularly steep precision approaches have a high noise reduction potential as the aircraft can stay at a higher altitude for a longer time. This effect is amplified by air vehicles capable of Short Take-Off and Landing (STOL) procedures.

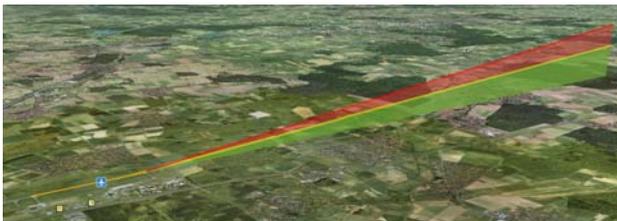


Fig. 8: 5.5° (red) and 3.5° (green) approach path inbound EDVE

During this work approach procedures based on GBAS with slightly higher glide path angles than usual (4.5° - 5.5° instead of 3° - 3.5°, see Fig. 8) were investigated. Therefore a simple software simulator of a MMR was created and integrated into a Generic Experimental Cockpit (GECO) simulator. The FAS data for an ILS look-alike approach (glide path angle 3.5°) and for approaches with steeper glide path angles were validated in this simulator. Pilots were familiarized with the new approaches in the simulator and some questionnaires were filled out regarding the workload and flight technical demands for the pilots.

After the GBAS Landing System (GLS) approaches were validated in the simulator the FAS data blocks were transferred into an actual ground installation at the research airport Braunschweig-Wolfsburg. The FAS data was checked with ground trials and some flight trials were conducted to verify the data gathered in the simulator trials.

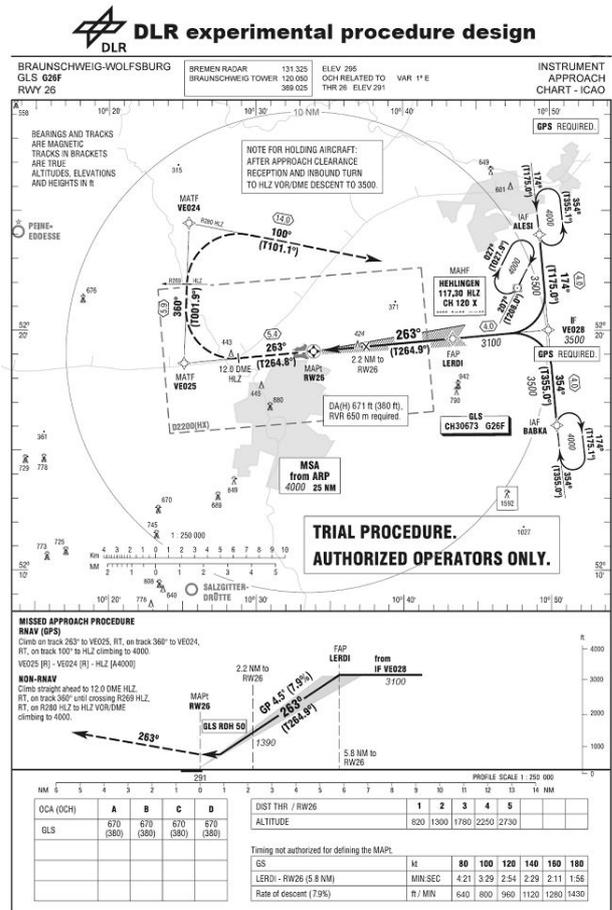


Fig. 9: GLS Approach Chart

Fig. 9 shows one of the approach charts designed for the airport Braunschweig-Wolfsburg. The approach chart is based on a published [9] GPS (RNAV) procedure for runway 26. The horizontal profile is exactly the same as in the case of an RNAV approach but the final approach is converted into a precision approach. Additionally, the vertical profile is adapted for each Glide Path Angle (GPA). All approaches (even though they have different GPA's) have a Threshold Crossing Height (TCH) of 50ft. This leads (due to the different GPA's and the unchanged position of the Final Approach Point (FAP)) to different intercept altitudes before the final descend. In the provided example the final approach starts at an altitude of 3,100ft Mean Sea Level (MSL). A GPA of 5.5° results in an intercept altitude of 3,700ft MSL accordingly.

In the upper left corner the Reference Path Identifier (RPID) is depicted. The simulator trials showed that it is practicable to integrate the runway number in the RPID. The first letter is always "G" to indicate a GLS approach. The fourth letter is a unique letter for each runway direction. The letters C, L, and R are omitted as it might lead to confusion if multiply runways for one landing

direction are present. In the middle of the approach chart the RPID is shown with the according channel number that is used to tune the approach with the desired flight path.

On the lower part of the approach chart the vertical profile of the approach procedure is shown. The GPA and the check altitudes are depicted. The tables are adapted for each GPA.

As the underlying RNAV approach is a non-precision approach, the charted obstacle clearance altitudes/heights (OCA/H) are higher than those for a precision approach. For simplicity the altitudes were conservatively maintained. For the flight trials the OCH was used as the decision height (DH) for all approaches.

The approach procedures are very close to the procedures described in [10] and therefore very easy to integrate into the existing Air Traffic Management (ATM) infrastructure. The design principle to keep the horizontal profile and the lateral positions of the navigation fixes constant is presumed to keep the situation awareness level for air traffic controllers and the pilots as high as possible.

6. FLIGHT TRIALS

One of the purposes of the flight trials was the verification of the results obtained in the simulator regarding pilot's acceptance and workload. Therefore, the approaches were conducted similar to the ones conducted in the simulator. Due to the architecture of the test system the tuning of the Multi Mode Receiver (MMR) during the flight trials was done by the cabin crew and the display of the deviation signals was slightly different. The deviations were displayed on the Course Deviation Indicator (CDI) during the flight trials whereas they were displayed on an experimental primary flight display and navigation display during the simulator trials.

The approaches were set up at the initial or intermediate segment in the appropriate altitude. From there the final approach has been conducted manually, following the displayed deviations on the CDI. The evaluation pilots stated that the workload was not rising excessively during the steep approaches. There was a noticeable rise of the required attention for a steep approach but the overall level remained in a tolerable state.

Another purpose of the flight trials was the validation of FAS data in the ground station and the verification of the operability of the designed procedures. It was discovered that the procedures were not demanding with the type of aircraft used. The approach speed was small enough to keep the vertical velocity on a reasonable level.

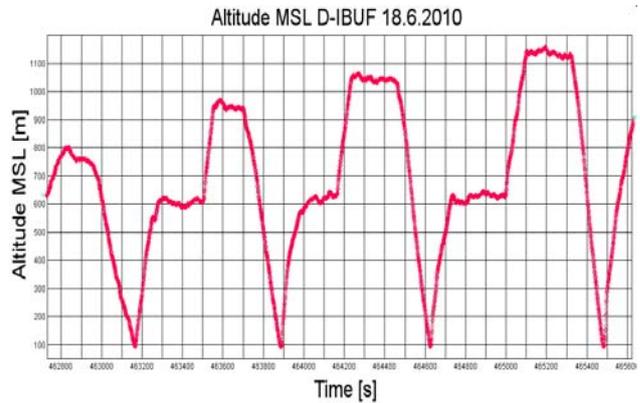


Fig. 10: Altitude (MSL) over Time

Fig. 10 shows the vertical profile that occurred during one test flight. It can be seen that the approaches with different GPA's had different intercept altitudes.

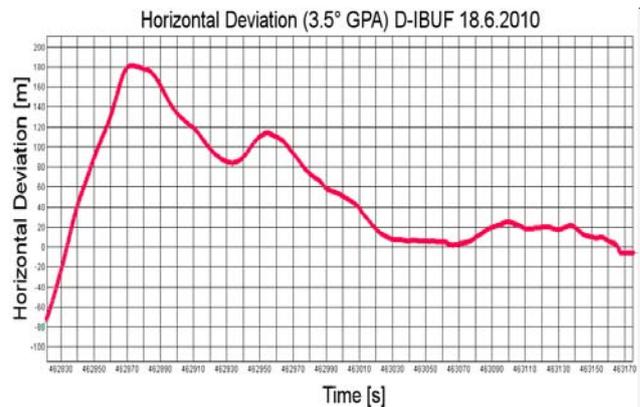


Fig. 11: Horizontal Deviation (3.5°) over time

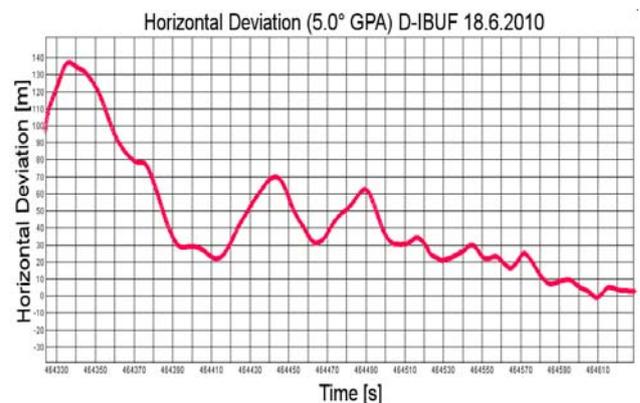


Fig. 12: Horizontal deviation (5.0°) over time

Fig. 11 and Fig. 12 show the rectangular horizontal deviations observed during an approach with a GPA of

3.5° (Fig. 11) and with a GPA of 5.0° (Fig. 12). It can be seen that in both cases the deviation decreases gradually after intercepting the localizer. In the last 100 seconds of each approach, the deviations are well within 40m during each approach.

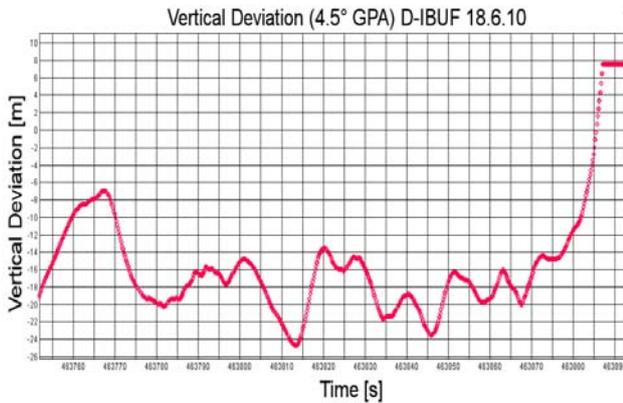


Fig. 13: Vertical Deviation (4.5°) over time

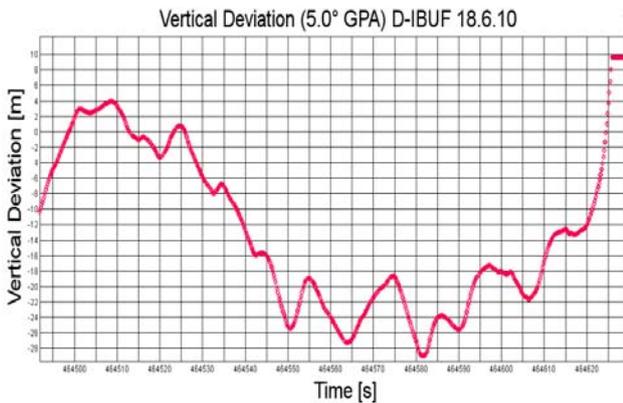


Fig. 14: Vertical Deviation (5.0°) over time

Fig. 13, Fig. 14 and Fig. 15 show the rectangular vertical deviations encountered during an approach with a GPA of 4.5° (Fig. 13), a GPA of 5.0° (Fig. 14) and a GPA of 5.5° (Fig. 15). The results show that the deviations behave similarly. The approaches were flown slightly below the desired glide path but even though they were manually flown it was managed to keep the deviations within a range of 10m as soon as a steady descend was established.

The pilots reported a steady behavior of the displayed deviation signals and no increased workload during the go around. The results show that no significant height loss was given during the go around after a steep approach. This reflects the results obtained in the simulator quite well.

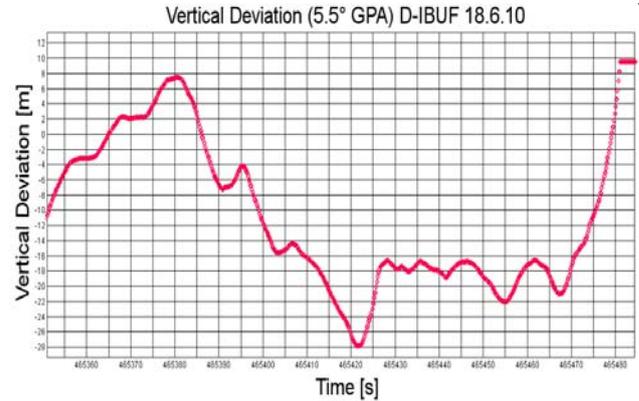


Fig. 15: Vertical Deviation (5.5°) over time

7. CONCLUSIONS

Concluding, no problems during GBAS guided steep approaches with this type of aircraft were encountered. The fact that they can be flown manually with a non standard display of the deviation signals is very promising for air taxi applications with similar types of aircraft or aircraft that have specific engine and aerodynamic properties tailored for steep approaches. Further tests will be carried out to investigate the system usability and the workload of different pilots with different types of aircraft. Additionally, the flare for an actual landing has to be further investigated.

The paper has also described the layout of the experimental airborne and ground installations at the Research Airport Braunschweig-Wolfsburg. The combination of a state-of-the-art GBAS ground station with additional research installation forms a perfect environment for investigations on flexible approach procedures. In a joint effort within the national funded project “Bürgerndahes Flugzeug” the both Institutes of Flight Guidance at DLR and TU Braunschweig are working closely together. Further trials are intended to investigate novel approach procedures (segmented and/or steep approaches) with an experimental GPS/aviationGATE on-board unit. With this combination detailed research on fault-detection-and-exclusion on dedicated failure scenarios can be accomplished in a realistic and close-to-operation environment.

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9. REFERENCES

- [1] A. Lipp, T. Feuerle and P. Hecker, "Interoperability Trials of GBAS Equipment", Proceedings of the 13th European Navigation Conference, ENC-GNSS 2008, Toulouse, France
- [2] T. Feuerle, U. Bestmann, M. Steen, B. von Wulfen, P. Hecker and A. Lipp, "Preparation for Upcoming Multi-Constellation GBAS Systems", TU Braunschweig, EUROCONTROL, Proceedings of the 22nd International Technical Meeting of the Satellite Division of the Institute of Navigation, ION GNSS 2009, Savannah, Georgia, pp. 1169 – 1174
- [3] M. Bitter, T. Feuerle, B. von Wulfen, M. Steen, P. Hecker, "Testbed for Dual-Constellation GBAS Concepts", Proceedings of the IEEE/ION PLANS 2010, Indian Wells/Palm Springs, CA, pp. 680 – 687
- [4] European Space Agency / European GNSS Supervisory Authority, "Galileo Open Service, Signal In Space, Interface Control Document", OS SIS ICD, Draft 1, 2008
- [5] M. Steen, T. Feuerle, U. Bestmann, M. Stanisak and P. Hecker, "Continuity and Integrity Aspects of an Integrated GBAS/INS Navigation System", Proceedings of the 21st International Technical Meeting of the Satellite Division of the Institute of Navigation, 16-19, September 2008, Savannah, Georgia, pp. 2920-2928
- [6] -, "Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment", RTCA Do-253C, RTCA Dec 2008
- [7] M. Steen, M. Kujawska and P. Hecker, "Integrated GBAS/INS Navigation System – Continuity and Integrity Aspects", Proceedings of the Symposium Gyro Technology 2009, Karlsruhe, Germany
- [8] M. Steen and P. Hecker, "GBAS/INS Navigation System: Further Developments of On-Board Integrity Monitoring", Proceedings of the 2010 International Technical Meeting of the Institute of Navigation, ION ITM 2010, San Diego, CA, pp. 386 – 393
- [9] DFS. Deutsche Flugsicherung, DFS Luftfahrthandbuch Deutschland (Aeronautical Information Publication, 2010
- [10] ICAO. Doc 8168, Vol I, Procedures for Air Navigation Services, Aircraft Operations, Flight Procedures, International Civil Aviation Organisation (ICAO), 2006
- [11] German Aerospace Centre. Luftverkehrsbericht 2008

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