Flight Inspection of GAST-D Approach and Taxi Guidance Systems

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BIOGRAPHIES

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ABSTRACT

The term “Ground Based Augmentation System (GBAS)” describes a method for instrument landing using ILS look-alike guidance computed from real-time differential corrections for global navigation satellite systems (GNSS). At the moment, GBAS approach service type C (GAST-C) installations are certified for approaches down to CAT I minima, i.e. decision altitudes of at least 200 ft. While the number of approved ground installations and certified aircraft are increasing continuously, many parties are waiting for a CAT II/III GBAS in order to allow approaches in significantly worse weather conditions. For this, the GBAS approach service type D (GAST-D) is currently developed in the frame of the ICAO. The publication of ICAO “Standards and Recommended Practices” (SARPs) regarding the implementation of GAST-D is expected for the year 2018. First installations at airports are assumed to become operational in the 2020 time frame.

GBAS GAST-D installations require a commissioning flight inspection prior to operational approval. This in turn requires the availability of appropriate flight inspection equipment and procedures. Flight inspection procedures and certified flight inspection systems (FIS) are available for GAST-C, but currently not for GAST-D. This is addressed by the research project MEGA (Inspection of GNSS-based CAT-III Approach and Taxi Guidance Systems) funded by the German Federal Ministry for Economic Affairs and Energy as part of the national “Aeronautical Research Programme V” (LuFo V). Within this project, the institutions represented by the authors will provide a suggestion as basis of future GAST-D inspection.

The project focuses on the development of GAST-D flight inspection procedures and equipment as a possible complement of an existing GAST-C capable FIS. For this, after having identified the differences between GAST-C and GAST-D, the requirements for GAST-D flight inspection, regarding both the FIS equipment and the flight procedures are gathered. Based on these requirements, work is ongoing to define future flight inspection standards and to integrate experimental GAST-D equipment into a flight inspection demonstrator system. In parallel, measurement procedures are developed, including an assessment of the complete process and measurement chain. At the end of project MEGA, demonstration flights will be conducted. The data of these flights will be combined with data recorded by other vehicles in order to demonstrate an exemplary GAST-D commissioning.

An additional focus is set on GBAS ground operations, both on runways (GAST-D) and on taxiways. As GBAS is currently only approved for landings but not for ground taxiing, the requirements for future GBAS-based taxi guidance systems are currently analyzed in order to define measurement procedures to enable such operations.

This paper presents some intermediate results and the ongoing work within project MEGA. Based on the GAST-C standards, the main differences to the GAST-D standards are pointed out. Flight inspection requirements for equipment and procedures are derived and presented. A new GBAS receiver with special flight inspection functionality and future GAST-D capability is introduced. Finally, the current state of the GAST-D flight inspection system demonstrator and procedure design is presented. In addition, a general overview of GBAS-based taxiing is given, comprising the requirements, challenges, and technical limitations of such operations.

INTRODUCTION

The ground based augmentation system (GBAS) is a precision approach system based on global navigation satellite systems (GNSS), which is harmonized by the International Civil Aviation Organization (ICAO). GBAS ground stations transmit several information messages to approaching aircraft via a VHF data link. The broadcast of differential corrections for visible GNSS satellites, approach parameters and integrity information enable appropriately equipped aircraft to follow GNSS based precision approaches. These approaches look identical to those from an instrument landing system (ILS) from the perspective of a pilot or flight controller (“ILS look-alike”).

GBAS based category I (CAT I) approaches, which are known as GBAS approach service type C (GAST-C), are certified and in operation at several airports. Current research and development work deals with the implementation and certification of the new GAST-D service for CAT III approaches. This service is going to allow aircraft to autoland even during poor visibility conditions. Contrary to ILS CAT II and III approaches, the protection areas can be reduced in the future, thus increasing the usable airport capacity during adverse weather conditions. In contrast to GAST-C, GAST-D does not cover the approach only, but the complete landing process.

Before a GAST-D installation can become operational, a commissioning flight inspection has to be conducted. For this reason, flight inspection equipment and procedures have to be developed, integrated, and validated to cover additional requirements by GAST-D.

GBAS corrections and guidance information have the potential to not be used exclusively by airborne vehicles. For this reason it is a current topic of research to investigate the applicability of GBAS in taxiing guidance. This would result in an approach and landing system with taxiing guidance, which can truly be used during CAT III conditions with zero visibility. The aircraft would be enabled to vacate the runway after landing guided by GBAS and thus enable following aircraft to also land during these conditions. As well as GBAS approach procedures, taxiing procedures also require a check and validation.

The mentioned developments in GBAS are the subject of the joint research project MEGA. Its main objective is the development of a GAST-D capable flight inspection system (FIS) demonstrator and its requirements concerning measurement and flight procedures. The intended application of this demonstrator is in inspection of GBAS approach, landing, and also taxiing inspection.

JOINT RESEARCH PROJECT MEGA

The project MEGA “Inspection of GNSS-based CAT-III Approach and Taxiing Guidance Systems” (German: Vermessung GNSS-basierter CAT-III Lande- und Rollführungssysteme) aims at developing a (flight) inspection system demonstrator, capable of measuring and calibrating signals from GAST-D ground stations. It is a joint research project of the Institute of Flight Guidance (IFF) of the Technische Universität Braunschweig (TUBS) and Aerodata, headed by the latter institution. Project MEGA consists of two sub projects:

- Flight Inspection System for GBAS Approach Service Type D (GAST-D), by Aerodata
- Taxiing and Ground Inspection System for GBAS / GAST-D, by the TU Braunschweig

Figure 1: Project MEGA logo

The project is divided into three main work packages (MWP). MWP 1 defines the requirements for GAST-D approaches and taxiing, and the resulting requirements for an inspection. For this, the current GAST-D developments are compared to operative GAST-C standards. The requirements for a (flight) inspection are then investigated based on GAST-D principles and on regulations like a future GAST-D extended version of Doc 8071 (see [1] and [2]) which is currently being worked on by ICAO. Further inputs come from conferences and workshops with flight inspection experts. Based on the requirements towards a GAST-D flight inspection, the necessary equipment is finally specified. The equipment has to be applicable in road and in flight experiments.

MWP 2 creates an experimental demonstrator for the inspection of GAST-D installations, based on the aforementioned specifications. The design of the measurement system hardware is defined and documented. The system is going to consist of a flight inspection GBAS navigation unit, a position and attitude reference system, and a real-time data acquisition system. The assembly of the prototype is supported and followed by an extensive testing program. Furthermore, the necessary measurement methods are developed. These are going to be based on possibly updated documents and regulations, and experiences from GAST-C flight inspection. Finally, from the definition of the measurement methods and regulations, the necessary flight procedures are developed and defined.

MWP 3 utilizes the prototype measurement system and the defined procedures for the generation of exemplary measurement data for the system verification. For this, the prototype system is integrated into TUBS's Dornier Do 128 research aircraft and into a measurement ground vehicle. In parallel, the measurement methods, procedures, and algorithms are implemented into software. The recorded data from the flight and ground experiments is used for the system's verification, by processing it with the methods from MWP 2 under consideration of the requirements from MWP 1.

GAST-D OVERVIEW

GBAS Approach Service Type D implements additions to GAST-C. Thus, every GAST-D ground installation is downwards compatible and can be used for GAST-C guidance. In the following paragraphs a couple of essential differences between GAST-C and GAST-D are going to be described.

GAST-D is going to allow CAT III approaches to airport runways, thus reducing the decision height for pilots to at least 15 m (50 ft), in contrast to 60 m (200 ft) for GAST-C/CAT I. This requires more stringent requirements towards the integrity of the system. Integrity must be proven to be at least 1-10^{-9} in any 15 sec (vertical) and 30 sec (lateral) time span.

Special attention is given to anomalies in the ionosphere. These can lead to a fast change in the ionospheric impact on the GNSS signal at the aircraft, but not at the ground station or vice versa. This means, that provided corrections are not applicable. For this reason, integrity is not only covered by the GBAS ground station, but also by the aircraft receiver. Additional monitoring on ground and in the aircraft allows the detection of these anomalies.

GAST-D uses additional message types (MT) compared to GAST-C. MT11 provides additional differential corrections, which are smoothed over a 30 seconds interval. In comparison with the solution from MT1 differential corrections, which are based on 100 seconds smoothed pseudo ranges, a detection of ionospheric effects is possible. The authentication, which is optional for GAST-C, becomes mandatory for GAST-D application. Thus, MT3 (Null Message) also is required for GAST-D operation, as well as the additional data blocks to MT2 (GBAS Related Data) ADB1 (Dmax, ephemeris decorrelation), ADB3 (ephemeris decorrelation, ionosphere gradient), and ADB4 (authentication: slot group definition). A detailed description of the message types is given in [3].

The main task of GAST-D is to guarantee the safe arrival of the aircraft in the defined touchdown zone. This is influenced by the dynamics of the aircraft, performance of the flight control, GAST-D certification of the aircraft, and parameters specific to the aircraft. The total system error (TSE) has to be kept in certain bounds for a GAST-D landing to be successful. The TSE consists of the path definition error (PDE), flight technical error (FTE) and navigation system error (NSE). It can be seen, that the requirements for GAST-D are not solely dependent on the ground station including data bases, but also on the aircraft and its equipment.

STATUS OF GAST-D STANDARDS

Before a commissioning of GAST-D capable GBAS ground stations at airports, the applicable documents and standards have to be finished and passed by the responsible institutions. RTCA has thusly published its GBAS related documents with GAST-D updates in terms of the interface control document (ICD) DO-246E [3] and the minimum operational performance standards (MOPS) DO-253D [4] in July 2017.

ICAO is currently working on completing the GAST-D additions to its standards and recommended practices (SARPs) of Annex 10 [5]. The state letter process for this document was completed in June 2017. A publication is expected as Amendment 91 to Annex 10 in November 2018, see [6]. After finishing work on the SARPs, the ICAO Navigation Systems Panel (NSP) GBAS Working Group (GWG) is now concentrating on implementing GAST-D into Doc 8071 Vol. II [2], see [7]. At this point, flight inspection standards concerning GAST-D are not yet available. For this reason, project MEGA suggests requirements for GAST-D flight checks from already available documents and drafts, and from experience with GAST-C flight inspection.

EUROCAE Working Group WG-28 is currently working on an update of its minimum operational performance specification (MOPS) ED-114A [8]. The future version ED-114B is going to cover the GAST-D ground systems. According to [9] it was decided to not update the MASPS ED-95 [10] but instead add a new appendix to ED-114B, which contains the assumptions taken regarding the airborne side for GAST-D. ED-114B is assumed to being finished by the end of the fourth quarter 2018, see [11].

GAST-D REQUIREMENTS

The main task of the GBAS flight inspection is to verify the proper functionality of the signal emitted from the ground station. Although GAST-D requires operations from both the ground station and the aircraft installation, the flight inspection concentrates on checking the ground station.

VDB Field Strength

Besides the flight validation of the GBAS procedures, the main task of GBAS flight inspection is the check of the VDB signal strength inside the GBAS service volume. Chapter 3.7.3.5.3 of [12] distinguishes between the minimum GBAS approach service volume and the minimum additional GBAS service volume for approach services supporting autoland and guided take-off.

The approach service volume is horizontally defined from 140 m left and right of the landing threshold point / fictitious threshold point (LTP/FTP) going out 35° to both sides of the approach path for 28 km. This is followed by a sector of 10° to both sides of the approach up to a distance of 37 km. The vertical approach service volume starts at the glide path intercept point (GPIP). Its maximum height above threshold (HAT) is limited by the greater angle of 7° or 1.75 times the glide path angle, and a height of 3000 m. The lower bound of the volume is defined by an angle of the glide path angle multiplied by 0.45 or 0.3, if required by the glide path intercept procedure, and by the larger value of half of the lowest decision height or 3.7 m.

The minimum additional service volume is defined along the full length of the runway. Horizontally it continues the minimum approach service volume left and right of the LTP until the stop end of the runway. Vertically the volume is defined between 3.7 m and 30 m above the runway center line and also joins the minimum approach service volume.

The data broadcast RF field strength and polarization requirements are formulated in chapter 3.7.3.5.4.4 of [12]. This paper only considers horizontally polarized signals, since these should be the standard at civil airports. Within the GBAS service volume, the minimum field strength should be -99 dBW/m² and the maximum -27 dBW/m². The minimum field strength within the additional service volume increases from -99 dBW/m² below 36 ft to 12 ft to -89.5 dBW/m² from 36 ft above the runway surface and higher. “The minimum and maximum field strengths are consistent with a minimum distance of 80 m (263 ft) from the transmitter antenna for a range of 43 km (23 NM).” ([12], chapter 3.7.3.5.4.4, p. 5)

Authentication

One additional challenge for inspecting GAST-D installations is to check all preconditions necessary for the authentication feature. The authentication feature has been introduced in the GBAS standards in order to protect the users against intentional VDB spoofing. For this, a number of checks have been added as additional requirements to the MOPS [4]. If any of these checks fail, no GBAS approach service shall be possible. The authentication feature relies on a lot of different details which have to be checked during flight inspection.

One crucial part of the authentication feature is to ensure that VDB messages of a specific ground facility are only received in VDB time slots assigned to them. In addition, all these slots have to be filled with VDB messages up to a certain degree. For a GAST-D flight inspection it is thus crucial to have the VDB reception synchronized with UTC time in order to ensure proper timing. All checks for the authentication can also be performed during a flight inspection in order to ensure that the ground facility is configured correctly and works stably with different types of GBAS receivers.

GAST-D FLIGHT INSPECTION SYSTEM DEMONSTRATOR

One of the main objectives of project MEGA is the development and validation of a GAST-D capable flight inspection system demonstrator. Compared to a standard FIS, the demonstrator system’s capability is reduced to receive, process, and record GBAS measurements and tune the GBAS receiver. Thus, no other navaid receivers are going to be integrated into the system. The main components of the demonstrator are going to utilize computers and receivers from Aerodata’s AeroFIS product family. An overview on the structure of the GAST-D FIS demonstrator is given in Figure 2. Some of the demonstrator’s components are shown in Figure 3.

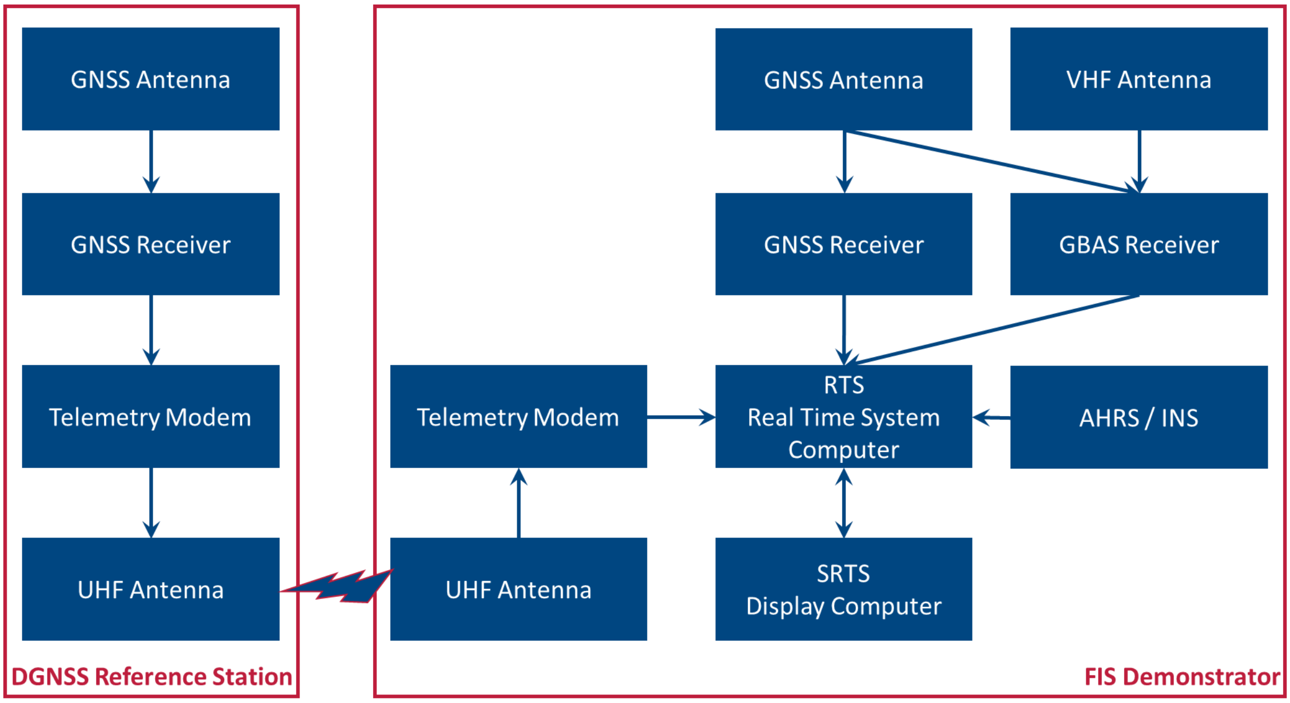

Figure 2: Structure of the GAST-D flight inspection system demonstrator

The core of every Aerodata FIS is the real-time system (RTS) computer, which performs several tasks. For flight inspection it is of utmost importance to know exactly where and when the accurately measured value has been received. Otherwise a reference value of a navaid cannot be accurately determined for the measured signal, e.g. from a VDB transmitter. Thanks to the real-time characteristic of the main computer, the exact time of measurement of the VDB signal level is known and can be referenced to the reference position solution. Thus, the reference position is known exactly at the time of the VDB measurement and the nominal VDB value can be calculated for the correct time and position.

Figure 3: GAST-D FIS demonstrator components (from left to right): real-time computer AD-RTS-0100, GNSS receiver AD-GNSS-0100, GBAS receiver AD-GBAS-0100

VDB ground stations transmit messages in 8 different time slots in 2 frames per seconds. This means, messages should arrive at the GBAS receiver at a 16 Hz data rate. The Linux based AD-RTS-0100 real-time computer is able to operate at a data rate of up to 100 Hz and thus allows the accurate recording and processing of the GBAS data provided by the receiver.

The reference position solution is also calculated by the real-time system. For this, it uses measurements from e.g. a dedicated FIS GNSS receiver, and an inertial navigation system (INS). The GNSS receiver is connected to a GNSS antenna and delivers its measurements directly to the RTS. The INS transmits its measurements to the RTS via ARINC 429.
The most accurate position solution is calculated from real-time kinematic (RTK) algorithms called phase differential GNSS (PDGNSS), which is certified for flight inspection applications by various ANSPs, see [13]. An INS is already installed in TU Braunschweig's Dornier DO-128 research aircraft D-IBUF and can be utilized by the FIS demonstrator. The INS attitude solution allows for the compensation of the lever arms between the receiving antennas and the INS. PDGNSS also requires a GNSS ground station, which transmits GNSS raw data measurements via UHF to the aircraft. The receiving UHF telemetry modem is also connected to the RTS.

The graphical user interface (GUI) is provided by the semi-real-time system (SRTS) / display computer. For the FIS demonstrator a Microsoft Windows based Laptop is used for this functionality. The software of the SRTS allows the control and monitoring of the flight inspection mission. It is used to set-up the flight procedures and to provide on-line preliminary results and final results after finishing the procedure.

Flight Inspection GBAS Receiver AD-GBAS-0100

The task of flight inspection is the check and calibration of air navigation aids and instrument flight procedures in flight, and by this ensure safety of air navigation by the use of navigation aids, satellite systems, and flight procedures. Thus, it has to be understood, in which way the navigation signal is received and processed in e.g. an airliner aircraft. For this reason, requirements for GBAS equipment in a flight inspection aircraft are defined by ICAO's Doc 8071 Vol. II [2] in the following way:

> *"[…] The aircraft GBAS equipment used for the flight test should meet the applicable standards required for the procedure being tested. There are situations that may require modifications to the flight test receiver that could invalidate the certification. […] In some cases, it may be desirable to acknowledge and suppress GBAS alerts, warnings and flags for the purposes of completing required checks."* ([2], chapter 4.3.1, p. 4-14)

This means, that an ideal flight inspection GBAS receiver is based on a receiver, which is certified for application in aviation on the one hand, and on the other hand provides additional functionality, which is necessary for the operation in flight inspection.

A GBAS ground station requires a commissioning flight inspection, before it can be used as a navaid in aviation. Before, VDB messages emitted from the station are marked in such a way, that aviation GBAS receivers ignore these messages. Thus, a flight inspection receiver needs to be able to receive and process VDB messages although these are marked as test messages. This functionality is available with Aerodata's new flight inspection GBAS receiver AD-GBAS-0100 (see right part of Figure 3). For full compliance with the above cited paragraph of Doc 8071 Vol. II, the AD-GBAS-0100 receiver is originally based on a certified aviation receiver and has been modified for additional flight inspection capabilities. The commissioning or test mode of the GBAS receiver is completed by the possibility to configure the D_{max} value and the lateral and vertical alert limits (LAL/VAL) during runtime via the FIS.

One of the main tasks of GBAS flight inspection is the check of the VDB signal. It has to operate in its signal strength limits and be free of interference. For this reason, it is necessary for the GBAS receiver to output a VDB signal level measurement. Doc 8071 demands, that "*The field strength should be measured as an average over the period of the synchronization and ambiguity resolution bits in the training sequence portion of the message.*" ([2], chapter 4.2.32, p. 4-12). The AD-GBAS-0100 receiver's functionality is able to fulfil this demand and to accurately allocate the signal strength measurement to its VDB message. In case a GBAS ground station operates more than one VDB antenna, the assignment of the signal strength to the VDB message also allows for the assignment of the signal strength to the transmitting ground antenna.

The VDB signal level can be measured between -120 and 0 dBm with a resolution of 0.1 dB. Measurements are reproducible with a precision of 1 dB and at a 3 dB absolute accuracy. The latter value is further improved by regular calibration and compensation in the FIS to an accuracy of 1 dB.

The flight inspection GBAS receiver is furthermore able to provide all of the received message types to the FIS. This includes the GAST-D specific messages as well. Furthermore both position solutions based on 100 seconds and 30 seconds smoothed pseudo ranges are made available. The message authentication, which is mandatory for GAST-D, is applied and its result is sent to the RTS.

GAST-D FLIGHT INSPECTION PROCEDURES

Based on these requirements for the minimum GBAS approach service volume (see above), the following GAST-D flight inspection procedures are proposed.

1. (Published) approaches
2. Partial orbit of ±15° at a distance of 37 km from the LTP (lateral coverage).
3. Partial orbit of ±40° at a distance of 28 km from the LTP (lateral coverage).
4. Level run at 3000 m HAT from a distance of 37 km to 24 km (vertical coverage).
5. Level run at 600 m HAT from a distance of 37 km to 4.5 km (vertical coverage).

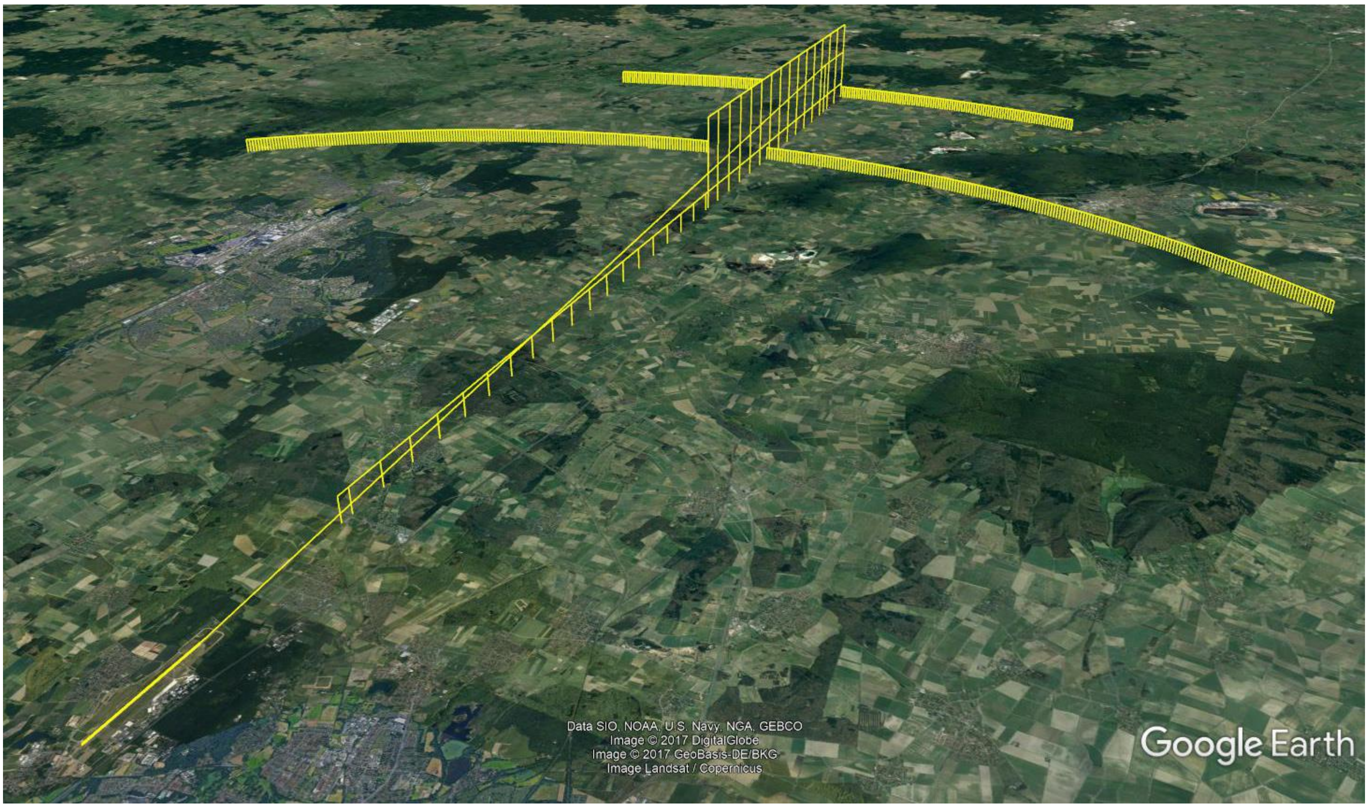

Figure 4: Exemplary flight inspection procedures for a GBAS approach to Braunschweig-Wolfsburg Airport EDVE (Source: 52° 18' 23.18" N and 10° 46' 53.27" E. GOOGLE EARTH, December 14, 2015. October 24, 2017.)

The angle spans of the partial orbits are increased so that the aircraft can settle on the arc before reaching the GBAS service volume. For the repeatability and comparability of the flight procedures it is recommended to use the autopilot flight guidance, which is provided by the flight inspection system. For flight procedure validation purposes, the published or to be commissioned approaches should be flown using the guidance from the GBAS receiver.

The additional service volume can be checked using the flight inspection aircraft, which is also used for the check of the approach service volume. Alternatively ground vehicles with appropriate equipment and an antenna at a height of 3.7 m can be used. For commissioning flight inspection it might be beneficial to check the signal strength at a height above the runway center line of 3.7 m during roll-out and also at 30 m during a low level run.

An example for a GBAS commissioning flight inspection mission using the described procedures at the Research Airport Braunschweig is shown in Figure 4.

GBAS BASED TAXIING

Nowadays, all taxiing (i.e. after having completed the landing and before commencing the take-off run) is done manually, based on the visual impressions by the pilots. Especially in low visibility conditions, this leads to significant challenges for the pilots and large capacity impacts for the airports. A GBAS based guidance system for taxiing could not only reduce the workload for the pilots, but would also allow airports to operate with a higher capacity in these conditions. Such a GBAS taxi service however could not be based on any of the existing GBAS approach services, but has to be defined from scratch in order to meet the distinct constraints of taxi guidance. The operational concept and performance requirements of such a GBAS service are drafted and analyzed in the frame of the project MEGA.

From a technical perspective, a GBAS taxi service could benefit from the existing VDB messages already broadcast. The positioning for such a service could use the existing differential corrections broadcast within the VDB message type 1. This would allow the taxiing aircraft to obtain a very precise position solution. For providing taxi guidance, this service could use path definitions received via VDB message type 4. This message type is used for broadcasting final approach segments (FAS) for precision approaches, but can also be used to broadcast Terminal Area Path (TAP) segments. It has been shown before that such TAP segments could also be used for GBAS based taxiing [14]. This way, a predetermined taxi route could be selected by future airborne GBAS components via a channel number. Being dependent on the GBAS VHF data broadcast (VDB), the same limits with respect to signal reception like line-of-sight have to be applied in general. However, with different constraints, the exact requirements on VDB reception might be relaxed for GBAS taxiing.

Based on this technical mode of operation, the necessary positioning requirements are currently derived in the project MEGA. In general, no vertical guidance is required for taxi operations. The horizontal performance required by such a service is determined by two constraints. On the one hand, all of the aircraft's undercarriage must not leave the paved surface. This relates the available width of a taxiway with the wheel gauge of the taxiing aircraft. On the other hand, the aircraft's wing tips have to stay clear of any obstacles. This constraint limits the allowable horizontal position error based on the wingspan and the available obstacle-free space. This also means that the required positioning performance of a taxi guidance system is not fixed but depends on the aircraft type and the ground layout. The idea currently foreseen in MEGA is to include the parameters describing the layout of the taxiway (width, distance from obstacles) in the TAP broadcast, so that each aircraft can derive its own positioning requirements in order to meet the required total system error (TSE).

As all taxiing is done manually at the moment, no performance requirements for such a taxi guidance system exist yet. The next steps within the project MEGA will be to define requirements on integrity as well as accuracy. Based on this, initial requirements for an inspection of GBAS taxiing will be derived too.

CONCLUSION

GAST-D is going to allow GBAS CAT-III operations. In order to conduct a successful certification and to guarantee a safe operation of GAST-D ground installations, a commissioning and regular flight inspection is necessary. For this reason, a flight inspection system, capable of processing GAST-D signals and procedures, has to be developed and implemented. Project MEGA is going to develop a FIS demonstrator incorporating the GAST-D functionality. In this way, the development and integration of a GAST-D capable FIS is going to be made available to flight inspection service providers. This demonstrator system is also developed with future GBAS based taxiing applications in mind. Thus, project MEGA also looks into current GBAS taxiing possibilities and their validation.

The next steps of project MEGA are going to be the evaluation of the measurement data processing procedures and of the approach towards GAST-D flight inspection. In parallel, the GAST-D FIS demonstrator is being developed and the software is implemented. The flight and ground tests of the demonstrator are scheduled for mid-2018.

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Figure 5: Project MEGA is supported by the German Federal Ministry for Economic Affairs and Energy.

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