GBAS GAST-D Flight Inspection

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ABSTRACT

The term "Ground Based Augmentation System (GBAS)" describes an ILS look-alike precision approach system using global navigation satellite systems (GNSS) along with local differential corrections. 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 low visibility conditions. For this, the GBAS approach service type D (GAST-D) was developed and standardized in the frame of the ICAO. While the ICAO Annex 10 "Standards and Recommended Practices" (SARPs) regarding the implementation of GAST-D are already available, the GBAS chapter for the ICAO "Manual on Testing of Radio Navigation Aids" (DOC8071) is currently only covering GAST-C, but is being worked on in order to include guidance for GAST-D flight inspection. Initial ground installations are planned to become operational within this decade.

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. This has been 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, suggestions for future GAST-D flight inspections were developed.

The project focused on the development of GAST-D flight inspection procedures and equipment as a possible complement of an existing GAST-C capable FIS. For this, the requirements for GAST-D flight inspection regarding both the FIS equipment and the flight procedures were gathered first. Based on these, a GAST-D flight inspection system demonstrator was developed. This demonstrator consists of standard FIS components and a GAST-D capable GBAS receiver, which is based on a TSO certified aviation landing system unit. The GBAS FIS demonstrator, and the accompanying flight inspection procedures and measurement techniques were tested and verified during a flight campaign at three different airports with GBAS installations in Germany.

This paper presents final results of the successfully completed project MEGA. The requirements towards GAST-D flight inspection are described, and flight procedures are proposed. The GBAS FIS demonstrator is introduced, and the results of the validation are presented.

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 messages to approaching aircraft via a VHF data link. The broadcast of differential corrections for usable GNSS satellites, approach parameters and integrity information enable appropriately equipped aircraft to conduct GNSS landing system (GLS) 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 focuses on a 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 low visibility conditions. In contrast to GAST-C, GAST-D does not cover the approach only, but the complete sequence of approach, flare and landing.

Before a GAST-D approach procedure 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.

The mentioned developments in GBAS have been the subject of the joint research project MEGA. Its main objective was 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 was in inspection of GBAS approach, landing, and also taxiing inspection. This paper focuses on the GBAS flight inspection of project MEGA and can be regarded as a continuation and update of [1] with a focus on the verification flights.

JOINT RESEARCH PROJECT MEGA

The project “Inspection of GNSS-based CAT-III Approach and Taxiing Guidance Systems” (German abbreviation: MEGA) aimed at developing a (flight) inspection system demonstrator, capable of measuring and calibrating signals from GAST-D ground stations. It was a joint research project of the Institute of Flight Guidance (IFF) of the Technische Universität Braunschweig (TUBS) and Aerodata, headed by the latter institution, and was successfully completed in 2019. Project MEGA consisted 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

This publication concentrates on the Aerodata sub project on the GAST-D FIS demonstrator. Additional information on the TU Braunschweig sub project on the taxiing and ground inspection system is available in [1] and [2].

The project was divided into three main work packages (MWP) in order to cover the progress necessary for the development of the GAST-D FIS prototype. In the first step, the requirements on GAST-D and its performance had to be evaluated. Since most of the standards and recommendations had not been finalized during this phase of the project, it was necessary to base the prototype system specification on draft versions and on GAST-C experience. An overview on the applicable standards is given in the following chapter.

The following two main work packages (MWP) of project MEGA incorporated the design and the verification of the GAST-D FIS prototype and the flight inspection procedures. These were developed based on the results of the requirements from MWP 1. The results of the system and procedure development, and examples from the verification are presented in the following chapters.

STATUS OF GAST-D STANDARDS

The first documents with updates on GAST-D were published by the RTCA in July 2017. These are the interface control document (ICD) DO-246E [3] and the minimum operational performance standards (MOPS) DO-253D [4].

ICAO has updated its standards and recommended practices (SARPs) of Annex 10 [5] in July 2018 in order to incorporate GAST-D. After finishing work on the SARPs, the ICAO Navigation Systems Panel (NSP) has started on updating the "Manual on Testing of Radio Navigation Aids" accordingly. Volume I on the "Testing of Ground-based Radio Navigation Systems" has been updated also in 2018 with its 5th edition [6]. The update to volume II of ICAO Doc 8071 [7], which covers satellite-based radio navigation systems and thus GBAS, has not been finished, yet.

GAST-D FLIGHT INSPECTION REQUIREMENTS

With at least a few of the standards and recommendations in place, requirements towards the flight inspection of GAST-D can be defined. The main task of the GBAS FI 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 [5] distinguishes between the minimum GBAS approach service volume and the minimum additional GBAS service volume above the runway for approach services supporting autoland and guided take-off. A detailed description of the service volumes is given in [1] and [5].

The data broadcast RF field strength and polarization requirements are formulated in chapter 3.7.3.5.4.4 of [5]. This paper only considers horizontally polarized signals, since these should be the standard at civil airports. Within the GBAS service volume, the field strength shall be within -99 dBW/m² and -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)." ([5], chapter 3.7.3.5.4.4)

Authentication

GBAS is in principle susceptible to spoofing attacks via additional VDB broadcasts. In order to eliminate such attacks, the GBAS authentication service was introduced. With strict message and timing requirements, the authentication can ensure that GBAS receivers supporting this authentication feature ignore additional VDB broadcasts. While only optional for GAST-C, the authentication feature needs to be active for GAST-D.

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 especially assigned VDB time slots. 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 reliably with different types of GBAS receivers.

GAST-D FLIGHT INSPECTION SYSTEM DEMONSTRATOR

One of the main objectives of project MEGA was 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 were integrated into the system. The main components of the demonstrator utilized 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.

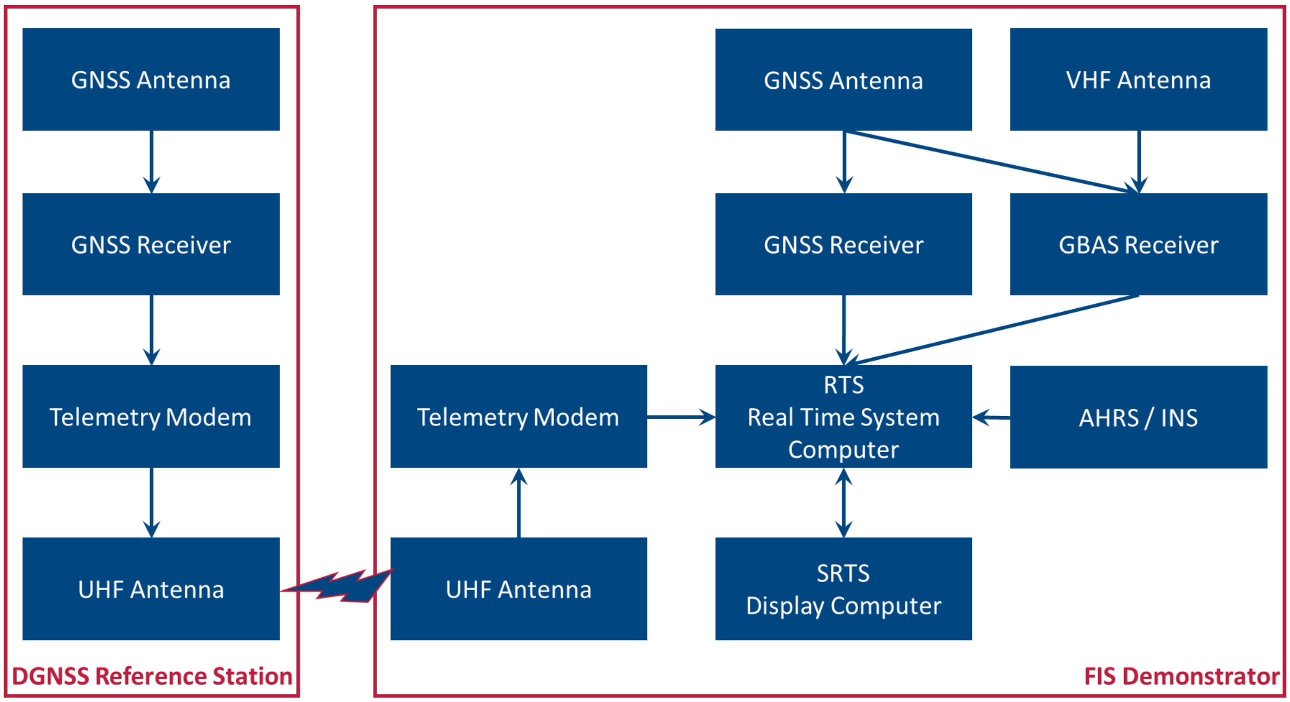


Figure 2: Structure of the GAST-D flight inspection system demonstrator

The heart of the GAST-D FIS demonstrator is the real-time system (RTS) computer, which allows for the recording and accurate time stamping of the measurement data. At the same time, the position, velocity, and attitude (PVA) reference solution is calculated in real-time by the RTS. During the validation flights for project MEGA, a GNSS receiver and an INS were used as inputs to the PVA calculations. 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 [8]. For this, a DGNSS reference station supplies its GNSS measurements via UHF telemetry to the FIS demonstrator on board the aircraft.

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 was 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.

As measurement sensor for the GAST-D FIS demonstrator, the Aerodata GBAS flight inspection receiver AD-GBAS-0100 was developed within MEGA. This receiver is originally based on a certified aviation receiver and has been modified for additional flight inspection capabilities in order to comply with chapter 4.3.1 of [7]. The additional FI capabilities include special flight inspection parameters and measurements like the 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.*" ([7], 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 VDB messages to the FIS. This includes both GAST-C and GAST-D messages. Furthermore, both position solutions based on 100 seconds and 30 seconds smoothed pseudo ranges are made available. The message authentication checks, which are mandatory for GAST-D, are performed and their results are sent to the RTS.

The FI capabilities are completed by the commissioning or test mode of the GBAS receiver with the possibility to configure the D_{max} value and the lateral and vertical alert limits (LAL/VAL) during runtime via the FIS.

A more detailed description of the GAST-D FIS demonstrator and its components is given in [1].

GAST-D FLIGHT INSPECTION PROCEDURES

Project MEGA has proposed flight procedures based on known requirements, experience from GAST-C procedures, and the geometry of the minimum GBAS approach service volume. While a more detailed description of these procedures is given in [1], the proposed measurement trajectories are summed up as follows.

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. Upper level run at 3000 m HAT from a distance of 37 km to 24 km (vertical coverage).
5. Lower level run at 600 m HAT from a distance of 37 km to 4.5 km (vertical coverage).

PROJECT MEGA VERIFICATION

The GAST-D FIS demonstrator and its procedures was tested in car and in flight tests at different GBAS installations in Germany. The road test evaluated the system performance and allowed for easy bug fixing and software improvements before going into the verification flight trials.

Road Tests

The GBAS FIS demonstrator had been integrated into a Volkswagen Passat type car, which is operated as an experimental research platform by the Institute of Flight Guidance of TU Braunschweig. This car was already equipped with antennas and an appropriate power supply, so that the integration of the GAST-D FIS could easily be achieved. For the road test, it was not necessary to integrate the UHF telemetry for the RTK/PDGNSS position reference and an INS or AHRS. The integration of the system and the antenna set-up is shown in Figure 3.

An initial road test was conducted directly at the research airport in Braunschweig utilizing the DLR experimental GBAS ground station. The trajectory around the airport inside the fenced area is depicted on the left side of Figure 4.

After this test of the general functionality of the demonstrator at the experimental GBAS transmitter, a second road test was conducted at Frankfurt / Main airport. This airport had an operational Honeywell SLS-4000 GAST-C ground station as well as an experimental Indra Navia/DFS GAST-D prototype ground station with two VDB transmitters at that time, so that different services could been tested. The trajectory of the road test is shown on the right side of Figure 4. The track describes a rough partial orbit in the west of the airport.

In summery these road tests allowed for the verification of the general functionality with three different GBAS ground station using GAST-C and GAST-D signals.

Figure 3: Integration of the GBAS FIS demonstrator into the TU Braunschweig research car

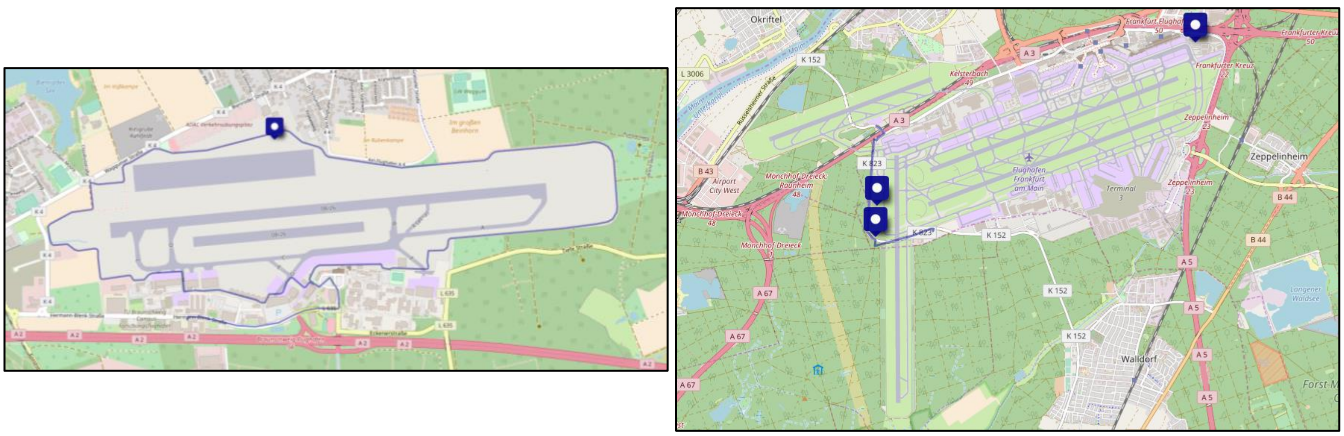


Figure 4: Track of the road test (blue line) at the airports Braunschweig-Wolfsburg (left) and Frankfurt / Main (right). The GBAS VDB transmitter locations are indicated. (map extract from OpenStreetMap, CC by-SA-License 3.0)

<u>Flight Tests</u>

For the verification flight tests, the GAST-D FIS demonstrator was integrated into the Dornier DO128-6 research aircraft D-IBUF of TU Braunschweig. The GNSS and VHF antennas of the aircraft were used for the GNSS position reference and for the GBAS receiver. An additional UHF antenna for the RTK/PDGNSS telemetry was installed. Furthermore the INS of the aircraft was connected to the FIS demonstrator in order to get accurate position, velocity and attitude measurements. The integration of the system into the aircraft and the antenna set-up is shown in Figure 5.

The flight tests were carried out at three different airports in Germany. A first, short flight was done at the research airport in Braunschweig (EDVE) in order to test the integration of the GAST-D FIS demonstrator and all of its components. For this, the experimental GBAS station of the German Aerospace Center DLR was successfully used. Compared to the earlier introduced flight inspection procedures a reduced subset of these was flown, since this was only a functionality test. An overview on the planned and the actually flown procedures in Braunschweig is given in Figure 6.

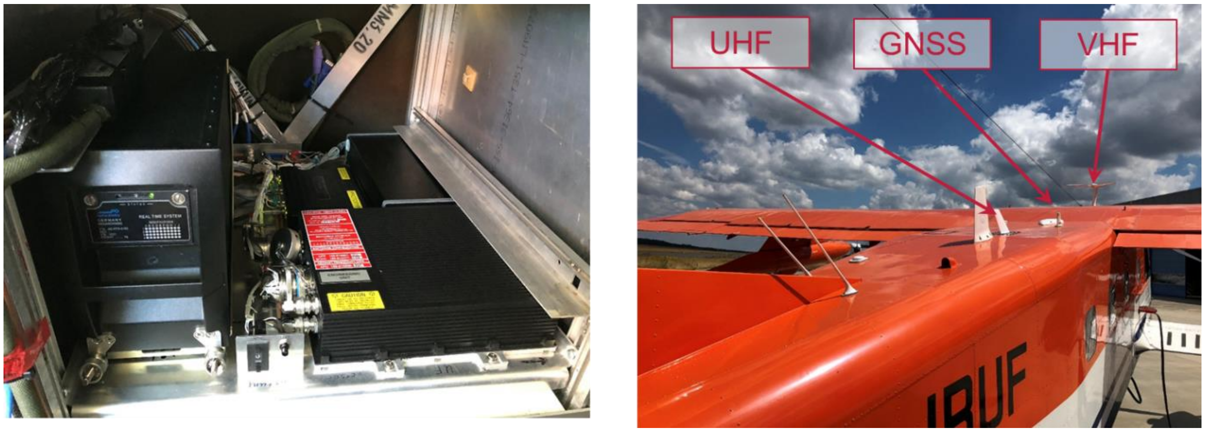


Figure 5: Integration of the GBAS FIS demonstrator into the TU Braunschweig Dornier DO 128-6 research aircraft D-IBUF

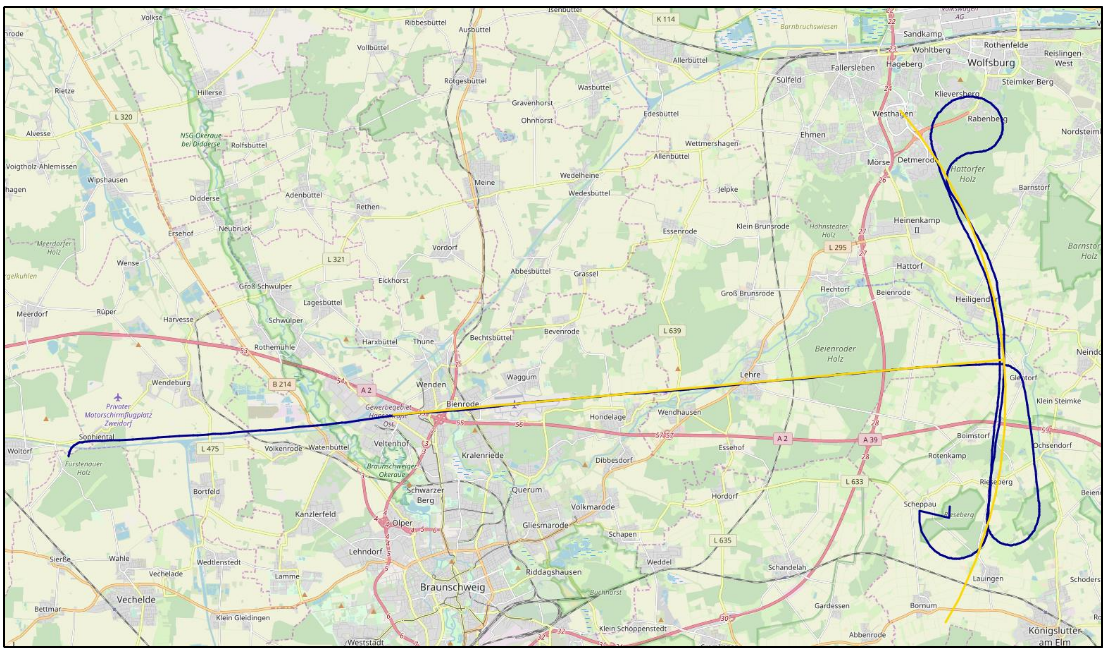


Figure 6: Track of the flight test (blue line) and of the planned procedures (yellow lines) at the airport Braunschweig-Wolfsburg. (map extract from OpenStreetMap, CC by-SA-License 3.0)

The second verification flight was conducted in Bremen (EDDW). The GBAS installation at Bremen airport was the first one in Germany to be approved for operation in 2012. The aim of the Bremen flight campaign was the test of the GBAS FIS and the procedures at an operational GAST-C ground station with potentially fewer interfering traffic movements. For this reason, a complete set of the earlier mentioned GAST-D flight inspection procedures was flown. Additionally the partial orbits were flown in both directions in order to be able to monitor potential timing problems.

The Bremen flights showed that the GAST-D FIS demonstrator works well with an operational GAST-C ground station so that the flight campaign was extended to Frankfurt / Main (EDDF) and its experimental GAST-D installation. The flight experiments were conducted on two different days. The second flight in Frankfurt was used for the verification of changes to the GBAS receiver firmware and to additions of the demonstrator software.

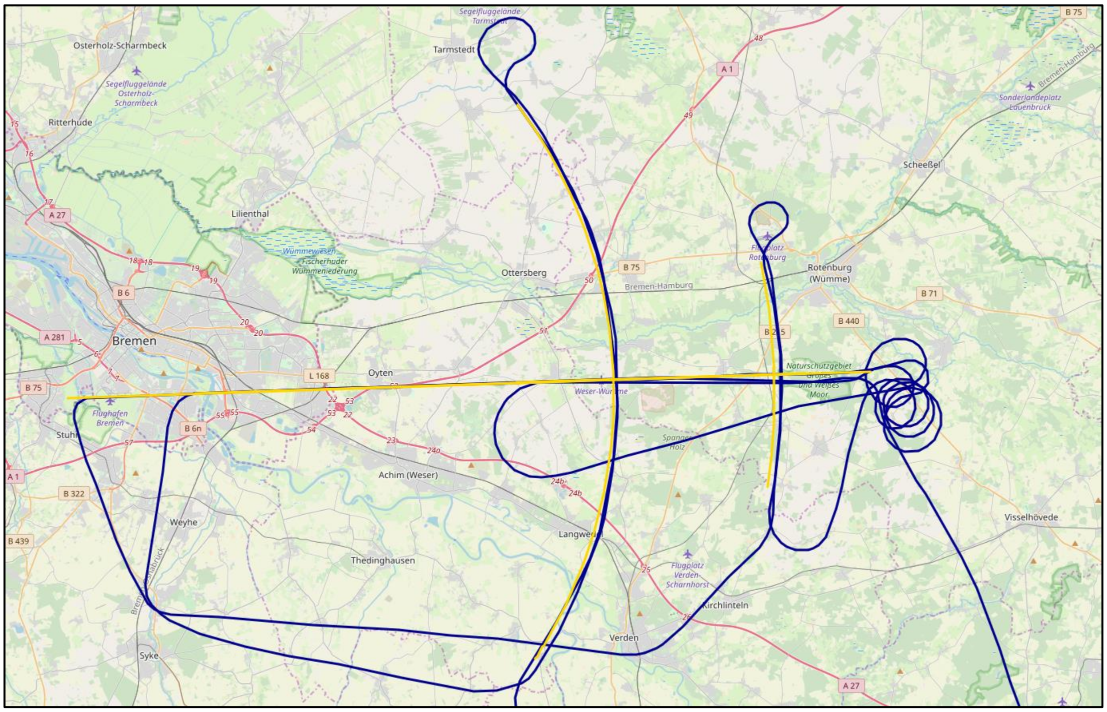


Figure 7: Track of the flight test (blue line) and of the planned procedures (yellow lines) for RWY27 at the airport Bremen. (map extract from OpenStreetMap, CC by-SA-License 3.0)

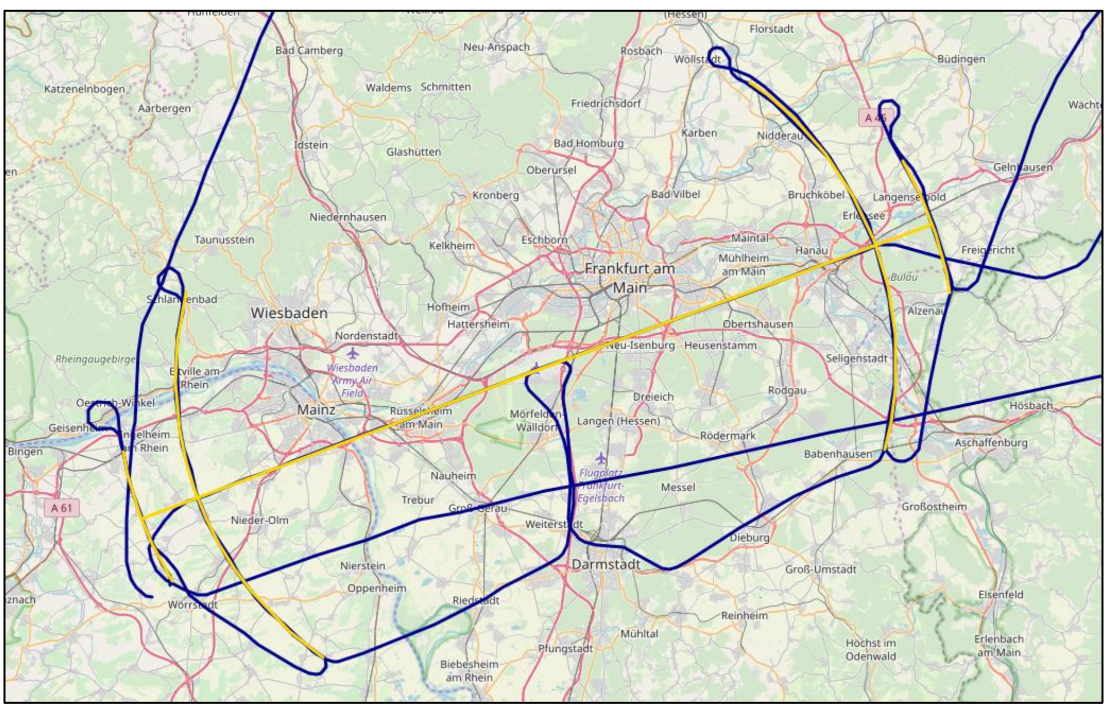


Figure 8: Track of the flight tests (blue lines) and of the planned procedures (yellow lines) for RWYs 07R and 25L at the airport Frankfurt / Main. (map extract from OpenStreetMap, CC by-SA-License 3.0)

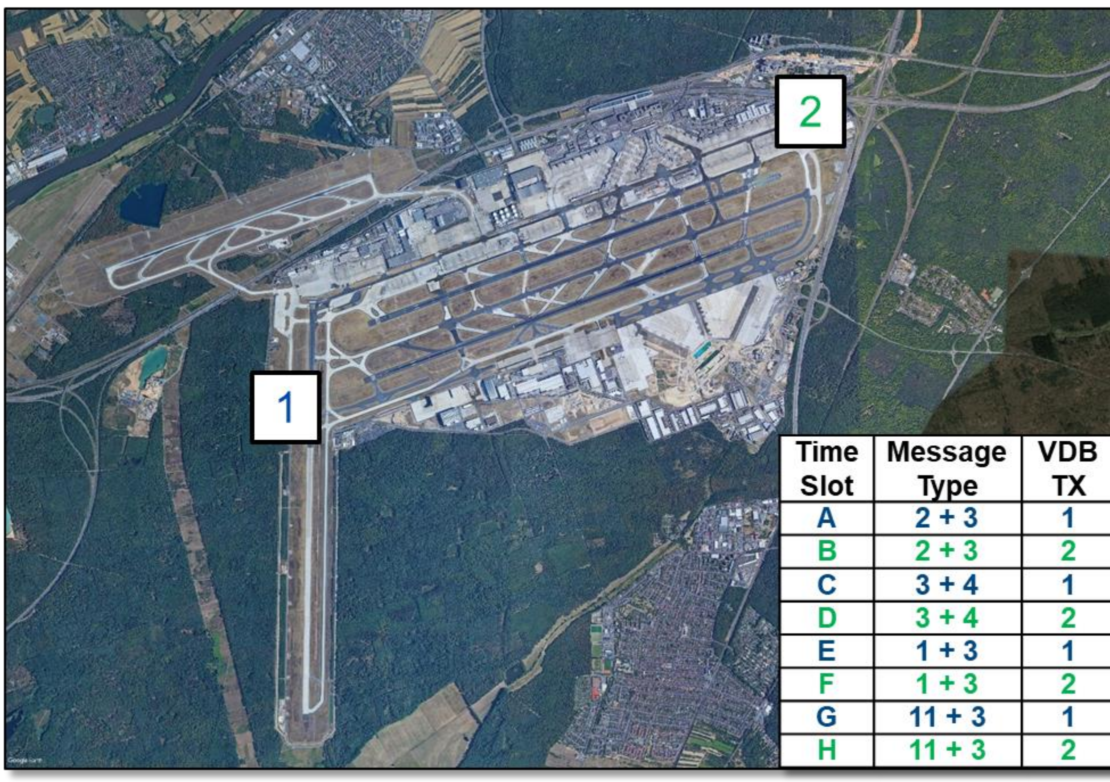
The first GAST-D flight tests were conducted to runway 07R at Frankfurt airport. Due to the high traffic volume at EDDF, the procedures were reduced to one 19 NM long approach and two partial orbits of ±35° at 17 NM distance from the threshold and two partial orbits of ±10° at 10 NM distance. These procedures were repeated during the second verification flight in Frankfurt for runway 25L. The planned and flown procedures are shown in Figure 8.

System Verification Results

For the verification of the GAST-D FIS demonstrator and the procedures, several steps were taken. Additionally to the GBAS FIS, the research aircraft was equipped with a Rockwell Collins GLU 925 GBAS receiver for comparison. The outputs of the various receivers were compared for validation. External tools (like Eurocontrol's Pegasus software and TU Braunschweig's TriPos library) were also used for this. These cross comparisons between different receivers and software solutions, showed and verified the functionality of the AeroFIS® based GAST-D FIS demonstrator.

Dual VDB Transmitter

The experimental GBAS ground station at Frankfurt / Main airport transmits its VDB signal from two separate transmitter antennas. These are located in the west and the east of the airport area. Since both transmitters work on the same frequency, the VDB messages are send on alternating VDB time slots. The location of the VDB transmitters and the distribution of the different message types on the VDB time slots and transmitter are shown in Figure 9.



Time Slot	Message Type	VDB TX
A	2 + 3	1
B	2 + 3	2
C	3 + 4	1
D	3 + 4	2
E	1 + 3	1
F	1 + 3	2
G	11 + 3	1
H	11 + 3	2

Figure 9: Experimental VDB transmitter locations and assignment of the message types to time slots and VDB transmitters at Frankfurt / Main airport. (map extract from Google Earth)

The AD-GBAS-0100 receiver and the real-time computer AD-RTS-0100 allow for an accurate measurement and time stamping of each of the received VDB messages. By knowing the exact timing of the messages, it is also known which transmitter broadcasts at which point in time. Thus, the FIS demonstrator was capable of measuring and inspecting two or more VDB transmitters at the same time.

Figure 10 shows the VDB field strength measurements for both VDB transmitters of the experimental GAST-D installation at Frankfurt / Main airport. These measurements were recorded during the approach to runway 25L. With the approach direction (from east to west) in mind, it can be understood from Figure 10, that the maximum field strength of transmitter 2 is received before the maximum field strength of transmitter 1 is recorded.

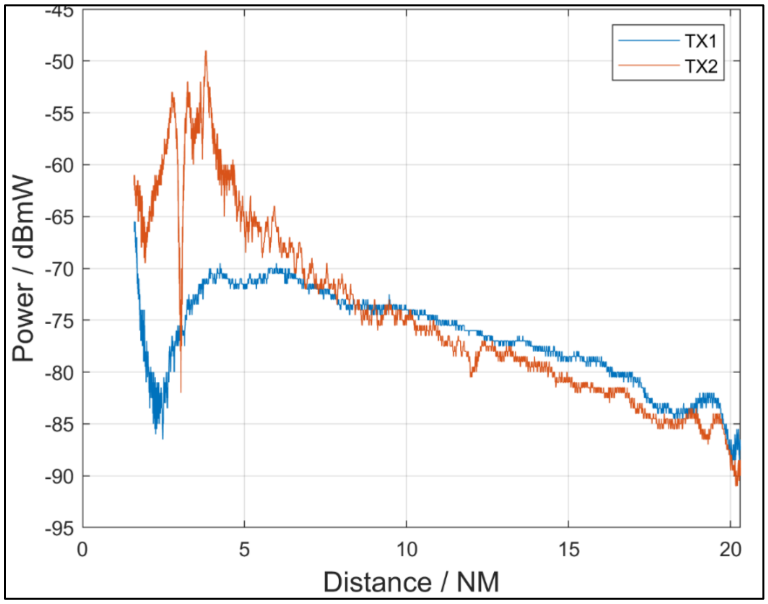


Figure 10: VDB field strength measurements of both experimental transmitters at Frankfurt / Main airport.

CONCLUSIONS

With the conclusion of project MEGA, Aerodata has a fully functional and verified GAST-D FIS demonstrator available. The industrial exploitation of the project results have led to the integration and extension of the GAST-D functionality and algorithms into the AeroFIS® flight inspection system family. The AD-GBAS-0100 is the new standard FIS GBAS receiver for current and future Aerodata AFIS with GBAS capability.

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REFERENCES

[1] C.-S. Wilkens, T. Feuerle, M. S. Stanisak and P. Thomsen, "Flight Inspection of GAST-D Approach and Taxi Guidance Systems," in *Proceedings of the 2018 International Flight Inspection Symposium (IFIS)*, Monterey, CA, USA, 2018.

[2] C.-S. Wilkens, P. Thomsen, M. S. Stanisak and P. M. Schachtebeck, "Inspection of GAST-D approach and taxi guidance systems," in *Proceedings of the International Symposium on Precision Approach and Performance Based Navigation (ISPA)*, Munich, Germany, 2017.

[3] RTCA, Inc., DO-246E - GNSS-Based Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document, Washington, DC, USA: RTCA, Inc., Special Committee 159, 2017-07-13.

[4] RTCA, Inc., DO-253D - Minimum Operational Performance Standards for GPS Local Area Augmentation System Airborne Equipment, Washington, DC, USA: RTCA, Inc., Special Committee 159, 2017-07-13.

[5] ICAO, Annex 10 to the Convention on International Civil Aviation, Aeronautical Telecommunications, Volume I, Radio Navigation Aids, 7. ed., Montréal, Canada: International Civial Aviation Organization, 2018.

[6] ICAO, Doc 8071 - Manual on Testing of Radio Navigation Aids, Volume I, Testing of Ground-Based Navigations Systems, 4. ed., Montréal, Canada: International Civil Aviation Organization, 2018.

[7] ICAO, Doc 8071 - Manual on Testing of Radio Navigation Aids, Volume II, Testing of Satellite Based Radio Navigation Aids, 5. ed., Montréal, Canada: International Civil Aviation Organization, 2006.

[8] C.-S. Wilkens, "A Multi-Constellation GNSS Based Position Reference for Flight Inspection," in *Proceedings of the International Flight Inspection Symposium IFIS*, Belgrade, Serbia, 2016.