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Flight Testing GLS Approaches Enabled by Wide Area Corrections in Kerkyra, Greece

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Abstract

Many airports with a high value to commercial air traffic have spatial or budgetary constraints which prevent the installation of a precision approach system. We previously designed a low-cost precision approach system which combines the advantages of both ground-based and satellite-based augmentation systems by using a converter between them in order to allow GAST-A approach types.

We installed, operated, and flight-tested such a system at Kerkyra Airport using an A320 aircraft. During these, we recorded data from a commercial multimode receiver as well as GPS raw data in order to prove the feasibility of the system. Data were analyzed using the Pegasus toolset as well as a highly precise reference trajectory computed from postprocessed carrier phase data.

The data recorded show excellent performance for approach guidance that is no different from that of the more expensive GPS landing system GLS and provides guidance in accordance with the localizer performance with vertical guidance standards.

Our low-cost precision approach system can provide precision approach-like guidance to appropriately equipped transport aircraft. Kerkyra Airport is extremely limited in availability of usable surface area, such that conventional precision landing aids cannot be placed on airport property. The system provides the ground-based augmentation system approach service type A, a category defined in Annex 10 to the convention of Chicago. This category has not seen any operational use until now but offers an opportunity to provide precision approaches based on GLS where guidance down to a certain altitude will be sufficient.

Keywords: GLS, flight test, GPS, GBAS

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1. Introduction

The ground-based augmentation landing system (GLS) is a locally installed differential GPS providing precision approach guidance for aircraft (Felux et al., 2013). It is intended to replace the instrument landing system (ILS) which has been in service since 1939 (Sanders & Fritch, 1973) and which was officially adopted by ICAO in 1948 (Vickers et al., 1997). Typically, a ground-based augmentation system (GBAS) installation consists of four GPS reference antennas connected to a central processing unit with a very high frequency (VHF) data broadcast unit (EUROCAE, 2013). It provides corrections to the GPS signals received by a user, as well as integrity, approach direction, and glide path information.

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In comparison to ILS, a GBAS offers a set of advantages, like smaller critical areas or a higher flexibility for the installation site; however, for a complete GBAS installation all costs could be as high as those for ILS.

A more cost-effective solution to provide the same guidance, but at a lower service level, called approach procedure with vertical guidance (APV), is the converter system named GLS approaches using satellite-based augmentation system (SBAS) (Dautermann et al., 2020). Basically, it is a transponder for a wide area differential GPS combined with final approach segment data blocks from national aeronautical information publications.

Both GLS and GLASS provide identical information to the approaching aircraft. But while GLS is already standardized and certified at an international level, GLASS is a new technology that still needs to prove its operational suitability.

Kerkyra International Airport (International Air Travel Association identifier CFU) is a good example of an airport that has to deal with tight area constraints. It is located on hilly Corfu island in the Mediterranean Sea, built partially on heaped up land into the ocean (Figure 1). There is very little open land area on the airport property so that classical radio navigation aids cannot be installed. An approach employing stand-alone area navigation supported by GPS is already in place, but a GLS could not be installed on the airport property due to the space requirements of a GBAS. The GLASS technology, however, does not occupy a lot of space apart from a VHF transmitter antenna and a GPS receiver antenna.

Hence, in collaboration with Kerkyra Airport, operated by Fraport Greece, we installed a GLASS transponder at the airport, and obtained an experimental frequency permission from the Hellenic civil aviation authority. Then, on December 1, 2020, we flew DLR's Advanced Technology Research Aircraft to Corfu, Greece in order to validate the installation of the GLASS transponder for GLS approaches.

2. Experimental Setup

The Advanced Technology Research Aircraft is an Airbus A320 equipped with the current Thales FMS2 and basic flight test instrumentation. It provides ARINC 429 (ARINC429-20, 2001) data acquisition from the aircraft's basic avionics, as well as additional sensors such as precise high-quality GNSS receivers, data storage, and real-time visualization of these data to the flight test engineer. It consists of six CRONOS data acquisition units by IMC (http://www.imc-berlin.com/applications/aerospace/), three controlling computers, and seven display screens for two engineer workstations. From the flight test instrumentation, a custom data stream can be provided to further experimental stations if needed. All data are recorded at a rate of 20 Hz.

Additional experimental equipment in the cabin includes a Collins GLU925 multimode receiver (MMR) connected

Figure 1. Kerkira Airport and GLASS installation location. The Kathrein VDB antenna is visible on the ridge of the yellow building in the northwest of the airport.

to the output of an experimental ANTCOM 3GNSSA-XT-1 multiband GNSS antenna and, via a high-frequency splitter, to the localizer antenna in the nose cone of the aircraft. The GLU925 is tuned to a specific GLS channel via custom interface software utilizing the ARINC 429 input bus. When correctly tuned and in range of the transmitter, it continuously receives data messages from the ground at 2 Hz. Applying correction and integrity data, the GLU925 computes its position together with lateral and vertical protection levels (LPL, VPL) according to RTCA (2017). Those limits bound the position uncertainty at the 99.99998% level and are continuously compared to the respective alert limit (LAL, VAL). The alert limits constitute the maximum allowed values for the protection levels. They scale down from their maximum value at the beginning of the approach to the final approach segment VAL of 25.4 m and LAL of 40 m. When the aircraft is in the precision approach region it outputs lateral and vertical angular deviations to the reference approach path provided by the final approach segment data block. The aircraft can then be steered along this reference path by the pilot.

On the airport premises, we installed an SBAS to GLS converter unit as described by Dautermann et al. (2020) and a Telerad EM9009 VDB transmitter connected to a Kathrein K552131 broadband omnidirectional antenna as shown in Figure 1. This combination broadcasts GLS corrections according to RTCA (2004) and EUROCAE (2013) as well as a final approach segment data block for runway 34 designed by the SHERPA project of the 7th EU framework program. The only change applied to the data block was switching the approach performance designator to zero (indicating an APV) and adjusting the aforementioned VAL to be compliant with the work described by Dautermann et al. (2020). The data are shown in Table 1.

Table 1
Final approach segment data used for the GLS approach procedure.

Operation type	**0**
SBAS provider	1 (EGNOS)
Airport identifier	LGKR
Runway	34
Runway letter	0 (none)
Approach performance designator	0
Route indicator	
Reference path data selector	0
Reference path identifier	S34A
LTP/FTP latitude	393530.9275N
LTP/FTP longitude	0195450.0400E
LTP/FTP ellipsoidal height (meters)	32.8
FPAP latitude	393642.9925N
Delta FPAP latitude (seconds)	72.0650
FPAP longitude	0195422.9185E
Delta FPAP longitude (seconds)	−27.1215
Threshold crossing height	15.0
TCH units selector (meters)	1
Glidepath angle (degrees)	3.00
Course width (meters)	105.00
Length offset (meters)	0
HAL (meters)	40.0
VAL (meters)	25.4
ICAO code	LG
LTP/FTP orthometric height (meters)	1.6

3. Flight Test Sequence and Data Recording

On December 1, 2020 we flew the flight test aircraft to CFU, initially approaching eastbound from Italian airspace to the west. Thereafter, for easier coordination with air traffic control, we followed the published approach and missed approach procedures of the area navigation (RNAV) approach to runway 34 and at times radar vectors given by the air traffic controller. We flew a total of six approaches to the decision altitude of 770 feet above mean sea level, five followed by a missed approach and the final one followed by a departure procedure back to the north. The track over ground is indicated by the yellow line in Figure 2.

The GLU925 outputs ARINC429 label called DGPS Status as part of the digital output data on the MMR datalink bus (Rockwell Collins, 2004). This label contains several bits indicating the internal checks of the GPS landing unit. The most interesting are bit 16 "Differential Correction Latency" (0 = normal, 1 = correction data old), bit 17 "At Least One IODE/CRC Mismatch" (0 = match, 1 = IODE/CRC does not match), bit 18 "LPL Currently Exceeds Alert Limit" (0 = false, 1 = true), bit 19 "VPL Currently Exceeds Alert Limit" (0 = false, 1 = true), bit 26 "Outside Precision Approach Region (PAR)" (0 = in region, 1 = not in region), and bit 27 "Outside Vertical Guidance Availability Region" (0 = in region, 1 = not in region) and are reported here.

Bit 17 is the result of comparison between the issue of data ephemeris (IODE) value received from the GPS satellite (NAVSTAR GPS Space Segment/Navigation User Interfaces, 2014) and the one belonging to the associated correction. This is additionally compared to the correctness of the cyclic redundancy check (CRC) contained in the messages received from the ground station using an exclusive or XOR.

Furthermore, we collected position and altitude data from the flight test instrumentation as well as protection level data contained in the ARINC429 labels 146 and 156.

4. Limitations

The experiment was conducted under the following boundary conditions.

The deviation information from the GLASS was shown to the pilot on an experimental display located in the electronic flight bag clipboard, but the airplane was controlled by reference to the trajectory for the published RNAV34 approach procedure generated by the flight management system.

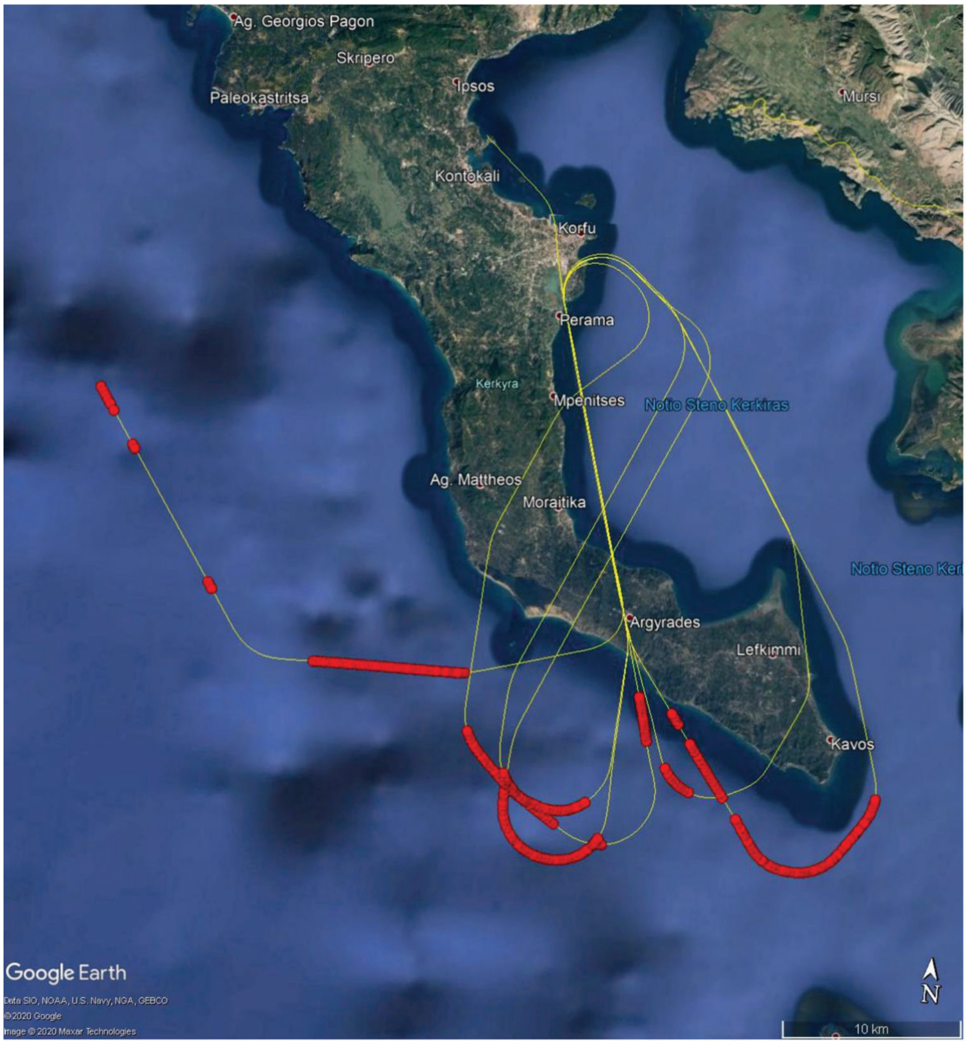

Figure 2. Ground track of the validation flights. Red dots show places where no VDB messages were received.

The correction data mentioned in Section 2 cannot be older than 7.5 s, otherwise they are considered invalid (RTCA, 2017, section 2.3.8.1.3.1) and approach guidance is lost.

The approach procedure is 5° offset from the runway track and therefore a non-precision approach. It cannot be used for automatic landings.

5. Results

Figure 3 shows the data recorded during the six approaches. The top panel depicts aircraft altitude (blue), VPL (red), and VAL (yellow). Since the vertical component is always controlling (Dautermann et al., 2012), the lateral one is omitted in this plot. The bottom panel shows the selected status bits as described earlier. Here a "1" is indicated in black.

While the aircraft was lining up for the approach at altitudes between 4000 and 3000 ft MSL and flying south of the mountainous area, we lost the reception of the VDB signal. The location of the signal loss is indicated by the red dots in Figure 2. Additionally, the GLU925 indicated "correction data old" in the differential correction latency bit. At the same time, VPL and LPL are set to their default values of maximum deflection and checking of their values against the alert limits is disabled. In Figure 3 we can see that these events occurred always outside the precision approach region, which is the area of final approach defined in RTCA (2017). The vertical guidance availability region (VGAR) bit, however, was flagged as "outside" when the differential correction latency was too high. The VGAR is not a requirement derived by the standards but rather a specific feature of the Collins GLU925. When the aircraft cleared the signal blockage of the hills, guidance was immediately restored and protection levels were output again by the GLU925. Otherwise, VPL behavior was as expected at a level of 15 meters and always below the alert limit.

We also encountered what appears to be a bug in the GLU925 firmware. The bit "IODE/CRC" mismatch was

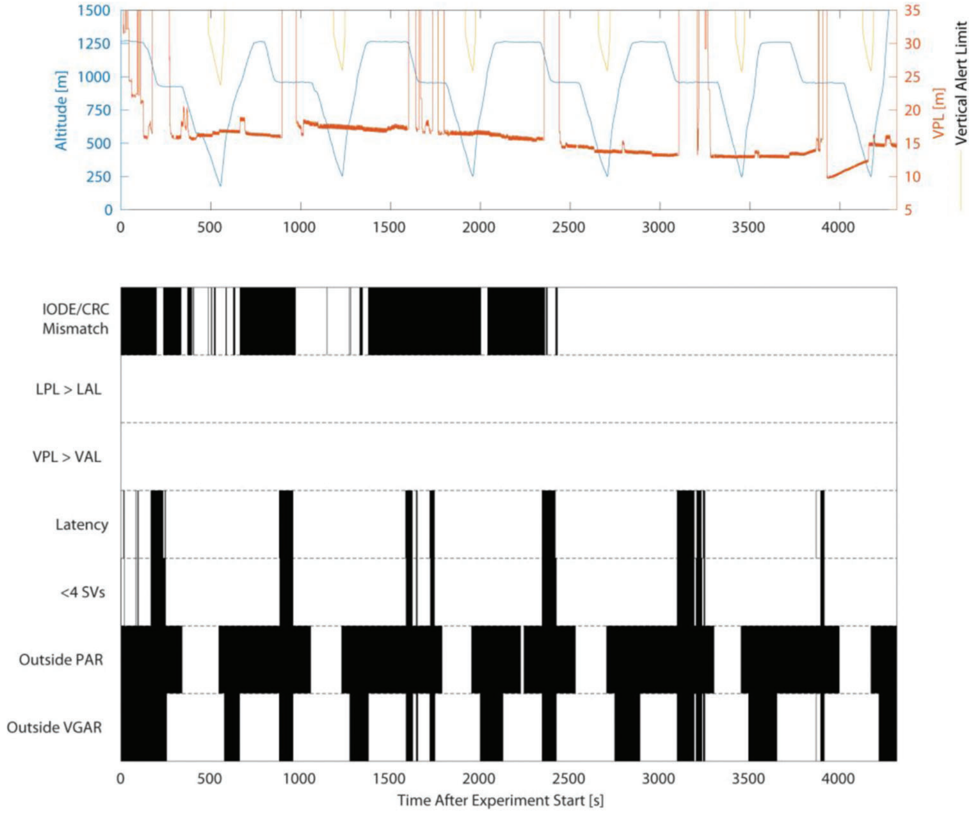

Figure 3. Data recorded by the GLU925 during the approaches. Top: altitude, protection levels, and alert limits. Bottom: status bits of the DGPS Status label. The bits indicating too high a latency correspond to the VDB outages in Figure 2.

active during the first half of the flight experiment. It was not caused by any fault in the systems but rather by two GPS ephemerides simultaneously having identical integer values for IODE. This behavior repeated itself on the next day during an additional test that we ran for confirmation. While this bug does not influence the *ad hoc* availability (only one satellite is removed from the navigation solution) it degrades the quality of the position solution. Collins Aerospace was informed about this software glitch.

The data collected during the flight trial are in line with the results reported, for example, by Jochems et al. (2022), who report both SBAS and GLS protection levels. For additional comparison, the supplemental material to Gonzaga-López et al. (2020) shows an official flight validation report for a pure SBAS final approach segment. Here, the SBAS protection level sawtooth pattern that is distinctly visible in Figure 3 can also be identified.

6. Conclusion

Flight testing revealed that the hilly terrain to the south of Kerkira Airport blocks signal reception of the GLS VDB broadcast. However, the approach service provided by the GLS is only required to be available inside the final approach segment starting at the final approach fix, typically 2000 ft above and 6.3 nautical miles from the threshold along the final approach track. From this point to the threshold, GLS service is available with the current GLASS station. From the initial approach fix to the final approach fix, navigation is accomplished using standard area navigation equipment. Alternatively, the approach design could be altered such that the intermediate and initial approaches are either at a higher altitude or such that the approach would begin east of the airport rather than west. The system cannot be placed on top of the hills to the south since the aircraft fuselage will likely block VHF signals during final approach. Otherwise, the GLASS system performed as expected and provided continuous and precise guidance during the final approach segment. It is ideally suited for airports such as Kerkyra, where the surface area and available budget are limited.

The approach procedure itself could be published by a national authority either as a GLS approach procedure or as a non-precision approach procedure indicating the GLS channel number as additional information. Here, the main effort should be on the ease of introduction. This means that a pilot or controller already familiar with GLS procedures should not require additional training to work with the GLASS system. A future study will involve pilots to determine which kind of presentation and flight management system coding is necessary to optimally utilize this approach service type. Furthermore, certification efforts based on the Australian ground-based regional augmentation system are ongoing at national and international level.

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