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CAT II / OTS CAT II operations using existing CAT I Ground Based Augmentation System (GBAS)

Findings from flight tests in a fully certified Airbus A330 Level D Flight Simulator

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Abstract— **Flight tests performed in an A330 simulator have shown that the existing standardised Ground Based Augmentation System (GBAS) CAT I with a Vertical Alert limit of 10m as per ICAO Annex 10, would be operationally suitable for CAT II and Other Than Standard (OTS) CAT II operations.**

Tests in an Airbus A330 Level D (fully certified training simulator) flight simulator were performed by EUROCONTROL in cooperation with Technical University of Berlin, to investigate whether the worst case errors of a GBAS CAT I precision approach system (10m vertical deviation) would still be acceptable for CAT II operations. Additionally similar assessment was performed for the new approach classification termed "Other Than Standard" (OTS) CAT II which allows operation of CAT II approved aircraft down to a decision height (DH) of 100ft on runways not meeting full Cat II requirements. OTS CAT II relaxes the approach lighting requirements which is compensated by a higher required Runway Visual Range (RVR) and higher guidance performance requirements (i.e. autoland). GBAS CAT I suitability to support OTS CAT II and CAT II operation would provide a new potential benefit for airlines that have invested in a GBAS CAT I system. Those benefits could be increased access to runways served by GBAS in low visibility conditions. It could improve as well traffic flow in low visibility operation by replacing the standard Instrument Landing System (ILS), which requires larger separation on final approach during CAT II/III operations due to technical design.

The tests demonstrated that failures up to 10m vertical deviation are operationally acceptable for CAT II operations as the landing point was always well within the landing box criteria used for the demonstration of autoland systems. Lateral deviations were easily detected but pilots expressed difficulty in detecting the vertical errors. Vertical errors less than 10m were not detected by the pilot based on cues in the visual segment. However pilots continued the approach and touchdown was within the normal touchdown zone. Some but not all pilots detected errors larger than 10m (i.e. 15m) which in some cases lead to a go around.

The visual cues were sufficient at the decision height (DH) to conduct the OTS CAT II operation. The perception was that due to the increased RVR required for OTS CAT II, the visual cues at DH were even better in OTS CAT II conditions than in standard CAT II conditions.

Keywords--GBAS; GLS, Low Visibility Operation; CAT II; OTS CAT II; Full Flight Simulator

I. INTRODUCTION

Ground Based Augmentation System (GBAS) is a new precision approach landing system using Global Navigation Satellite System (GNSS) navigation with differential correction provided by a ground station. It has been certified on certain GBAS equipped aircraft for CAT I operation. To assess its suitability for CAT II operations, tests in an Airbus A330 Level D full motion flight crew training simulator were performed by EUROCONTROL in cooperation with the Technical University of Berlin.

One purpose of the tests was to investigate whether undetected worst case errors within the certification boundary of a GBAS CAT I system, would be acceptable in a CAT II or Other Than Standard (OTS) CAT II operation. The latter is a new classification of operation introduced in EU OPS [1]. The objective was to demonstrate compliance with landing performance requirements like Obstacle free Zone (OFZ) as defined in ICAO Annex 14 Volume I [2] and Touchdownzone (TDZ) as defined in the FAA Advisory Circular AC120-28D and EASA CS AWO [3].

The other motivation was to evaluate if the pilots would be able to detect the possible vertical and lateral errors generated by the GBAS CAT I system during the visual segment (100ft above ground until touchdown) and the acceptability of the operation by the pilots.

GBAS CAT I suitability to support OTS CAT II and CAT II operation would provide a new potential benefit for airlines that have invested in a GBAS CAT I system. Those benefits could be increased access to runways served by GBAS in low visibility conditions.

It could improve as well traffic flow in low visibility operation by replacing the standard Instrument Landing System (ILS). ILS requires an increased separation between approaching aircraft on final approach during CAT II/III operations due to technical design. The capacity during low visibility operation could be upgraded by using GBAS subject to suitable runway and taxiway layout to the benefit of airport and aircraft operators.

II. BACKROUND

A. GBAS Landing System

The GBAS Landing System (GLS) is a precision approach system. GLS provides augmentation and final approach segment (FAS) path definition to the approach and landing guidance functions. This augmentation meets the ICAO Standard and Recommended Practices (SARPS) Annex 10 requirements [4] and airborne as well as ground equipment have been certified for CAT I.

The GBAS is divided in three distinct sub-systems as depicted on Figure 1

- The satellite sub-system (space based constellation), which provides both the aircraft GNSS receiver and the ground GBAS station with ranging information
- The ground station sub-system, which monitors the satellite signals and calculates/broadcasts pseudo-range corrections, integrity parameters, various locally relevant data such as atmospheric data and Final Approach Segments (FAS) defining the path in space to enable Precision Approach (PA) operations
- The aircraft sub-system, which receives both the satellite signals and the GBAS signals, supplying navigation output/guidance to the flight instruments and to the autopilot

According to EUROCAE ED144 standard [5], which contains ILS equivalent performances for GBAS, GBAS CAT I performance would not meet integrity and continuity requirements for CAT II operations. However, ground station continuity and integrity requirements to conduct OTS CAT II operations as published in EU OPS are less stringent than EUROCAE ED144 as they take full credit for the visual segment of CAT II operations. These EU OPS 1 requirements can be met by the standardized GBAS CAT I system because:

- Most existing GBAS CAT I systems provide higher accuracy than the SARPS CAT I requirements, and indeed are fully compatible with ILS CAT II or even CAT III accuracy requirements
- The probability of missed detection and the continuity requirement are fully compatible with EU OPS 1 ground station requirements

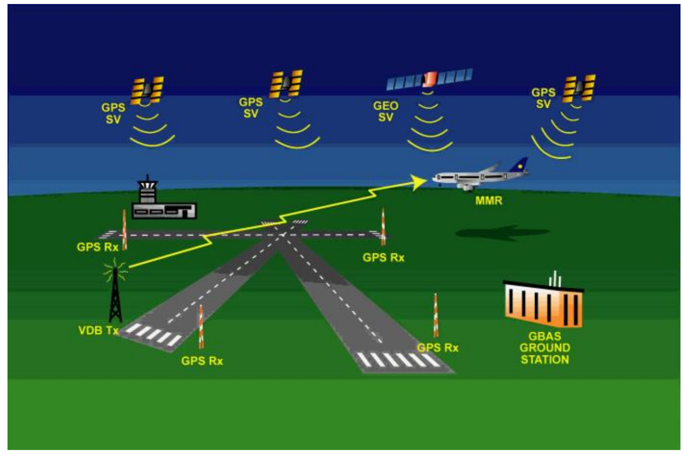

Figure 1. *Grond Based Augmentation System (GBAS)*

However, differences remain between ILS and GBAS that need to be assessed to validate fully the suitability of GBAS CAT I system for CAT II operations:

The CAT I integrity requirement permits errors larger than the ILS CAT II requirement. Therefore it has to be demonstrated that the worst guidance error from GBAS would lead to a successful landing or a safe recovery by the pilot.

ILS integrity provides a flag if the error exceeds 2m. According to GBAS CAT I SARPS vertical deviations would not exceed 10m without an alert to the pilot. The vertical performance between ILS and GBAS differs in the kind of possible failures. Disturbances and offsets to the nominal path produced by ILS are typically angular. The ILS guidance gets more precise coming closer to glidepath and localizer transmitter. Offsets produced by GBAS can be parallel to the standard glide path and can remain in size or even increase (see Figure 2.)

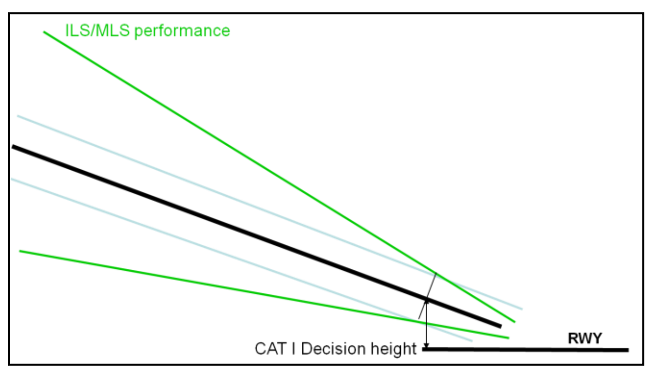

Figure 2. *GBAS and ILS vertical Performance*

B. OTS CAT II Operation

OTS CAT II is a new operation defined in EU OPS 1 [1] that allows CAT II capable aircraft and pilots to fly approaches down to 100ft decision height with less stringent approach lighting requirements, if conducted with autoland down to the runway threshold or with Head-Up Display (HUD) guidance. The required Runway Visual Range (RVR) minima to conduct such approaches depend on the decision height, the aircraft category and the available approach light system. The table below summarizes the conditions used for the simulations in both the CAT II and OTS CAT II.

TABLE I. WEATHER MINIMA CAT II VS. OTS CAT II

Operation	CAT II	OTS CAT II
Approach Light System	CAT II/III	Intermediate Approach Light System (length ≥ 420m)
RVR	300m	450m
DH	100ft	100ft

According to EU OPS 1 [1], a pilot may not continue an approach below the Category II decision height unless visual reference containing a segment of at least three consecutive lights being the centre line of the approach lights, or touchdown zone lights, or runway centre line lights, or runway edge lights, or a combination of these is attained and can be maintained. This visual reference must include a lateral element of the ground pattern, i.e. an approach lighting crossbar, the landing threshold or a barrette of the touchdown zone lighting.

These operations have been specified only for ILS and Microwave Landing System (MLS) in EU OPS 1 which is in force since July 2008. Applicability to GBAS operation was the second objective of these simulations.

III. TEST SERIES

A. Test Strategy

The tests are very repetitive and it was expected that pilots would very quickly understand that the tests are about flying paths with various errors. The reaction of pilot would certainly be affected by this feature and therefore this could have an effect on the results. Pilots might just be expecting the situation and react accordingly. During normal operation the approach follows a long period of cruise, especially after long haul flights. Also the picture which appears at decision height looks different every time. Therefore, to minimize the risk of pre-emptive correction to errors the following test strategy was applied:

- Brief the pilot that the purpose of the tests is about comparing CAT II and OTS CAT II
- Provide no further information about the possibility of vertical or horizontal errors
- Following each run the pilots complete a questionnaire about the flown approach
- After the tests, present the exact objectives of these tests
- At the end the pilots complete a questionnaire about acceptance of vertical and lateral offsets

B. Test facility

To conduct such tests the key requirements for the simulator were:

- ILS autoland capability (which is sufficient to emulate GBAS autoland capability as ILS or GBAS guidance play the same role in the operation).
- The HMI shall be realistic notably for the Primary Flight Display (PFD) flight data and the ILS deviations.
- It is of prime importance to have a well simulated visual capability with the applicable RVR values and DH, as external references are the key factor in landing/missed approach decisions.
- Possibility to realistically simulate ICAO and EU OPS 1 CAT II and OTS CAT II approach lighting.
- Cockpit motion is also very important as the simulations are targeting missed approach procedures very close to the runway threshold, and contact during the go around phase might happen. Additionally pilots will most likely detect unexpected aircraft movements linked to the failures if the motion is well represented.
- Monitoring requirement: the actual trajectory needs to be recorded and analyzed afterwards to see where the aircraft lands and whether the protected area is infringed.

The simulator used was the ZFB Full Flight Simulator (See Figure 3.), formerly located at the Technical University of Berlin and now part of the Finnair Flight Training Centre in Helsinki. It is a JAA certified full motion simulator with a modern visual system according to JAR STD 1A Level D. The simulator provides two possible aircraft configurations, A340 and A330. The A330 configuration was used.

Figure 3. *Airbus A330 Full Flight Simulator*

The flight characteristics correspond to an existing reference aircraft. The aircraft type is an Airbus A330-322 with Pratt & Whitney engines PW 4168 which is in service at LTU Airlines and has the German registration D-AERQ and the serial number MSN 127.

The simulation runs on an IBM RS/6000 host computer which processes all the aerodynamic and flight mechanical parameters, the engines and all systems which are not integrated as hardware. The FFS is equipped with original hardware of the simulated aircraft. Moreover, the host integrates and controls other simulation components such as the visual and motion systems, control loading, sound system, Instructor Operator Station (IOS) and also the flight compartment (cockpit).

The hardware is integrated in the simulation process, the so called "hardware-in-the-loop". The original hardware adheres to the ARINC standard (ARINC 429). The interfacing to the original hardware is also done by the host computer connected via Ethernet to the DMC-Interfaces (DATAPATH-C Micro-Computer). DMC-Interfaces enable the communications transfer between Ethernet and ARINC.

The motion system is a hydraulically operated platform with 6 degrees of freedom (6 DOF). It realizes the rotary and translatory movement of the simulated aircraft. In addition, a control loading system gives dynamic force feedback to the pilot depending on actual control force. This is only the case for rudder, nose wheel steering and horizontal stabilizer trim. The integrated sound system simulates the acoustic environment like for instance engine sound and spoiler noise.

The flight deck provides two touch-screen displays with a graphical user interface which is called the Instructor Operating Station (IOS). In general the IOS allows the instructor to operate, control and monitor the simulation. Mainly position control, weather settings and malfunctions were commanded via the IOS.

Audio and video recording capabilities are provided for full flight experiments.

C. *Pilot qualification requirements*

All pilots were airline pilots fully qualified for the type of aircraft of the simulator (Airbus A330) and they held a low visibility procedures (CAT II/III) endorsement as required for CAT II and OTS CATII operations. No test pilot participated.

D. *Test scenarios*

A total of 56 approaches were flown in the simulator. 30 approaches were flown in OTS CAT II conditions and 26 approaches were flown in normal CAT II conditions. The approaches were flown using the ILS and autopilot channels of the aircraft but the ILS signal was modified in order to emulate an undetected position error in the GBAS system. This error lead to centred localizer and glide path indications on the aircraft instruments while the real position of the aircraft was below or above the normal glide path.

Following failures were simulated:

- Constant vertical biases of +/-5m, +/-10m and +/-15m.
- Constant lateral bias of 14m
- Increasing vertical biases starting from zero with a rate of 0.7m/s
- Autoland warnings when the bias exceeded the GBAS vertical alarm limit which was in this case assumed to be 10m.

For the runs with CAT II conditions a runway with precision-approach-light-system was used. For the runs with OTS CAT II conditions a runway with non-precision-approach-light-system was used.

An arrangement of both type of approach-light-system is provided in Figure 4. The main difference are the two red stripes of lights starting from the threshold, left and right of the centreline lights. In addition for a precision approach light system, the length of the centreline lights is 720m to 900m instead of 420m for a non-precision-approach-light-system. Therefore an OTS CAT II approach requires a higher RVR.

The approaches were flown by 6 operational A330 rated pilots including captains and first officers, working for three different companies in Europe.

Figure 4. *Precision-Approach vs. Non-Precision-Approach light-system*

E. *Data recordings*

During the tests 74 parameters containing aircraft state and configuration data were recorded. These data contain the flown aircraft trajectory including details like aircraft latitude and longitude, wheel height above threshold, vertical speed, as well as information concerning the status of the autoflight system. The recorded vertical trajectories of the aircraft expressed as wheel height above threshold versus distance to threshold are provided in the three graphs in Figure 5. The graphs also contain the following surfaces:

- OFZ (dashed red line): Inner approach obstacle limitation surface of the Obstacle Free Zone (OFZ), starting 60 m before the threshold with an upstream slope of 2%, as defined in ICAO Annex 14 Volume I. Obstacles along the approach must be below this surface
- TDZ (green horizontal line): touchdown zone as defined in the FAA Advisory Circular AC120-28D and EASA CS AWO.

CAT II operations require the approach to be flown “auto-coupled” which means continued use of the automatic flight control system or the Head Up Display Landing System (HUDLS) down to a height of 80 % of the Decision Height, while OTS CAT II operations require the use of Autoland capability or approved HUDLS until touchdown. The decision height in all CAT II and OTS CAT II runs was 100ft above ground.

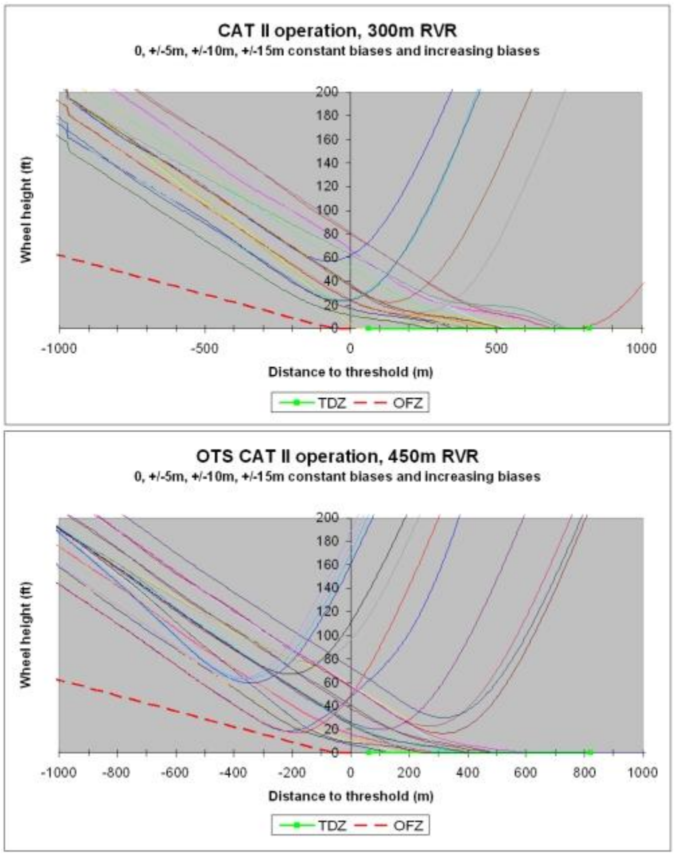

Figure 5. *Vertical profiles for the CAT II,OTS CAT II and CAT I tests*

F. *Discussion of results*

During the tests performed, all pilots landed when the vertical biases were less than +/- 10m in both OTS and normal CAT II conditions. Some, but not all, pilots performed a go around with +/- 15m vertical bias.

Remarkably, if the approach with the -10m bias was presented to the pilots in good visibility conditions, pilots reported that they would most probably initiate a go around due to the 4 red lights that would be visible on the Precision Approach Path Indicator (PAPI) just before touchdown (see Figure 6. .

According to EU OPS 1, the required visual cues at the decision height to continue the approach in CAT II or OTS CAT II conditions are 3 consecutive lights of the approach light system. In general, with only these visual cues and without any out-of-tolerance deviation on the instruments or auto-land warning light, pilots tend to continue the approach. This indicates that especially in low visibility, pilots have very high confidence in the reliability of the landing system.

Most of the pilots had great difficulty to detect the vertical biases at the decision height because of the fact that the visual cues at this height were too marginal, although sufficient to make the decision to continue the approach. As visual landing aids as the PAPI are not visible at the Decision Height with the applied RVRs, instrument indications are still being relied upon to judge the relative position to the nominal approach path. However, in the case of the GBAS errors, instruments indicated an “on profile condition”. The pilots were able to make a visual judgment of the relative vertical position of the aircraft with regards to the nominal approach path only when the threshold lights became visible to them.

Based on visual cues, lateral deviations were detected more easily than vertical deviations.

Tests performed with linearly increasing biases provided similar results: as long as the bias was within +/- 10m and did not lead to an alert in the cockpit, pilots continued the approach.

Despite the reduced approach light system, the overall visual perception below the decision height in OTS CAT II conditions was slightly better than in normal CAT II conditions due to the higher RVR.

The results of the questionnaires indicated that vertical errors of up to +/- 10m in CAT II or OTS CAT II conditions were about the limit of what the pilots would consider as acceptable to make a safe landing, if protected by an obstacle free zone. They all indicate lateral offsets are easier to detect than vertical offsets. This could be because of the missing related picture of how a “normal” approach in CAT II or OTS CAT II conditions should look like. The pilots remarked that most of them had only a few or even no experiences in flying an approach in CAT II conditions as most of the time the weather was either well above CAT II minima or in the other case, CAT IIIB operations were performed with automatic landings and roll-outs.

Figure 6. *VMC approach with -10m bias at 200ft and 50ft*

Still, all the approaches performed in CAT II and OTS conditions lead to either a go around or a landing in the defined touchdown zone. None of the CAT II or OTS CAT II recorded profiles infringes the Obstacle Free Zone.

G. *Video recordings*

The snapshots below provide examples of the available visual cues in CAT II conditions with a precision approach light system, at respectively the Decision Height of 100ft, 50ft and 20ft above ground for a normal approach on the left side and an approach with a vertical bias of -10m on the right side.

It is obvious to see that before 50ft above ground it is very difficult to realize the offset from the normal approach path. Not until the recognition of the dislocation of the green threshold lights the pilot may detect the vertical bias. The period to make the decision for a go-around is very short as the aircraft approaches with a speed of 140kts or 272 km/hour.

Figure 7. *CAT II approach: normal (left) versus -10m bias (right) at 100ft / 50ft / 20ft*

Figure 8. shows examples of the available visual cues in OTS CAT II conditions with a non-precision approach light system at the Decision Height of 100ft, 50ft and 20ft above ground for a normal approach on the left side and an approach with a vertical bias of -10m on the right side.

Thus it appears that the higher RVR gives the possibility to identify earlier the threshold lights which permits visual detection of the offset. Still, the pilots mentioned that the different visual cues using the non-precision-light-system had little or no impact on their decision to continue or abort the approach.

Figure 8. *OTS CAT II approach: normal (left) versus -10m bias (right) at 100ft / 50ft / 20ft*

IV. CONCLUSIONS AND FURTHER WORK

The tests were very successful as they have shown that the existing GBAS CAT I standardised system using a Vertical Alert Limit (VAL) of 10m as per ICAO Annex 10 would be suitable for CAT II operations.

The tests demonstrated that failures up to 10m vertical deviation are operationally acceptable for CAT II operations as the landing point was always well within the landing box criteria used for the demonstration of autoland systems. Lateral deviations were easily detected but pilots expressed difficulty in detecting the vertical errors. Vertical errors less than 10m were not detected by the pilot based on visual cues in the visual segment. However pilots continued the approach and touchdown was within the normal touchdown zone. Some but not all pilots detected errors larger than 10m (i.e. 15m) which in some cased lead to a go around.

Lateral deviations were more easily detected. In general, pilots expressed much more difficulty in detecting vertical errors.

The visual cues were sufficient at DH to conduct OTS CAT II operations. The perception was that due to the increased RVR limits for OTS CAT II, the visual cues at DH were even better in OTS CAT II condition than in CAT II condition.

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