Final Project Report

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Abstract

The project "GBAS Cat II/III L1 Approach" (P15.03.06) covered the system and ground subsystem aspects of the GBAS CAT II/III using GPS L1. This system enables improved low visibility operations (precision approach and landing as well as guided Take-Off) with improved resilience by limiting the capacity reduction in degraded situations through absence of operationally relevant critical and sensitive zones. A single GBAS ground installation can support multiple runways also on large and complex airports. The system performance was validated for TRL 6 / V3 maturity by ground and flight tests, using two prototypes developed within the project by two manufacturers and installed at two airports, Toulouse and Frankfurt in cooperation with the related GBAS airborne project and in context of the SESAR Operational Focus Area "LVPs using GBAS". The maturity for industrialization, approval and later deployment was confirmed by SJU (SESAR solution #55 / Release 4).

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Intellectual Property Rights (foreground)

This deliverable consists of SJU foreground.

Acronyms

Acronym	Definition
ANSP	Air Navigation Service Provider
ATM	Air Traffic Management
CAT	(Precision Approach) Category
DH	Decision Height
EASA	European Aviation Safety Agency
ECAC	(ICAO) European Civil Aviation Conference
EUROCAE	European Organization for Civil Aviation Equipment
GAST (D)	GBAS Approach Service Type (D: to support operations down to CAT IIIb using the GPS L1 signal)
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
L1 (C/A)	Legacy GPS Signal broadcast by all satellites broadcast in L-Band (1575 MHz) using the Coarse/Acquisition Code
LVP / LVC	Low Visibility Procedure / Low Visibility Conditions
ICAO	International Civil Aviation Organisation
NSP	(ICAO) Navigation System Panel - since 2015: Navigation Panel
OFA	(SESAR) Operational Focus Area
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
TRL	Technology Readiness Level
VDB	Very High Frequency Broadcast

1 Project Overview

The project "GBAS Cat II/III L1 Approach" (P15.03.06) covered the Ground Based Augmentation System (GBAS) CAT II/III solution based on GPS L1 (ICAO GAST D Solution) – a satellite-navigation technology with ground based augmentation for precision approach and landing operations including auto-land and guided Take-off. It enables improved resilience under low visibility conditions (LVC) by limiting the capacity reduction through absence of operationally relevant critical and sensitive zones.

1.1 Project progress and contribution to the Master Plan

The GBAS CAT III technology based on GPS L1 C/A (GPS legacy signal, single frequency) - SESAR solution #55: “Precision approaches using GBAS CAT II/III based on GPS L1” - supports automatic approach and landing (including automatic roll-out) down to CAT IIIb and Guided take off.

Validation of improved low visibility operation using GBAS Cat II/III based on GPS L1 was performed by the GBAS projects "GBAS operational implementation" (P06.08.05), the airborne "GBAS Cat II/III (airborne equipment P09.12)" and the "GBAS Cat II/III L1 Approach" (P15.03.06) projects for a TRL 6 / V3 maturity level. The validated operations cover approach and landing down to Cat IIIb (including automatic roll-out) and guided Take off for mainline aircraft as well as Cat II or Cat IIIa for business and regional Aircraft.

The validation for the TRL 6 / V3 level of maturity at the end of SESAR 1 demonstrated the readiness of the solution for industrialization & approval. The project "GBAS Cat II/III L1 Approach" complemented the operational CAT II/III validation to confirm the concept of operations.

The validation activities were performed on system level with pre-industrial prototype equipment developed & implemented in the airport and aircraft operational environment by the project and the GBAS Cat II/III airborne subsystem related project. The ground development, implementation and verification are related to the enabling technology: GBAS Cat II/III based on Single-Constellation / Single-Frequency GNSS (GPS L1).

The GBAS system project "GBAS Cat II/III L1 Approach" validated CAT III L1 touch-down performance by auto-land flight tests for pre-defined airport scenarios.

The validation of the maturity level allowing subsequent industrialization and deployment (TRL 6 / V3) was performed using the Thales GBAS ground subsystem prototype installed at airport Toulouse / Blagnac and complemented with the Indra Navia ground subsystem prototype installed at Frankfurt / Main airport. The validation was performed by means of ground and flight tests conducted in cooperation with the GBAS Cat II/III airborne subsystem related project.

Besides the flight demonstration and ground & air measurements and simulation related performance & safety assessments were performed.

The touch-down performance and safety of use were confirmed and with it the suitability of the technology to perform landing down CAT IIIb and guided take-off was demonstrated.

A single GBAS ground installation can provide cost efficient precision approach and landing as well as guided take-off operations for multiple runways also on large and complex airports and with improved resilience in low visibility conditions.

Code	Name	Project contribution	Maturity at project start	Maturity at project end
CTE-N07b	GBAS Cat II/III based on Single-Constellation / Single-Frequency	Two GS PTs (Thales & Indra Navia) were developed and verified within	TRL 3 / (V2)	TRL 6 / (V3)

	GNSS (GPS L1)	the project.		

The project "GBAS Cat II/III L1 Approach" contributed to the validation of the SESAR solution "Precision approaches using GBAS CAT II/III based on GPS L1" (solution #55 in SESAR release 4): Within the project "GBAS Cat II/III L1 Approach" validation to demonstrate a maturity level ready for industrialization and deployment, V3, were performed.

- GBAS CAT II/III flight trials in Toulouse which were considered as contribution to solution "Precision approaches using GBAS CAT II/III based on GPS L1"
- GBAS CAT II / III flight trials in Frankfurt to complement the validation of the solution

The performed validation exercises are related to the operational improvement "Improve Low Visibility Operation using GBAS Cat II/III based on GPS L1" in the European ATM Masterplan AO-0505-A [2].

The validation was performed through Flight Tests conducted at both airports using mainline aircraft as well as business aircraft.

It has been considered very important to verify several ground and airborne systems from different points of view to be sure that conclusions take into account a wide range of options (e.g. airframe and environment influence). The SESAR solution has been assessed on two-runway airports operations in flight tests.

The applicable integrated roadmap dataset is DS15 [49]

1.2 Project achievements

GBAS technology in support of low visibility operations allows for increased resilience at low visibility conditions by maintaining runway capacity. GBAS CAT II/III has no aircraft operationally relevant critical and sensitive zones. It was validated in the context of the project cluster covering "LVPs using GBAS" by the operational GBAS project that the absence of operationally relevant critical and sensitive zones allow for a implementation such that runway occupancy times in low visibility conditions are reduced, resulting in reduced spacing between arrival aircraft. The amount of runway throughput gained depends on wake turbulence separation and any other additional spacing needs.

The system and ground subsystem related project ("GBAS Cat II/III L1 Approach", P15.3.6) validated on system level the required touch-down performance and absence of aircraft operationally critical and sensitive zones. With the demonstration of touch-down performance and safety of use, the suitability of the GBAS CAT II/III L1 technology to perform landing down CAT IIIb and guided take-off are confirmed.

It has been demonstrated through several flights and complemented with simulations, that under low visibility conditions the GBAS CAT II/III L1 solution enables to perform:

1) GBAS automatic approach and landing operations down to Cat IIIb minima for mainline aircraft (with more sustained accuracy in aircraft guidance on final approach) incl. automatic roll-out, with decision heights (DH) below 50 ft down to no DH & Runway Visual Range (RVR) between 50m and 200m;

2) GBAS automatic approach and landing down to Cat II or Cat IIIa minima for business and regional aircraft (with more sustained accuracy in aircraft guidance on final approach), with DH between 50 ft and 200 ft and RVR between 200m and 550 m;

3) GBAS guided take-off

The "GBAS Cat II/III L1 Approach" project covered the system and ground subsystem related aspects of GBAS CAT III L1 (GAST D). The airborne developments were conducted by the "GBAS Cat II/III" (airborne equipment P09.12) project. The related "GBAS operational implementation" project (P06.08.05) developed and validated the operational aspects of optimized CAT II/III operations.

Two pre-industrial ground prototype systems from two ground equipment manufacturers (Thales and Indra Navia as part of the NATMIG consortium) were developed.

The prototypes were implemented on two European Airports (Toulouse and Frankfurt), both with a parallel runway system.

Performance and interoperability on system and ground subsystem level were verified in lab and on-site by ground and with flight tests in close coordination with the related airborne GBAS CAT II/III project (P09.12). For this purpose the EUROCONTROL PEGASUS toolset was extended to GBAS CAT II/III L1 (GAST D) capability and has allowed comparison between the SESAR and non SESAR ground and airborne prototypes.

In the "GBAS Cat II/III L1 Approach" project (P15.03.06), the GBAS CAT II/III L1 specific concept of operations and CAT III approach criteria were developed, and the operational and technical safety assessed.

The project members continuously provided significant and relevant contributions in the relevant standardization working groups at ICAO NSP, EUROCAE WG-28 and RTCA SC159 WG4 to the development and evolution of the applicable standards: ICAO Annex 10, EUROCAE ED-114 and RTCA DO-253. Furthermore the relevant GBAS related international working groups LATO and I-GWG where strongly supported by the project. The project covered also aspects of equipment approval preparation in Europe, by pursuing the evolution of regulatory framework & involvement of EASA as basis for later certification.

The project contributed to the assessment of the economic aspect with the GBAS cost assessment

The work was performed in three phases:

- Phase 1 focused on system concept assessment and early verification based on the GBAS CAT II/III L1 data broadcast implementation.
- Phase 2 laid the focus on the performance verification and system validation according to the ICAO CAT II/III L1 draft standard.
- Phase 3 covered enhanced solutions beyond the minimum ICAO requirements allowing to gain full operational benefit of the GBAS CAT II/III L1 solution. This is particularly related to better support of large and complex airports through multiple data broadcast transmit antennas & sites (multiple VDB) and increased robustness.

Together the GBAS CAT II/III related operational and technical projects (grouped in the operational focus area "LVP using GBAS") demonstrated that GBAS provides significant benefits to increase the runway capacity with a cost efficient solution: GBAS can support multiple runways of an airport and can provide lower total cost of ownership compared to legacy systems.

As a result the GBAS CAT II/III L1 solution is developed and validated to V3 (TRL 6) maturity level, allowing to start the industrialization, approval and subsequent deployment.

1.3 Project Deliverables

The following table presents the relevant deliverables that have been produced by the project.

Reference	Title	Description
Since the project covers system as well as ground subsystem aspects, the deliverables are separated into the two classes: System Level deliverables & Ground Subsystem Level deliverables		
System Level		
D03	High level performance allocation and split of responsibilities between air and ground	This document reviews the high level GBAS requirements pertaining to the airborne part and the ground part. It identifies the most impacting requirements in terms of accuracy, integrity and continuity based on GBAS Cat II/III Development

		Baseline SARPs Proposal, the ICAO conceptual paper as well as the RTCA GBAS MOPS. This document also provides a critical analysis of the initial GBAS Cat II/III high level system architecture as defined by ICAO. It provides elements of requirements validation based on previously performed analysis and complementary analysis performed within the project 15.03.06. Finally, this report contains a traceability matrix between the ICAO SARPS requirements and issues identified and discussed within this document. It highlights any missing validation items or missing requirements that needed to be further defined and studied within the project.
D16	System Validation Plan	This document describes the System Validation Plan of the SJU 15.03.06 project (GBAS CAT II/III L1 Approach). This plan describes in detail the activities necessary for the system technical validation of the two ground station prototype installations at Toulouse and Frankfurt airports including the necessary ground testing and flight testing/trials. Verification exercises defined with respect to the requirement matrix which was established in D03.
D19	System Validation Report	This report provides the GAST D system verification – verification of the system composed of satellite, aircraft and ground elements. It also summarizes the signal in space and performance verification of the two independently developed GAST D compliant ground station prototypes at the installation sites. The ground subsystem verification performed in Toulouse and Frankfurt has been an input to this task. System verification activities have been carried out in a cooperative effort with the airborne GBAS project (P09.12). The result of the validation exercises is traced back to the underlying requirements in the systems requirement matrix.
D32	Extended System Verification Report (15.03.06-D32, incl. 09.12 part as consolidated deliverable)	This document provides the verification report for the Extended GAST D System Verification activities conducted on the two ground station prototypes installations at Toulouse and Frankfurt airports. Inspection, test and analysis verification methods have been applied to verify enhanced CAT II/III solutions for a wider range of potential airports, especially large airports. The ground subsystem verification of the enhanced solution performed in Toulouse and Frankfurt has been an input to this task. System verification refers to the verification of the system composed of satellite, aircraft and ground elements. System verification activities have been carried out in a cooperative effort with the airborne GBAS project (P09.12)

D20-02	GBAS CON OPS (including CAT II/IIII L1 specificities)	This document is the final version of the GBAS CAT II/III L1 (GAST D) Concept of Operations that summarises all operational aspects (ATC procedures and interface, Pilot procedures and interface, maintenance procedures and approach design process and, AIS, NOTAM, Charting…) and operational environment that are new to GAST D introduction
D25	GBAS CAT II/III L1 Cost Assessment Report	This document is a report of a cost assessment activity, carried out by manufacturers and ANSPs, aimed to provide cost estimations relevant to a complete GBAS CAT II/III L1 System, covering both the airborne segment and the ground segment.
D33	OFA 01.01.01 GBAS CAT II/III L1 Updated Safety Assessment Report and security considerations	This document contains the Specimen Safety Assessment for a typical application of the OFA01.01.01 (LVPs using GBAS) relative to GBAS CAT II/III operations based on single GPS frequency (L1). This operational safety assessment addresses both CAT III approach & landing operations and Guided Take-Off in Low Visibility Conditions. This assessment was conducted considering the operational change (optimised operations) described in the GBAS CAT II/III Functional Description update Report/OSED (06.08.05 D47) and the technical change described in the GBAS CONOPS including CAT II/III specificities (15.03.06 D20). The report presents the assurance that the identified Safety Requirements for the V1-V3 phases are complete, correct and realistic. This document is an updated version of the 15.03.06 D22 Safety Assessment Report issued in January 2015 and includes a dedicated appendix on security considerations.
D34	Regulatory Aspects - Final Report	The report summarizes the work performed and results achieved within P15.03.06 on regulatory aspects which represent a contribution to the preparation of European approval processes for GBAS CAT II/III based on GPS L1. It documents the background and steps performed by the SESAR GBAS CAT II/II L1 projects. It summarizes the technical discussion and achieved status in interaction with the regulatory organisations (i.e. EASA) at the end of P15.03.06
Ground Subsystem & Site related		
D04	Ground Architecture & Airport Installation	This document gives the ground equipment installation requirements as identified in the SESAR 15.03.06 project. It is intended to be a high level description and architecture document, independent of any particular airport or ground subsystem manufacturer. The purpose of the document is to

		provide ANSPs with an analysis of the ground architecture and airport installation issues for a GAST D ground station. The scope is, based on the present status of standards and development, to describe the challenges related to a GAST D airport installation, and to identify the main differences with a GAST C installation. The contributions to this document is based on studies, general experience and participation in international discussion and standardisation bodies, but as none of the participants have any experience with GAST D installations in practice, it is expected that further development and testing will provide more details on siting requirements.
D09 / D10 / D27	PT1 Delivery Form and Verification Report (Phase 1 / 2 / 3)	These deliverables refer to the Thales GBAS CAT II/III L1 (GAST D) ground station prototype development in the various phases and summarize the results of the GBAS station development and verification activities of Thales in the different phases: Phase 1: the station hardware and software development to implement GAST D SIS transmission protocol and message types Phase 2: the station hardware and software development to implement GAST D performance Phase 3: the station enhanced hardware and software development for better support for large airports by dual GBAS data broadcast transmit sites and increased GAST D robustness.
D07 / D08 / D26	PT1 Ground System Performance & Safety Report (Phase 1 / 2 / 3)	These reports cover the Thales GAST D ground subsystem (PT1) related performance and safety assessments. Part 1 (D07) covered the performance and safety requirement identification, algorithm development and initial performance assessments. Part 2 (D08) focused on the safety assessment summary and performance feasibility assessment. Part 3 (D26) extended the previous ones towards increased robustness of the ground subsystem prototypes, by updates of the technical safety assessment to cover multiple VDB performance aspects; provides assessment results based on the long term and seasonal variation evaluation for normal and non-normal performance and the updated assessment of the GAST D ionospheric gradient mitigation.
D17 & D30	Implementation & SIS Validation report site 1 (D17) Extended Implementation and Site 1 Verification Report (D30)	These reports describe the implementation, the tools and the tests at GBAS site 1. D17 provides the results of the signal-in-space validation for the GBAS GAST D prototype PT1. D30 provides the results from the verification exercises related to the long term site performance evaluation, to the GPS multipath assessment made on ground (LOCA)
D12 / D14 / D28	PT2 Delivery Form and Verification Report (Phase 1 / 2) and PT2	These deliverables describe the tests performed on the PT2, in order to verify that the requirements

	Delivery Form and Verification Report for large airport installations	described in deliverable D11 are met. Phase 1: Indra Navia had the scope to prepare the PT2 for installation at the airport in Frankfurt. Hence, the tests also contain a selection of tests for "FAT" with DFS, and lab interoperability tests with Honeywell Phase 2: Prototype updates at the airport in Frankfurt. Phase 3: describes the suggested solutions to meet the challenges of large airport installations, in particular for the VDB installation with multiple VDB antennas in order to cover a large airport, and for the monitoring terminal with extended needs for data handling and monitoring. The report also includes analysis from tests made on site, and subsequent updates suggested as a consequence of the site 2 trials
D13 / D15 / D29	PT2 Safety Assessment Report (Phase 1 & Phase 2) / TN: PT2 GS performance (Phase 3)	The Prototype 2 Indra Navia Safety Assessment Report provides Phase 1 (D13): the Functional Hazard Assessment and the Preliminary System Safety Assessment for the architecture of the ground station prototype. Phase 2 (D15): focussed on the integrity monitoring, in particular the one which is specific for GAST D Phase 3 (D29): updated safety assessment of the site 2 PT2 ground station, after upgrades of the monitoring algorithms: describes the updated monitoring architecture, and gives the system performance evaluation results as derived using data from the site
D18 & D31	Implementation & SIS validation report site 2 (D17) Extended Implementation and Site 2 Verification Report (D31)	This report describes the GBAS GAST D ground station implementation, the tools and the tests at site 2. D18 provides the results of the signal-in-space validation for the GBAS GAST D ground station prototype PT2. D31 provides the results of the Phase 3 verification for the GBAS GAST D ground station prototype PT2 (Indra Navia)

1.4 Contribution to Standardisation

Significant and relevant contributions were provided by the project on regular basis throughout the project to following standardisation organisations:

- ICAO NSP contributions with numerous inputs related to GBAS CAT II/III L1 (GAST D) Annex10 standard validation based on project achievements.
- ICAO IFPP contributions with respect to the definition of GBAS CAT II/III L1 approach procedure criteria
- EUROCAE WG-28 with contributions to definition and initiation of work to develop GBAS CAT II/III L1 ground equipment standard (MOPS ED-114B).

- RTCA SC159 WG4 with inputs from system and ground side primarily related to aspects of the GBAS data broadcast (multiple VDB). Airborne contributions were covered by the GBAS CAT II/III airborne project (P09.12).

The standardisation inputs are summarized on a repetitive basis in project deliverable D23-01 to D23-04 ([33] to [37]) for work performed until end of 2014. Contributions from 2015 and 2016 are covered in D10 of SESAR project "Multi GNSS CAT II/III GBAS" (P15.03.07).

Aspects of the GBAS CAT II/III L1 Procedure design criteria as part of the work related to ICAO IFPP were provided in the projects deliverable D21 [31].

Measurement results used for compatibility between the GBAS VDB link and the two legacy systems ILS and VHF COM, in order to update existing frequency coordination criteria in ICAO Annex 10, Vol. I were performed within "GBAS Cat II/III L1 Approach" (P15.03.06) and reported in the projects deliverable D24 [38].

As a result of the contributions the GBAS CAT III L1 requirements in draft Annex 10 GAST D standard have been validated. Compared to the initial version at start of the project several adaptations were identified by the project and introduced to the final version.

Validation of the GAST D SARPS has been completed. After ICAO NSP approval in December 2016 the material is to be submitted to the Air Navigation Commission end-2016 and published for state review in 2017 for applicability in late 2018.

Besides the standardisation support the GBAS related international working groups, namely the worldwide recognized International GBAS Working Group and the primarily on ECAC concentrating Landing and Take-off Focus group (LATO) of the EUROCONTROL Navigation Steering Group (NSG). Reports were provided on a repetitive basis in projects deliverable D02 ([4] to [12]).

With the V3 maturity of the GBAS solution in phase 3 work was performed aiming to contribute to the preparation of European approval processes for GBAS CAT II/III. The work on regulatory aspects consisted primarily in exchange with EASA via SJU to provide information on the GBAS CAT II/III L1 (GAST D) solution and answer comments evolved after review of the related SESAR deliverables. The work and achieved status is summarized in D34 [48].

1.5 Project Conclusion and Recommendations

Satellite based precision approach and landing operation below CAT I minima down to CAT IIIb become available with GBAS.

It has been demonstrated, through several flights, ground and lab tests and complemented with simulations that under Low Visibility Conditions (CAT II/III) the GBAS CAT II/III L1 solution enables to perform:

1.) GBAS Automatic Approach and Landing down to Cat IIIb minima for Mainline Aircraft with Automatic roll-out with a DH below 50 ft down to no DH & RVR between 50m and 200m, with more sustained accuracy in aircraft guidance on final approach,

2.) GBAS Automatic Approach and Landing down to Cat II or Cat IIIa minima with a DH below 200 ft down to 50 ft & RVR between 200 m and 55 m for Business and Regional Aircraft (with more sustained accuracy in aircraft guidance on final approach)

3.) GBAS guided take-off

Performing these operations can be supported by a single ground installation on multiple runways also on large and complex airports.

The GBAS CAT II/III L1 solution improves the runway throughput in low visibility conditions, thus ensures resilience to adverse weather conditions by using GBAS.

The GBAS CAT II/III L1 represents a solution ready for industrialization and deployment and is covered in the SESAR release 4 SESAR Solution #55: “Precision approaches using GBAS CAT II/III based on GPS L1”.

With the successful validation of a TRL 6 / V3 maturity of the GBAS CAT III L1 solution as a safe, frequency efficient, cost efficient, and sufficiently mature solution it is recommended to start industrialization, approval and deployment to support the achievement of the SESAR goals.

It is also recommended to further explore future advances in terms of robustness and system flexibility by the inclusion of new GNSS constellations (Galileo) and use of dual GNSS frequency to the GBAS CAT III solution (MC/MF GBAS). The maturity level of such advanced technology needs to be increased.

In the context of above given recommendations it shall be emphasized that further research oriented activities are deemed as necessary in order to obtain a full coverage of the verification and validation activities of advanced GBAS using multiple satellite core systems and multiple GNSS signal frequencies. It shall also be mentioned that further industrialization as pre-requisite needs cooperation with regulatory bodies like EASA to develop and reach the certification specifications..

2 References

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