Final Project Report

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Abstract

Project 15.03.07 aimed to establish a MC/MF GBAS system specification achieved by verification using simulations and mock-ups. The MC/MF GBAS configuration considered in the study is GPS and GALILEO constellation providing signals on L1/L5 frequencies. The study has been done in four main steps:

- 1) a research work to address and resolve key open topics and provide the trade-offs to establish the system concepts;
- 2) a system architecture and requirements definition with the goal to establish equivalent specifications to GAST-D baseline development SARPS;
- 3) the development of ground mock-ups and GNSS signal simulators needed to demonstrate and verify the concepts, the MC/MF critical functions and the performance, and
- 4) the verification activities, including SESAR project 9.12 (GBAS CAT II/III Airborne Receiver) contributions, and the mock-ups and simulators. The verification activities have been performed at Lab level, and at airport level (Toulouse/Blagnac platform and Barcelona/El Prat platform).

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This deliverable consists of SJU foreground.

Acronyms

Acronym	Definition
ATM	Air Traffic Management
EASA	European Aviation Safety Agency
ESA	European Space Agency
GAST-F	GBAS Approach Service Type F
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GALILEO	European GNSS
L1 / E1	GNSS frequency band 1575.42 MHz
L5 / E5a	GNSS frequency band 1176.45 MHz
LVP / LVC	Low Visibility Procedure / Low Visibility Conditions
ICAO	International Civil Aviation Organisation
IFree	Ionosphere free processing method
MC	Multi constellation
MF	Multi frequency
RVR	Runway Visual Range
SARPs	Standard and Recommended Practices
VDB	VHF Data Broadcast

1 Project Overview

A Ground-Based Augmentation System (GBAS) is a safety-critical landing system that supports Low Visibility Operations by local augmentation at airport level of the primary GNSS constellation(s) (i.e.: GPS and/or GALILEO) by providing enhanced levels of service that support all phases of approach, landing, departure and surface operations. While the main goal of GBAS is to provide integrity assurance, it also increases the accuracy.

The 15.03.07 SESAR project targeted the evolution of single frequency GBAS CAT I (GAST-C) and CAT II/III (GAST-D) based on GPS L1 towards multi-constellation (MC), multi-frequency (MF) GBAS (GAST-F) taking into account other constellations such as Galileo and new signals coming with the Galileo and modernized GPS satellites.

The overall goal of this project was to solve open issues and to define a multi-constellation multi-frequency solution up to CAT III capability, enabling required performance and robustness by using satellites from different constellations and applying multiple/dual frequency signal monitoring and processing. The 15.03.07 SESAR project has considered a MC/MF GBAS configuration based on the use of the signal provided by GPS and GALILEO constellation on L1/E1 and L5/E5 frequencies.

1.1 Project progress and contribution to the Master Plan

Project 15.03.07 aimed to establish a solid system specification for the selected MC/MF GBAS configuration based on GPS and GALILEO achieved by verification using simulations and mock-ups. The study has been done in four main steps.

The first step consisted on a MC/MF research-intensive work to address and resolve key open topics and provide the trade-offs to establish the MC/MF GBAS concepts. Main topics covered include:

- Satellite constellation and signals characterisation
- Environment modelling: ionosphere, troposphere, interferences, multipath
- Receiver signal processing
- Measurement processing
- Integrity monitoring definition and performance
- VDB subsystem

The second step concerned system architecture and requirements definition with the goal to establish equivalent specifications to GAST-D baseline development SARPS. A set of candidate processing options for the selected MC/MF GBAS configuration has been shortlist, from the analysis of the first step. Based on these options, system concept and system specifications have been defined, and preliminary safety analysis carried out. The impacts on the ground infrastructure and airport installation aspects have also been analysed.

In the third step, these specifications have been used to develop ground mock-ups and GNSS signal simulators needed to demonstrate and verify the concepts, the MC/MF critical functions and the performance.

The last step covered the verification activities performed following a verification plan developed within the project and including SESAR project 9.12 (GBAS CAT II/III Airborne Receiver) contributions and the mock-ups and simulators. The verification activities have been performed at Lab level, and airport level (Toulouse/Blagnac platform and Barcelona/El Prat platform). At airport level the interoperability, testing was conducted with Honeywell MCMF airborne receiver mock-up developed in SESAR project 9.12.

The main verification objective tested was to prove the selected MC/MF GBAS configuration feasibility (TRL-4 verification) by meeting the requirements and specifications defined in the System Definition activities. Two independently developed GBAS ground subsystem mock-ups (mock-up #1 from Thales Electronics/DSNA/Eurocontrol (with TU Braunschweig equipment) and mock-up #2 from INDRA) supported the definition of these requirements and were the main tool for the verification, together with the GNSS Signal Generator Simulator tool developed by Selex and the analysis tool, PEGASUS, developed by Eurocontrol.

Based on the Research phase results, the most promising candidate concept and processing options were defined. Major threats to MC/MF GBAS operations were identified, and possible mode degradation paths were defined focusing on ground subsystem general monitoring methods and actions, as well as airborne positioning modes for each of the identified alternatives.

Because of analysis and discussions, three suitable nominal GAST F mode processing options were identified, with the main focus on the first two of the following with the highest potential:

- I-Free L1/L5 and E1/E5a (Dual Frequency)
- L1/E1 single frequency + dual frequency iono monitoring
- L5/E5a single frequency + dual frequency iono monitoring

The first two most promising options were evaluated during verification activities with ground station mock-up(s) and the airborne mock-up. Testing several processing options allowed identifying the most promising candidate MC/MF processing and concept options, switching logics and monitoring & mitigation concepts.

- In the GS mock-up #1, two GNSS MF reception antennas, using multipath limiting antennas with adapted preamplifiers from the GAST-D prototype at TLS Airport, were fed into two MC/MF GNSS receivers with GNSS raw data. The MC/MF GNSS receivers supported a MC/MF processing and real-time VDB messages generation unit.
- In the GS mock-up #2, both real data and simulated data was processed to verify differential corrections and integrity data. GNSS data was obtained from the four ground reference antennas in the BCN Airport and from the GNSS Signal Generator Simulator. In order to test a subset of MC/MF candidate solutions, off-line MC/MF GBAS data processing and VDB message generation were carried out.
- Honeywell MC/MF GBAS airborne receiver mock-up processing activities included evaluation of I-Free and L1/E1 processing options via online processing during a flight data recording campaign and/or offline post-processing. Interoperability test at VDB level was performed with the Mock-up #1 with this GAST-F airborne mock-up. In addition, backward interoperability test was carried out with GAST-D airborne prototype (in the scope of project 9.12).

The system verification objectives were categorized as follows:

- Accuracy
- Integrity
- Multipath

- GNSS Interference Environment
- Interoperability

The verification exercises were carried out under nominal and/or anomalous conditions, the latter understood as the appearance of one of the following events:

- Ephemeris anomaly
- Interferences in one frequency
- Ionospheric anomaly
- Excessive acceleration anomaly
- Reference Receiver anomaly

The maturity level obtained was TRL-4, covering the proof of concept (as proposed in D04, MC/MF GBAS Concept chapter), the verification of the candidate processing options and an initial proposal for the standardisation requirements of the GAST-F system.

The MC/MF GBAS concept covered the identification of the major threats to MC/MF GBAS operations, and definition of the possible mode degradation paths, focusing on ground subsystem general monitoring methods and actions, as well as airborne positioning modes for each of the identified alternatives. Also, the analysis of the VDB backwards compatibility, achievable accuracy and availability, as well as mode switching position domain transients.

The OI Steps and Enablers that the project has worked on were the following:

Code	Name	Project contribution	Maturity at project start	Maturity at project end
CTE-N07c	Ground Based Augmentation System (GBAS) Cat II/III based on Multi-Constellation / Multi-Frequency (MCMF) GNSS (GPS + GALILEO / L1 + L5)	Advancing in the system concept definition, solving open issues, verification of the candidate processing options, definition of the specifications and standardisation proposal.	TRL-2	TRL-4
A/C-02b	Enhanced positioning using multi constellation GNSS dual frequency	Verification of the positioning accuracy, integrity, continuity, availability and robustness by trade-off of different processing options identified during the research phase of the project, specified and verified using mock-ups and GNSS Signal Simulator. Also, real data in airport environment has been used for the verification activities.	TRL-2	TRL-4

Applicable Integrated Roadmap Dataset is DS15 [19].

The expected improvements of this solution, with respect to the GBAS single-frequency (GPS-L1) solution for Cat-II/III, will be the increase of the availability and robustness of GBAS operations at airports during Low Visibility conditions. In addition, the increase of availability is also expected for the area experiencing anomalous ionosphere activity (either equatorial, auroral or polar regions), or the regions with low satellite visibility due to local environmental constraints.

In addition, safety aspects will be improved, for instance in the areas prone to intentional and unintentional RF interference, due to the frequency diversity of the dual-frequency approach.

Efficiency and continuity of the service will be assured via the constellation diversity, avoiding any common mode failure that would affect the performance of the system.

1.2 Project achievements

The project was a valuable contribution to the definition of the selected GBAS multiconstellation and multifrequency configuration system, taking advantage of the development of the new constellations (like Galileo) used in combination with GPS, and the availability of new frequencies (the new GPS L5 or Galileo E1 and E5a), with better theoretical performances that the existing one (GPS L1).

The different activities in the project (research, specifications, simulations, verifications, mock-ups) were oriented to confirm the performance expected, with respect to the GAST-C and GAST-D GBAS systems, like increased robustness of the solution, mitigation of the main threats (such as ionosphere perturbations or interferences), or increased availability and continuity, due to the constellation diversity.

A preliminary concept of the system definition of the selected MC/MF GBAS configuration has been developed, considering a set of candidate options that optimise the benefits of the combination of the additional frequencies and constellations, in coordination with the airborne side (9.12).

An experimental proof of concept has been performed (TRL-3), at Lab and airport level. Preliminary verification activities have been performed at Lab environment, with real data and simulated data (TRL-4), and initial data collection activities have been started in an airport environment (early TRL-5). Interoperability testing with an airborne mock-up (WP 9.12) has been performed. The maturity level achieved is TRL-4.

A conceptual framework of the architecture choices for the MC/MF solution has been prepared and presented to the standardisation fora (ICAO NSP Navigation System Panel), and an initial system specification has been developed and verified, as basis for the proposed SARPs for the GAST-F concept.

1.3 Project Deliverables

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

Reference	Title	Description
D03	MC-MF GBAS Trade-offs and Recommendations	This document presents the research and studies performed on different key topics, and the final recommendations for the processing options, both at ground and airborne level, and for the proposed VDB datalink to support these processing options. This document is the major input for the system definition activities. The document also identifies further work needed to consolidate the concept (ie. The consolidation of the GNSS signal characterisation once the new frequencies will be declared operational).
D04	System Architecture, Requirements Definition and Safety aspects	This document presents the architecture at system level and the system requirements definition, the allocation of responsibilities between ground and airborne subsystems, and the detailed VDB datalink structure and messages. A preliminary safety assessment is also included. This document is the main input for the standardisation activities, covering the concept definition and the proposed changes to the SARPs.
D05	Ground Architecture and Airport Installation	This document presents the analysis of the GBAS Ground Station architecture, the different elements and the installation requirements. This document is the input for the siting recommendations to be included in the international standards and recommendations.
D09	MC-MF Operational Changes relative to GAST-D	This document presents the analysis of the operational changes envisaged in the GBAS MC/MF concept with respect to the single frequency (GAST-D) implementation
D11	VDB Spectrum Use for MC-MF GBAS	This document describes the status of the use of the spectrum and the forecast capacity to cover the GBAS deployment envisaged in the near future. Different scenarios have been simulated, and the results are presented.

D10	Regular reports on submission to and activities of relevant GBAS standardisation Groups	These documents (yearly reports) present the status of the standardisation activities, open points and future work plan.

Other documents delivered during the project execution would be relevant for the follow-on activities:

Reference	Title	Description
D02	LATO and IGWG meeting reports	These yearly reports present the state-of-the-art on the GBAS topics, the activities performed in different countries, ANSPs, air navigation authorities, manufactures, etc.
D06	MC-MF System Preliminary Verification Plan	This document describes the verification activities performed in the project for the verification of the concept, as defined in D04 and D05. The verification objectives to reach the TRL-4 maturity level were described.
D08	System Verification Report	This document presents the results of the verification exercises proposed in D06
D14	Ground Mock-up 2 and Verification Tool Development	This document describes the G/S Mock-up used in the verification exercises

1.4 Contribution to Standardisation

The main objective of this project was to propose the initial draft of modification to the current standards (mainly ICAO SARPs and EUROCAE WG 28) to cope with the MC/MF solution.

A preliminary presentation of the main outcomes of the project was performed in the ICAO/NSP at several meetings. Unfortunately, delays in the consolidation of the GAST-D standards, that was the priority at that time, influenced in the discussion on the GAST-E and GAST-F issues. An Action and an explicit item for MC/MF GBAS standards in the work programme were open at ICAO and will be progressed once the GAST-D standards will be agreed at ANC level.

Standardisation contribution was focalised in the ICAO SARPS, Annex 10 Vol. 1, in the following sections:

- Chapter 2.4: GNSS as navigation aid, recording and termination requirements

- Chapter 3.7: General Provisions, GBAS definition and performance requirements
- Chapter 3.7.3.5: Functions, Coverage, data link characteristics
- Appendix B, 3.6: detailed technical characteristics for GBAS and GRAS
- Attachment D, 7: Guidance material and explanations

Also, standardisation contributions to EUROCAE ED114 evolution towards MC/MF has been started.

1.5 Project Conclusion and Recommendations

The project has contributed to verify the expected improved performance on the GBAS system supporting Low Visibility Approaches and Landing when based on the dual constellation (GPS/Galileo) and dual frequency (L1/E1 and L5/E5a) use.

The main key issues for this solution have been studied, and a set of candidate processing options has been selected, specified and verified with mock-ups (G/S mock-ups within 15.3.7 and airborne Rx mock-up within 9.12) and simulators, reaching a maturity level of TRL-4.

Due to several reasons (such as low maturity of the constellations, unknown fault modes of new signals or many open points in the MCMF GBAS concept like the processing scheme selection) further discussion on GAST E and GAST F issues is needed.

The project recommends to continue working in this solution, with more advanced prototypes, and consolidating the remaining open issues. For this, a close relationship with the core constellation responsible (ESA and GSA for Galileo in Europe) is desirable. In particular, contributions to the "GALILEO OS needs in support of SoL" document should also be open to industry.

Further consolidation of the technical solution is needed, covering the antennas, receivers and processing methods. When the concept and the technical solution reach the required maturity level, the verification of the operational improvements is expected, at flight level and at airport capacity level.

The standardisation activities will continue, advancing in the proposal for an extension of the current standards to cope with MC/MF aspects. A liaison with the certification authorities (EASA), national authorities and the GALILEO system designer (ESA) is mandatory to advance in the certification process of the final equipment.

2 References

[1] SESAR Programme Management Plan, Edition 03.00.01

[2] European ATM Master Plan

[3] Multilateral Framework Agreement ("MFA") signed between the SJU, EUROCONTROL and its 15 selected members on August 11, 2009, amended on 14 June 2010, 19 October 2010 and 2 July 2012

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[6] 15.03.07, T3.1- System Architecture Requirements Definition and Safety aspects, D04, Edition 00.01.00, September 2016

[7] 15.03.07, T3.3- Ground Architecture and Airport Installation, D05, Edition 00.01.00, June 2016

[8] 15.03.07, T4.1- MC-MF System Preliminary Verification Plan, D06, Edition 00.01.00, Mai 2016

[9] 15.03.07, T4.3- System Verification Report, D08, Edition 00.01.00, October 2016

[10] 15.03.07, T5.1- MC-MF Operational Changes relative to GAST-D, D09, Edition 00.01.00, September 2016

[11] 15.03.07, T6.1- Regular reports on submission to and activities of relevant GBAS standardisation Groups, D10-001/002, Edition 00.01.00, November 2015 / September 2016

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[13] 15.03.07, T2.2- GNSS Signal Generator Specs & Design, D13-001, Edition 00.01.00, December 2014

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[19] WPC - C.01: Dataset 15, D15, Edition 00.00.01, July 2016

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