Final Project Report

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Abstract

Project 9.27 main objectives were to prepare the next generation of GNSS receivers using dual-frequency L1/L5 signals and at least two constellations. To do so, two GPS/Galileo mock-ups and a software simulation platform have been developed, validated, and the obtained results have been shared with the standardisation working group to help maturing the MOPS and ConOps. The efforts should be maintained in the frame of SESAR 2020 to identify the benefits of these multi-constellation receivers and define their conditions of use.

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Acronyms

Acronym	Definition
ABAS	Aircraft Based Augmentation System
ADS-B	Automatic Dependent Surveillance – Broadcast
ARAIM	Advanced RAIM
ATM	Air Traffic Management
ConOps	Concept of Operations
DFMC	Dual-Frequency Multi-Constellation
EUROCAE WG62	EUROCAE Working Group in charge of Galileo receiver standardization for civil aviation
GAL	Galileo
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
H-ARAIM	Horizontal ARAIM
ICAO	International Civil Aviation Organization
ICD	Interface Control Document
INS	Inertial Navigation System
IWG	Interoperability Working Group
MCR	Multi-Constellation Receiver
MOPS	Minimum Operational Performance Standards
MRSP	Multi-constellation Receiver Simulation Platform
OS	Open Service (Galileo)
RAIM	Receiver Autonomous Integrity Monitoring
RF	Radio Frequency
RINEX	Receiver INdependent EXchange format
RNP	Required Navigation Performance
RTCA SC-159	RTCA Special Committee in charge of GPS receiver standardization for civil aviation

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SBAS	Satellite Based Augmentation System
SIS	Signal In Space
TRL	Technical Readiness Level

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1 Project Overview

The main objective of Project 9.27 was to study the next generation of multi-constellation GNSS receivers (MCR) for improved navigation performance: this includes support to standardization, technical studies and prototyping of Galileo/GPS equipment. Project 9.27 also supported studies related to hybridization of GNSS with low-cost inertial systems.

1.1 Project progress and contribution to the Master Plan

In a first step, the efforts focused on the specification of Galileo/GPS airborne equipment with Aircraft Based Augmentation System (ABAS) and Satellite Based Augmentation System (SBAS) capabilities, either for mainline and regional aviation or for business and general aviation. In parallel, several studies have been launched to:

- Evaluate possible analogue and digital technologies for the development of future MCR products;
- Assess for ABAS the performance of the new generation of Advanced Receiver Autonomous Integrity Monitoring (ARAIM) algorithms using multi-constellation signals, in particular for lateral navigation (Horizontal ARAIM or H-ARAIM);
- See the potential benefits of integrating low-cost inertial sensors in future navigation systems.

Based on the specifications elaborated during the first phase, the developments of two MCR mock-ups have been launched, one for Mainline / Regional Aviation, and a second for Business / General Aviation, plus software MCR Simulation Platform (MRSP).

The simulation platform aimed at studying different multi-constellation features (such as fusion and advanced integrity concepts), using observables and navigation data as inputs, e.g. from RINEX files of true data.

The mock-ups assessed the readiness of technologies for future MCRs, and provided to the standardization working groups feedback on the use of Galileo and modernized GPS signals, and on the different functioning modes of the MCR (nominal and degraded). Additionally, the mock-ups were tested with respect to the procedures drafted in the Minimum Operational Performance Standards (MOPS) [4], which allowed maturing the proposed tests. At the end of the project, the level of maturity reached for MCRs is deemed to be TRL 4, since most of the technology components have been validated in a laboratory environment.

Code	Name	Project contribution	Maturity at project start	Maturity at project end
A/C-02b	Enhanced precision and availability / continuity of positioning (based on GNSS dual frequency, Galileo, GPS L5) on airport surface and in flight	Use of Galileo and GPS L5 signals has been assessed in the frame of prototyping activities and associated tests. Slight improvement in terms of accuracy has been shown (limited by the late deployment of Galileo and GPS block IIF and III satellites) and improvements in terms of integrity have been evaluated through the integrity studies focused on future H-ARAIM	TRL2	TRL4

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		(D30). Note that project 9.27 did not address the positioning on airport surface.		

1.2 Project achievements

The scope of project 9.27 was to assess the technical feasibility and performance of future multi-constellation receivers, with a specific focus on GPS and Galileo signals.

In a first phase, specification activities have been carried out to define the MCR for Mainline / Regional aviation and for Business / General aviation, and support standardization at EUROCAE Working Group 62, even if the MOPS for Galileo and GPS/Galileo airborne equipment are still in a draft state (see section 1.4 for further details).

In a second phase, two mock-ups have been developed to assess the functioning and performance of receivers using dual-frequency dual-constellation signals. These developments can be summarized by the following achievements:

- step 1: implementation of GPS L1 C/A and RAIM/FDE;
- step 2: addition of SBAS L1;
- step 3: addition of GPS L5 and Galileo E1/E5a signals;
- step 4: implementation of H-ARAIM and testing on real signals.

In parallel, the MCR software simulation platform has been used to assess and compare the difference integrity schemes, namely RAIM/FDE on GPS L1 signals, SBAS on GPS L1 signals and finally H-ARAIM/FD on Galileo E1/E5 and GPS L1/L5 signals.

In addition, complementary activities have been carried out to support the integration of MCR in future avionics:

- Standardisation studies related to MCR for state aircrafts, and definition of the flight test campaign to assess equipment performance;
- Integrity studies related to multi-constellation ARAIM algorithms;
- Studies on the use of low cost inertial systems hybridized with multi-constellation receivers;
- Aircraft heading / attitude estimations based on the use of dual-antenna multi-constellation receivers.

1.3 Project Deliverables

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

Reference	Title	Description
D15	MCR definition document for mainline / regional aviation v2	Specification and preliminary concept of operation for a MCR in mainline and regional aviation; used as a baseline to develop Thales's mock-up
D17	MCR definition document for business / general aviation v2	Specification and preliminary concept of operation for a MCR in business and general aviation; used as a baseline to develop Honeywell's mock-up

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D19	Report on low-cost technologies for future receivers v2	Details a possible RF front end architecture with minimal size and power consumption and addresses the potential benefits (and constraints) of multi-core processors in future MCR
D18	Report on Integrity techniques v2	Study of the ARAIM performance with a static Integrity Support Message, with possible extension to multi-constellation applications and with alternative solutions to provide integrity in a dual-constellation (possibly single-frequency) context
D32	Report on integrity techniques v3	Specific focus of Eurocontrol on the H-ARAIM performance, targeting RNP 0.1 operations and ADS-B mandates and deriving suitable core constellation performance commitment levels to support these services.
D24	Final test report of MCR prototype for mainline / regional aviation v2	Includes the final test results obtained with the mock-up developed by Thales Avionics, mainly based on laboratory tests with RF simulators, but also using GPS L1/L5 and Galileo E1/E5a satellite signals on a static antenna. A version of H-ARAIM has been implemented and tested.
D25	Final test report of the Receiver Simulation Platform v2	Includes the final test results of the MCR simulation platform developed by Alenia, for dual-constellation dual-frequency signals. ARAIM has been implemented and tested.
D30	Final test report of MCR prototype for business / General Aviation v3	Includes the final test results obtained with the MCR mock-up developed by Honeywell, using real signals and simulated ones, and with additional tests on Honeywell's specific version of ARAIM algorithm.
D29	Report on MCR GNSS based heading/attitude estimation v2	Details the improvement brought by dual-frequency dual-constellation measurements on the determination of aircraft attitude / heading using two GNSS antennas
D31	Studies for future MCR standardisation report v3	Specific focus of Eurocontrol on the H-ARAIM performance, targeting RNP 0.1 operations and ADS-B mandates and deriving suitable core constellation performance commitment levels to support these services

1.4 Contribution to Standardisation

Through the implementation and validation of dual-frequency dual-constellation receivers, project 9.27 has contributed to the standardisation activities of EUROCAE WG62, which aims at publishing MOPS for Galileo/ABAS airborne equipment [4], GPS/Galileo/ABAS airborne equipment and GPS/Galileo/SBAS L1/L5 airborne equipment.

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Performance objectives have been reviewed by Thales and Honeywell, test procedures have been refined, and Galileo documentation has been extensively reviewed, in particular the Galileo OS SIS ICD v1.2 [5] (published for consultation in June 2014) and the Ionospheric Correction Algorithm for Galileo Single Frequency Users v1.1 [6].

Note that although the requirements and associated tests have been constantly updated and reworked within the 2010 – 2015 period to take into account the latest evolutions on Galileo constellation, the different MOPS drafted by EUROCAE WG62 are not mature enough to initiate the development of a certified product.

A preliminary version of the GPS/GAL/SBAS MOPS is now foreseen in 2018, and the final version in 2020. In parallel, RTCA SC-159 intends to publish a first version of a MOPS for GPS/SBAS L1/L5 airborne equipment in 2020-2021, and possibly a MOPS for DFMC SBAS L1/L5 receivers in 2021-2022.

In addition to participation to the EUROCAE WG62, Honeywell and Thales Avionics have provided some comments to the international Interoperability Working Group (IWG) in charge of the definition of the SBAS L5 ICD, and the associated DFMC Definition Document. The final SBAS L5 ICD should be released by end 2016, allowing the prototyping of DFMC receivers with the final SBAS L5 definition.

Finally, the integrity studies carried out by Eurocontrol have been useful to mature the ARAIM concept proposed by the EU / U.S. Working Group C Subgroup ARAIM: Eurocontrol has provided results on Horizontal ARAIM incorporated into the Milestone 2 Report published in February 2015, and was also involved in the Milestone 3 report published in February 2016. After that date, WG-C should continue the effort to help EUROCAE WG-62 and RTCA SC-159 in the standardization of this new generation of integrity algorithm. The next step is the finalization of H-ARAIM concept of operation and preliminary standardization in 2018.

1.5 Project Conclusion and Recommendations

Through the development of early mock-ups, project 9.27 demonstrated the readiness of technologies for dual-frequency dual-constellation airborne receivers.

At the conclusion of the project, we consider that TRL-4 has been achieved and prototyping activities should be continuing in the frame of SESAR 2020 to reach TRL-6 level. However, the performance standards for this new generation of receivers are not ready yet, and the new operations allowed by improved positioning performance are still under study. It is therefore recommended that SESAR 2020 also focus on the elaboration of the concepts of operations using dual-frequency multi-constellation equipment, either augmented by SBAS systems (using L1 or L1/L5 augmentation) or using ABAS (with RAIM or ARAIM).

Future studies should also address the improvement of robustness of against GNSS interference and possibly spoofing. Finally, they should clarify whether a dual-constellation receiver could be sufficient after 2020, or whether it will be necessary to track simultaneously three or even four constellations. In that case, the TRL of DFMC receivers will probably have to be reassessed, to account for the computational load required to track and process several tens of satellites.

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