Final Project Report

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Abstract

The project determined the requirements on Global Navigation Satellite Systems to support European Air Traffic Management (ATM) particularly in terms of performance and robustness; to define a baseline for use of GNSS by European ATM in a first phase until 2020 (Step 1) and a second baseline until 2030 (Step 2); and to establish a roadmap for the transition to the recommended baseline. The outcome of this project is used by project 15.03.01 "Navigation Technologies Specifications" to derive an overall Navigation Baseline.

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This deliverable consists of SJU foreground.

Acronyms

Acronym	Definition
ABAS	Aircraft-based Augmentation System
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
ATM	Air Traffic Management
ANSP	Air Navigation Service Provider
APNT	Alternative Position, Navigation and Timing
CNS	Communications, Navigation, Surveillance
CONOPS	Concept Of Operations
DME	Distance Measuring Equipment
ECAC	European Civil Aviation Conference
GALILEO	European Global Navigation Satellite System
GAST	GBAS Approach Service Type
GBAS	Ground-based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSSF	Galileo System Simulation Facility
KPI	Key Performance Indicators
NOTAM	Notice to Airmen
PBN	Performance Based Navigation
PED	Portable Electronic Devices
PPD	Personal Privacy Devices
RAIM	Receiver Autonomous Integrity Monitoring
RFI	Radio Frequency Interference
RNP	Required Navigation Performance
SARPs	Standards and Recommended Practices
SBAS	Satellite-based Augmentation System

1 Project Overview

The SESAR "GNSS Baseline Study" project determined the requirements on Global Navigation Satellite Systems to support European Air Traffic Management (ATM) particularly in terms of performance and robustness; to define a baseline for use of GNSS by European ATM in a first phase until 2020 (Step 1) and a second baseline until 2030 (Step 2); and to establish a roadmap for the transition to the recommended baseline.

The project assessed current and upcoming technologies used to support specific phases of flight according to aviation performance requirements. Thereby the proposed GNSS baseline takes into account technologies, mitigation capabilities against known GNSS vulnerabilities, as well as operational needs coming from stakeholder groups like Airspace Users and Air Navigation Service Providers (ANSP).

The outcome of this project focussed on GNSS aspects whilst mapping to the four Key Performance Areas (KPAs): environment, cost-efficiency, safety, and capacity/quality of service, defined by the ATM Master Plan, was performed by the overseeing project on "Navigation Technologies Specifications" (15.03.01).

1.1 Project progress and contribution to the Master Plan

The contribution to the ATM Master Plan is made through the development of the GNSS roadmap and based on two main studies. These defined the boundaries of ATM using Global Navigation Satellite Systems. The first one identified common or most demanding requirements on GNSS to support all currently foreseen applications during all phases of flight (like terminal area, en-route, approach or landing). The second study identified possible scenarios using GNSS technology in aviation considering multiple GNSS constellations like GPS, GALILEO and others, different frequencies these systems are operating on and augmentation systems on board an aircraft (Aircraft-based Augmentation System, ABAS), at satellite system level (Satellite-based Augmentation System, SBAS) or as part of a landing system (Ground-based Augmentation System, GBAS).

The "GNSS Baseline Study" is about evaluating different GNSS technologies, frequencies and augmentations to support European Air Traffic Management (ATM) particularly in terms of performance and robustness. Therefore it assesses existing solutions rather than defining new technologies or improving existing solutions.

The GNSS and conventional navigation aspects are combined within the Navigation Specification Technologies project (15.03.01), and used to derive an overall navigation baseline. It maps the proposed technology against the SESAR ATM Master Plan key performance areas. The project does not provide a solution on its own, however the results can be used by projects working on improving technologies or using GNSS as part of their solution. In this context the following table shows how results of this project can support enablers as described in the most recent list of navigation enablers from Integrated Roadmap Data Set 15 that are related in contribution in this project.

The first half of this project played an important role in identifying key technical elements of the baseline for civil and military airspace users. This was concluded in the baseline and roadmap activity in conjunction with SESAR Step 1 Concept of Operations (CONOPS).

The table below shows the level of maturity of the enabler with regard to the project contribution and baseline solution. The developments of GNSS baseline project provide significant developments to current technology and systems level.

EN Code	Name	Project contribution	Maturity at project start	Maturity at project end
CTE-N01	GPS L1/L5	Technical results coming from the performance assessment as well as the vulnerability assessment of ionosphere and radio interference on GPS L1/L5 are contributing to this enabler supporting the understanding of pros/cons of this constellation and its combinations of frequencies. The GNSS baseline complements this view by contributing economic assessment results.	TRL 3	TRL 6
CTE-N02	GALILEO E1/E5	Technical results coming from the performance assessment as well as the vulnerability assessment of ionosphere on GALILEO E1/E5 are contributing to this enabler supporting the understanding of pros/cons of this constellation and its combinations of frequencies. The GNSS baseline complements this view by contributing economic assessment results.	TRL 3	TRL 6
CTE-N03	GLONASS-K	Complementing the results accomplished in phase 1, technical results coming from this assessment made in phase 2 especially for northern latitudes support the understanding of pros/cons of this constellation to the overall GNSS baseline.	TRL 3	TRL 6
CTE-N05	GNSS performance assessment system	The need for independent GNSS performance monitoring of the GNSS elements included in the GNSS baseline in order to meet the integrity and continuity requirements has been analysed considering certification and legal recording requirements. Additionally a set of Key Performance Indicators (KPIs) have been defined in order to monitor a GNSS core constellations.	TRL 3	TRL 6
CTE-N06	Space Based Augmentation System (SBAS)	Technical results on satellite based augmentation coming from the performance assessment are contributing to this enabler supporting the understanding of this augmentation technology. The GNSS baseline complements this view by economic assessment	TRL 6	TRL 8

		results.		
CTE-N06a	EGNOS V2.4.X	Technical results coming from the performance assessment are contributing to this enabler supporting the understanding of this augmentation system. The GNSS baseline complements this view by economic assessment results.	TRL 6	TRL 8
CTE-N06b	EGNOS V3	GNSS baseline derived in Step 2 recommends EGNOS V3 adoption in the scope of long term research. The deployment of EGNOS V3 shall be considered as part of the overall navigation roadmap and will be further handled by studies or projects such as SESAR 2020. The maturity of EGNOS v3 is as reflected by the updates in ATM masterplan website. EGNOS v3 system is currently under evolution towards a multi frequency and multi constellation configuration and currently being assessed with the objective to have them operational by 2020.	TRL 2	TRL 3
CTE-N07	Ground Based Augmentation System (GBAS)	Technical results coming from the vulnerability assessment of ionosphere and radio interference on GNSS are essential elements of GBAS system design. This contribution compliments the GBAS ground segment developments with addressing the above mentioned threats. GBAS R&D and deployments related developments are being followed in many SESAR projects. This enabler is one of the general GBAS related enablers and the status of this enabler's maturity is as reflected in ATM masterplan at the time of writing this report.	TRL 6	TRL 8
CTE-N07a	GBAS Cat I based on Single-Constellation / Single-Frequency GNSS (GPS L1)	Technical results coming from simulations and from vulnerability assessment of ionosphere on GNSS are contributing to this enabler. GBAS GAST-C related R&D activities and deployments related developments are being followed in many SESAR projects. This enabler is one of the GBAS Cat 1 related enablers and the status of this enabler's maturity is as reflected in	TRL 6	TRL 8

		ATM masterplan at the time of writing this report.		
CTE-N07b	GBAS Cat II/III based on Single-Constellation / Single-Frequency GNSS (GPS L1)	The results coming from GNSS monitoring sub task provides evaluation of RFI as a vulnerability especially using GNSS repeaters and their impact on GAST-D.	TRL 3	TRL 6
CTE-N07c	GBAS Cat II/III based on Multi-Constellation / Multi-Frequency (MCMF) GNSS (GPS + GALILEO / L1 + L5)	This contribution relies on other closely related SESAR projects like "Multi GNSS CAT II/III GBAS" with their assessment on GNSS vulnerabilities to GAST-F concepts. GBAS GAST-F related R&D activities and deployments related developments are being proposed in future SESAR/EC projects. This enabler is one of the GBAS Cat III related enablers and the status of this enabler's maturity is beyond the schedule of this project and this is also reflected in ATM masterplan at the time of writing this report.	TRL 2	TRL 3
CTE-N13a	A-PNT (Alternative Positioning Navigation and Timing)	A very new system concept has been proposed and assessed to provide navigation service by replacing DME equipment with a system based on SSR/Mode S signals and formats and retaining legacy DME functionality. Mode N, where N stands for Navigation, offers the opportunity of a direct substitution of the DME equipment or even a replacement of the SSR Mode S transponder. APNT related R&D activities and deployments related developments are being proposed in future SESAR projects beyond step 2 and further. The status of this enabler's maturity is as reflected in ATM masterplan at the time of writing this report.	TRL 1	TRL 3

1.2 Project achievements

GNSS baseline is an essential utility to prove functional capability, performance, vulnerabilities and their mitigation measures in order to derive operational benefits and plan further strategic initiatives by different members of European Civil Aviation Conference (ECAC) and specifically at local level by ANSPs and airport authorities. The GNSS baseline is used to derive an overall navigation roadmap and demonstrate the civil-military interoperability involving complex aviation performance requirements from available technology used in deployment.

To develop the GNSS baseline the project started with studying the impact of intentional / unintentional vulnerabilities on GNSS, mainly threats coming from ionosphere effects and from Radio Frequency Interferences. Besides these, specific vulnerabilities to GNSS augmentation users on northern latitudes due to their geographical aspect on satellite geometry and effects such as scintillations have been studied as well. In this study a selected set of these threats have been characterised followed by a quantification of their impact on aviation grade GNSS receivers with complimentary studies arising from other SESAR studies. From here, mechanisms for mitigating ionosphere vulnerabilities to aviation approaches (precision approaches / non-precision approaches) have been investigated and threat models (for GBAS) for characterising specific failure modes have been created.

New concepts such as Advanced Receiver Autonomous Integrity Monitoring and their augmentation to GNSS relative to other integrity schemes have been studied as well as the benefits of providing an alternate source of Position, Navigation and Timing with integrity provision using identified candidate technologies.

Supporting legal aspects due to relying more and more on GNSS technology, the need and process for introducing GNSS monitoring at state level have been investigated as well as ways for distributing temporal and local warnings have been proposed.

The detailed result of this project can be used as a starting point for a first level assessment of a chosen technology solution for a given flight phase. GNSS baseline and roadmap can then be used for early interoperability between different GNSS constellations, for various integrity dissemination measures identified and their capability to support en-route and approach procedures for different service levels.

1.3 Project Deliverables

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

Reference	Title	Description
D03	Overall GNSS Requirements Summary	This report collects GNSS Positioning, Velocity and Time (PVT) requirements from all aviation application domains, e.g. navigation and surveillance. This means that these requirements are not direct technical system requirements for GNSS system elements, but instead focuses on the performance that needs to be achieved by individual GNSS system elements in order to satisfy particular aviation applications. Requirements are expressed in the common language of Required Navigation Performance (RNP) parameters, accuracy, integrity, continuity and availability. A link to the operational robustness concept as defined in SWP 15.03.01, D03 (Navigation Requirements) is established and the

		associated basis for setting application and environment – specific performance requirements (in particular availability and continuity) is discussed.
D04	Configuration Report	This report presents and justifies the configurations (constellations, augmentations, frequencies) that are candidates for the GNSS baseline and are proposed for further analysis. An analysis of GNSS configuration elements (navigation constellation, frequencies, augmentation) is done, looking precisely into the status and perspectives of such systems. Different criteria to be taken into account to select GNSS configurations are presented.
D05	GNSS System Analysis Report	This report collects the outcome of performed simulations and analysis on the performance of future GNSS element combinations. It provides conclusion of navigation requirements feasibility in perspective of GNSS infrastructure planned upgrades. It identifies performance level gaps in specific areas due to limited deployment of ground segment infrastructure or integrity support dissemination means which prevent potential navigation flight operations and proposes associated solutions whenever feasible. For each identified navigation requirement specified at this task input, the document provides an evaluation of the associated GNSS solution and conclusion on its feasibility as well as potential necessary GNSS infrastructure upgrades. It finally identifies key performance drivers, including their related margins and provides conclusions and recommendations on the future use of GNSS systems.
D06-002	Vulnerability Report - Issue 2	This report focuses on the two main threats for GNSS when used for aviation purposes namely: ionosphere effects and signal interference and presents the methodology used and results obtained for characterising the threats. For the ionosphere impact assessment three different ionosphere monitoring systems have been used to monitor ionosphere activity over Europe (EUROCONTROL), Germany (DFS), and Norway (NORACON) respectively. The largest encountered events during the monitoring period have been selected for characterisation. The monitoring is followed by an ionosphere impact assessment on GNSS users and a review of related requirements. This is followed by a review of mitigation actions for the most affected scenarios. A comprehensive review of different types and categories of interference is carried out followed by a review of the GNSS receivers used for the impact assessment. Six threat scenarios for interference

		on aviation operations are defined and reviewed in detail by the effect and possible mitigation on various receivers and operations. The threat scenarios identified are the following: Personal privacy devises (PPD), industrial or commercial in or out of band emissions, portable electronic devices (PED) carried on-board aircrafts, intentional jamming and spoofing, GNSS repeaters, and inter-system interference caused by the GNSS systems themselves.
D07	GNSS Monitoring and NOTAM Requirements	This report analyses the need for independent performance monitoring of the elements included in the GNSS baseline in order to meet the integrity and continuity requirements considering certification and legal recording requirements. Additionally a preliminary analysis is performed of the GNSS prediction system that needs to be put in place to inform users about operational impact of predicted GNSS un-availabilities via NOTAMs.
D08	GNSS Baseline Report	This report is considering all technical and non-technical aspects including economic, institutional, receiver complexity/cost to determine proposed GNSS baseline for SESAR deployment. A key element of the work is the assessment of the operational benefits that will be enabled by technical capabilities of future GNSS systems structured around SESAR Key Performance Areas (safety, capacity, environment and cost efficiency). An assessment of the GNSS baselines has been done by different aviation stakeholders (ANSPs and AUs) considering how the technical capabilities provided by GNSS Baselines could result on operational benefits. The document defines the preliminary GNSS baseline for SESAR until 2030 and for the long term research evolution.
Contribution to 15.03.01 D05	Roadmap towards SESAR Navigation Baseline	This report provides a roadmap for transition from the current navigation infrastructure to the SESAR navigation baseline over time and that for different stakeholders (e.g. ANSPs, Airspace users, Certification/regulatory authorities, GNSS...). The roadmap links to enablers to implement the SESAR navigation baseline. 15.03.04 contributes with GNSS aspects to this overall navigation roadmap as this document is consolidating inputs of several projects.
D10	GNSS Iono Vulnerability Report	This report continues the work done in task 6 on GNSS ionospheric vulnerability assessment. It adds results of an extension of the ionosphere monitoring campaign to the interval 2013-2015 and improves ionosphere impacts assessment and mitigations evaluation studies. Detailed results of the

		ionosphere monitoring campaign for the whole range 2011-2015 can be found in Annex 1 of D10 as a separate document.
D11	GNSS RFI Vulnerability Report	This report complements the work described in D06-002 on GNSS RFI vulnerability assessment covering new aspects which have not been assessed there. The technical work in this deliverable focuses on maturing capabilities associated with each of the three areas of the mitigation plan, e.g., threat monitoring, risk assessment and mitigation means deployment. Further actions and principles at the regulatory levels (preventive mitigation actions) are discussed.
D12	GNSS Monitoring Report	Complimentary deliverable to D07 by defining a set of Key Performance Indicators (KPIs) in order to monitor the GNSS core constellations, GBAS and SBAS. The detailed definition of these KPIs has been devised as well as the associated architecture. In order to confirm the validity of the devised KPIs, a test campaign has been carried out covering both GPS and GLONASS constellations.
D13	Mode N APNT System Concept Report	Description of a new concept of a spectrum efficient navigation system, which could be used as a DME substitute with APNT capabilities. It provides the background, concept details and gives an overview on the expected benefits of such a system. The document is intended to provide the baseline for further development within the SESAR programme.
Refer to 15.03.01 D09	SESAR Navigation Baseline and Roadmap	Incorporation of GNSS into the Navigation Baseline and Roadmap. The deliverable provides a comprehensive assessment of different aspects that have an impact on the SESAR navigation baseline, as well as the description of the navigation architecture proposed. It includes, among others, studies of the following topics: safety, technical, economical, status of the fleet, spectrum, back-up level assessment, regulatory and civil-military interoperability aspects. 15.03.04 contributed the GNSS aspects to the final navigation baseline and roadmap.

1.4 Contribution to Standardisation

15.03.04 project has provided a GNSS baseline which is further used to derive a navigation roadmap. Specific elements of the roadmap such as key technologies (ABAS, SBAS, and GBAS) would require either new standards or upgrade of existing standards to accommodate recent advancements. Development of such standards could start by using 15.03.04 outcome of the GNSS baseline as a reference. For example one such project which is dedicated to future standards of GBAS is "Multi

GNSS CAT II/III GBAS" (15.03.07) which will be one of the first steps in having GAST-F standards. 15.03.04 has delivered its results on GNSS vulnerabilities on ionosphere and on radio frequency interference to 15.03.07 for consideration and is thereby indirectly contributing to GBAS GAST-F standards. Similarly when other technologies (such as Advanced Receiver Autonomous Integrity Monitoring, ARAIM) mature 15.03.04 can once again be used as a starting point for development of standards.

The work on GNSS RFI Vulnerability Report, building on a similar task in project "Spectrum Management & Impact Assessment" (15.01.06), has generated a "GNSS RFI Mitigation Plan". The draft of this document has already been published as guidance material for States on the ICAO European Region website and is undergoing final editorial review for inclusion in the next update of the ICAO GNSS Manual, Doc 9849.

For the management of compatibility between DME and new GNSS signals in the E5/L5 frequency band, a compatibility check has been included in the Eurocontrol Network Manager Radio Frequency Function Best Practices Manual, and associated tools are being implemented to support the frequency assignment planning process. This has also been agreed with the ICAO European Region Frequency Management Group.

1.5 Project Conclusion and Recommendations

This project is one of the stepping stones towards supporting ECAC wide navigation technologies both for ground and on-board an aircraft to prepare the technical enablers in line with ATM Masterplan. The GNSS baseline developed is expected to bring benefits to all stakeholders together with operational improvements and new procedures being developed within SESAR.

This project enabled different aviation stakeholders (from ANSPs, regulatory organizations, industry, manufacturers, service providers, research institutes and airspace users) to develop the GNSS baseline and support the overall navigation roadmap. It provided specific performance expectations from GNSS based navigation assets for different flight phases and different aviation service levels defined by Eurocontrol for SESAR until 2020 as well as long term until 2030.

The project supported transition into PBN by identifying GNSS functional vulnerabilities and proposes mitigation measures. 15.03.04 also complimented the CNS robustness scenarios devised by Eurocontrol for supporting new procedures based on RNP. Candidate solutions from alternate technologies (APNT) and their capability to meet performance requirements were considered for the GNSS baseline.

It is recommended to continue the work of "GNSS Baseline Study" in SESAR 2020 as the technology improves over time, new technologies are arising and the understanding of GNSS vulnerabilities on ionosphere and radio frequency interference is evolving. The outcome of this project can be used as an inputs into SESAR 2020 project. The baseline analysis performed for GNSS enabled technologies such as GBAS and SBAS in the critical phase of flight (approach and landing) can be used to provide valuable information on system capability, safety and certification aspects, effect on environment, runway utilization and overall airport capacity.

It is important to continue the ionosphere monitoring campaign performed by 15.03.04 during the prominent phase of solar cycle 24 using GNSS measurements recorded over ECAC region. This has increased the confidence in the maximum magnitudes of the different effects under observation as the current solar cycle has not shown peak activities as expected. These maximum magnitudes are used later on as input into simulations on mitigation strategies.

New technologies should be assessed along with changes in operational environments. The GNSS Baseline should be monitored and updated when new facts become available to ensure European Air Traffic Management remains a successful player in a global industry.

2 References

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[12] SESAR Project 15.03.04, GNSS Iono Vulnerability Report, D10, 01.00.00, 25/04/2016

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