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SESAR 2020 PJ.14-W2-79a TRL6 CN GAST D Extended Scope

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Authors of the document

Beneficiary	Date
Indra	08.11.2022
DFS	30.08.2022
SINTEF	24.08.2022

Reviewers internal to the project

Beneficiary	Date
DFS	30.08.2022
Indra	30.08.2022
SINTEF	30.08.2022

Reviewers external to the project

Beneficiary	Date

Approved for submission to the S3JU By – Representatives of all beneficiaries involved in the project

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AENA	04.10.2022
DFS	04.10.2022
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I-CNSS

INTEGRATED COMMMUNICATION NAVIGATION SURVEILLANCE SYSTEMS

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Abstract

The contextual note describes the SESAR Solution PJ.14-W2-79a GAST D Extended Scope that has achieved a maturity level TRL6. It provides to any interested reader (external and internal to the SESAR programme) an introduction to the SESAR Solution in terms of scope, main operational benefits, relevant system impacts as well as recommendations for further work. The PJ.14-W2-79a activities address performance assessment of GAST D in challenging environments. These environments are severe ionospheric gradient and scintillation conditions, ground segment RFI threats, and large and complex airport environments. The relevant performance requirements are specified in ICAO Annex 10 Vol. I and ICAO Doc. 8071 Vol. II. This contextual note complements the technical TRL6 data pack PJ.14-W2 D9.1 comprising the SESAR wave 2 deliverables.

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1 Purpose

This contextual note introduces the SESAR Solution PJ.14-W2-79a GAST D Extended Scope. It provides to any interested reader (external and internal to the SESAR programme) an introduction to the SESAR Solution in terms of scope, main operational benefits, relevant system impacts as well as recommendations for further work. SESAR 1 solution 15.03.06 (solution #55) together with SESAR 2020 GAST D Extended Scope implement the maturity level TRL6 for the technological solution GAST D.

This contextual note complements the technical TRL6 data pack PJ.14-W2 D9.1 comprising the SESAR wave 2 deliverables.

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2 Improvements in Air Traffic Management (ATM)

A Ground Based Augmentation System (GBAS) is a Global Navigation Satellite System (GNSS) - dependent alternative to Instrument Landing System (ILS). It uses a GBAS ground station to transmit corrected GNSS data to suitably-equipped aircraft to enable them to fly a precision approach with much greater flexibility. It uses differential GNSS principle to improve the performance of stand-alone GNSS, ensuring the required integrity and accuracy. The GBAS system consists of a GBAS Ground subsystem, a GBAS Aircraft subsystem and the GNSS Space Segment. The Ground Subsystem provides the aircraft with approach path data and for each satellite in view corrections and integrity information. The corrections enable the aircraft to determine its position relative to the approach path more accurately. The GBAS service that supports CAT II/III precision operations is called GBAS Approach Service Type D (GAST D).

Building upon SESAR 1 15.3.6 and SESAR 2020 wave 1 PJ.14-03-01 solutions, the objective of SESAR 2020 PJ.14-W2-79a GBAS was to further improve the performance of the GAST D solution in challenging environments. These environments include severe ionospheric and scintillation conditions, ground segment Radio Frequency Interference (RFI) threats, and large and complex airport environments. The relevant technical specifications are covered by the ICAO Standards and Recommended Practices (SARPs) and ICAO Doc. 8071 Vol. II. The target maturity of the wave 2 GAST D extended scenarios was TRL6.

3 Operational Improvement Steps (OIs) & Enablers

The operational improvement steps and technical enablers defined in SESAR 2020 wave 1 to support wave 1 solution PJ.14-03-01 and its continuation in wave 2 PJ.14-W2-79a are:

- POI-0025-NAV GBAS applicability to challenging operational environments in Low Visibility Conditions (LVC)

  This Operational Improvement (POI) supports enhanced GBAS performance and robustness under ground threat conditions such as RFI (including jamming) occurrences.

- CTE-N07f Enhanced GBAS robustness under ground threat conditions

  This technical enabler supports GBAS CAT II/III Single-Constellation/Single- Frequency solution operating in airport environments that face technical problems related to RFI (including jamming) threat conditions.

- POI-0026-NAV GAST D applicability to Equatorial and Nordic regions

  This POI supports achieving Improved Low Visibility Operation using GBAS CAT II/III based on GPS L1 also in geographical areas that are subject to severe ionosphere conditions.

- CTE-N07e GBAS CAT II/III based on Single-Constellation / Single-Frequency GNSS (GPS L1) extension to equatorial and Nordic regions

  This technical enabler supports GAST D extension to geographical areas with severe ionosphere conditions such as equatorial and Nordic regions. Monitoring and mitigation techniques are required to cope with the adverse ionosphere conditions.

- POI-0027-NAV Enhanced interoperability and efficiency of GBAS infrastructure

  This POI covers the benefits achieved by standardizing the data set to be transmitted from the GBAS GS. It provides cost reduction, interoperability, and enhances the conformity of data usage.

- CTE-N07g GBAS Ground Station status data provision

  This technical enabler supports provision of a harmonized set of GBAS GS service status data are provided over an ATC and Maintenance interface to external systems (such as ATC display or Maintenance systems). Standardizing the set of data reduces costs, eases interoperability, and enhances conformity of data usage.

All technical modeling work was carried out in European ATM Architecture (EATMA) within the scope of SESAR 2020 wave 1 PJ.14-03-01. In wave 2, only description and attribute value updates have been done. Applicable Integrated Roadmap Dataset is DS22.

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The technical enabler CTE-N07g from wave 1 PJ.14-03-01 was revisited to confirm the completeness of the enabler in order to move maturity to TRL6. All development and validation activities were carried out in PJ.14-03-01. This included a security risk analysis activity.

4 Background and validation process

The GAST D performance requirements as defined by ICAO Annex 10 are the overlying requirements to fulfil. These apply irrespective of where geographically the GAST D system is operating and irrespective of the complexity of the airport environment. The verification of the GAST D solution in SESAR 1 was, however, limited to operating conditions typical of mid-latitude regions and relatively non-complex airport environments. The solution was not validated for more adverse ionosphere conditions that are typical of equatorial and high latitude geographical regions. Threats such as unintentional and intentional RFI (i.e., including jamming and spoofing) were identified, but not thoroughly investigated. A multiple VHF Data Broadcast (VDB) transmitter scheme was developed and verified to provide adequate VDB coverage at large and complex airports (i.e., Frankfurt International airport) in SESAR 1, however, verifying VDB coverage in areas that are difficult to physically measure is essential to maintain and operate a GBAS system over time. Extending the SESAR 1 GAST D solution to tackle these adverse or complex environments was the goal of PJ.14-03-01 GAST D Extended Scope (TRL4) and further matured in PJ.14-W2-79a to TRL6.

The high-level technical validation objectives were:

- Ionosphere monitoring: The technical validation objective for the GAST D Ground Station was to validate that the ionosphere monitor meets the GAST D performance requirements in the regions prone to higher anomalous ionospheric behaviour.

- Large and complex airports: The technical validation objective for the GAST D Ground Station was to verify that the ground architecture and siting fulfil the requirements for VDB runway coverage on large and complex airports.

- Extended Performance Assessment in Threat scenarios (RFI): The technical verification objective for the GAST D Ground Station was to validate the detection and mitigation of RFI by additional measurement and monitoring equipment. There are currently no requirements mandating the detection of such signals.

The technical validation of the above objectives required different approaches and utilized different validation techniques, platforms, and tools. An essential part of the validation activities included ionosphere/scintillation data collection at Tenerife Norte Airport (data logger station deployed in wave 1 and data collection took place in wave 1 and wave 2). RFI event logging took place at various European locations (Trondheim, Asker, Amsterdam, Noordwijk, and Helsinki in wave 1 and expanded to include Moss, Ålesund, Sodankylä, and Prague in wave 2). Data analysis, simulations, and lab tests, carried out by solution partners were validation techniques employed for the Ionosphere monitoring and analysis exercises as well as for the RFI characterization and analysis exercises. Field tests were performed at Frankfurt International Airport in Germany by DFS for GBAS VDB coverage related exercises (wave 1 and wave 2) and for Air Traffic Control (ATC) and maintenance interface verification exercises (wave 1 only).

5 Results and performance achievements

The main findings from the overall validation exercises in PJ.14-W2-79a is summarised below.

5.1 Ionosphere monitoring and analysis

The enabler CTE-N07e deals with the extension of GAST D to equatorial and high latitude regions. In this project several years of data has been collected at Tenerife Norte containing periods of adverse ionosphere. The presence of scintillation is a key difference between the high and low magnetic latitudes and the mid-latitudes. Scintillation adds considerable noise to the GNSS signals and affects GBAS service continuity and availability. Integrity is less affected since it does not create a differential error for the approaching aircraft.

The project has identified a need for a scintillation monitor to mitigate the impact of scintillation on the GBAS integrity monitors, as their continuity and integrity performance suffer during scintillation. This may impact integrity if not accounted for. A scintillation monitor has been developed but it cannot detect all levels of scintillation, so some robustness to scintillation in the ground station GBAS integrity monitor design may be necessary.

Mitigation of the ionospheric gradient threat is demonstrated using exhaustive simulations. In this project we show that the presence of scintillation impacting integrity monitors and changes to the ionospheric gradient threat model making it more severe, may result in a trade-off between tighter siting constraints and reduced GAST D availability. This trade-off is subject to operational needs. Availability simulations have been performed to validate the ionospheric uncertainty estimate of 4.1 mm/km. They show that GAST D availability beyond 99.9 % is attainable at Tenerife Norte on average, taking into account that adverse ionosphere may occur in some periods of the year. The number of GNSS satellite signals affected simultaneously by scintillation has an impact on these results and for Tenerife Norte it is rare that more than two are affected.

The technical enabler CTE-N07e is considered to have achieved the target TRL 6 as we now have the necessary understanding of what is required for the extension from mid-latitudes to high and low magnetic latitudes.

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5.2 Large airports with complex environments

The SESAR 2020 solution PJ.14-W2-79a GAST D Extended Scope addresses GBAS GAST D operation and maintenance in large and challenging airport environments with multiple runways and complex layouts. To perform GBAS field strength verification, VDB ground measurement equipment and a runway coverage simulation tool were developed and technically validated in SESAR 2020 Wave 1 (2016-2019). The equipment GBAS Measurement Tool (GMT) was used to validate among other ICAO minimum VDB field strength requirement for autoland in 36ft to 100ft above the runway. Building upon this work, PJ.14-W2-79a aimed to validate the ICAO Doc 8071 Vol. II ±3 dB measurement uncertainty requirement. For this, a horizontally polarized VDB measurement antenna that fits on a measurement van and provides omnidirectional characteristic for an installation in 12 feet above ground was developed and used as part of the validation platform to technically verify the ±3 dB measurement uncertainty requirement. The validation exercise determined the maximum measurement error for the field measurement set-up. The value exceeds the ICAO recommended measurement accuracy demonstrating that achieving the ICAO requirement is very challenging.

No technical enabler has been defined for the VDB Measurement tool, GMT. This tool is an off-line tool to be used by airport technical maintenance personnel to be able to carry out the necessary operational and maintenance of a GBAS system at an airport.

The tool is not modelled in EATMA.

5.3 GBAS Ground Station RFI threat analysis

For GAST D, the technical enabler CTE-N07f covering GBAS Ground Station robustness to RFI has achieved the maturity level of TRL6. In wave 1, detection of unintentional RFI and alerting to ATC was implemented and validated. The RFI signals observed on the GPS L1 frequency during the monitoring campaign and analysed in wave 2 are analogous to the RFI signals upon which the wave 1 detection and alert solution is based. Thus, the wave 1 implemented solution can be migrated to TRL 6.

In the context of GAST F, however, thanks to the Dual-Frequency Multi-Constellation (DFMC) capabilities of the technology, further improvements can be sought in terms of mitigation and robustness measures.

The SESAR 2020 solution PJ.14-W2-79a GAST D Extended Scope addresses GBAS GAST D operation and performance in large and challenging airport environments. The number of incidents of deliberate or inadvertent interference that render GPS inoperable for critical infrastructure operations is increasing. To address the RFI issue, the validation exercises focused on environment monitoring and characterization, as well as RFI threat evolution analysis. A number of low-cost multi-band GNSS RFI event loggers developed by SINTEF were deployed at various European locations, capturing and characterizing RFI events during wave 2. A broad RFI event database has been accumulated and analysed to study the evolution of the RFI threat dynamics and characteristics. Statistical analysis of the captured RFI events has also been performed to establish probability of occurrence, occurrence rate on the L1/E1 frequency only, L5/E5a frequency only, as well as the two frequency bands together. Analysis of observations made on the adjacent bands such as Galileo E5b has also been carried out.

6 Recommendations and Additional activities

The main recommendations are summarized for the three main objective areas:

Ionosphere monitoring and analysis

PJ.14-W2-79a identified a need for a scintillation monitor to handle scintillation occurrence impact on GBAS integrity monitor performance. It is recommended to discuss this topic within appropriate GBAS working groups and standardisation forum.

Improvements to the scintillation monitor and the ionospheric gradient monitor could help counteract the negative impact of adding scintillation robustness to the integrity monitors. As the GBAS community is moving towards dual frequency multi constellation (DFMC) GAST F, it is interesting to investigate whether dual frequency integrity monitoring in the ground subsystem could improve GAST D performance. This will require the availability of a certified DFMC GNSS receiver, which is also needed for GAST F. In this context robustness to scintillation and adverse troposphere should be revisited.

Large airports with complex environments

The uncertainty of the measured VHF field strength exceeds 3 dB. The requirement is very challenging due to the pattern change during measurement. The ground reflexion has probably the most significant impact on the pattern change, which is very difficult to compensate.

The big challenge is to determine the influence of the ground reflexion to improve quality of the antenna correction table. This could reduce a bit the measurement uncertainty. Additional improvement could be to use external sensor like gyroscope to improve accuracy of the vehicle direction angle.

From a standardisation viewpoint, it is recommended to re-evaluate the ICAO ± 3 dB measurement uncertainty requirement.

GBAS Ground Station RFI threat analysis

It is recommended to continue the work on the RFI topic in the context of GAST F. Thanks to the DFMC capabilities of GAST F, improvements can be sought in terms of mitigation and robustness measures.

7 Actors impacted by the SESAR Solution

For Air Navigation Service Providers (ANSP) and Airport Operators it is essential that the GBAS solution is validated to operate safely when encountering challenging ionospheric conditions. The PJ.14-W2-79a activity dealing with ionosphere gradient monitoring has shown the feasibility of GAST D safety operating under such conditions. The feasibility of the ICAO Annex 10 Vol I GAST D performance requirements are validated.

ANSP must demonstrate to the national safety authorities that the installed GBAS Ground Station is able to provide a service in compliance with ICAO requirements in airports of varying size and complexity. As ANSP, it is also essential to ensure a cost-efficient and reliable operation and maintenance framework to support the demonstration of compliance. The PJ.14-W2-79a GAST D Extended Scope activities related to measuring and verifying VDB field strength coverage (and its compliance with ICAO Doc 8071 Vol II requirements) has contributed to the above operation and maintenance framework.

Understanding GBAS resilience against unintentional RFI and employing appropriate measures to ensure the safe GBAS ground segment operating environment is vital for the ANSP and Airport Operators who are responsible for providing a safe and efficient GBAS service. The PJ.14-W2-79a RFI activities have contributed to understanding the RFI threat to the GBAS service and determining mitigation measures.

The work carried out in SESAR 2020 wave 2 PJ.14-W2-79a solutions is limited to the ground segment. This work does not involve any change to the airborne equipment. Thus, no impact on Airspace user.

8 Impact on Aircraft System

The work carried out in SESAR 2020 PJ.14-W2-79a does not lead to any change in the interface between ground segment and airborne segment, and thus, has no impact on the Aircraft System.

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9 Impact on Ground Systems

PJ.14-03-01 (wave 1) and PJ.14-W2-79a (wave 2) GAST D Extended Scope[1] has contributed to the following:

- GBAS Ground Station Air Traffic Control interface specification - defined interface technology and GBAS service provision and status parameters to be read by ATC systems (input to ED-114B standardization) and validation of the implemented physical interface
- RFI (unintentional) monitor and alert function developed and validated
- An Ionospheric Gradient Monitor (IGM) was developed and validated using data collected at Tenerife. To handle scintillation occurrence impact on IGM performance, a scintillation monitor was developed and validated.

[1] The following items have no impact on the Ground Systems as such, however, were essential to achieving the target objectives of solution PJ14-W2-79a:

- Extensive library of RFI occurrences collected – analysed, characterized – covering GPS, GALILEO, and GLONASS frequencies
- Update of SESAR 1 GAST D Safety Assessment report – added/modified safety requirements, limitations, recommendations, replaced out-of-date standards with references to current standards
- Cost Benefit Analysis covering review of SESAR 1 CBA (2016) and SESAR Deployment Manager CBA (2020), updated ground segment cost items and estimates (not including airborne segment), list of benefits
- Yearly publication of the European Ionosphere Threat Model
- Deployment of a GBAS data Logger station at Tenerife Norte Airport for ionospheric and scintillation data collection
- Development of advanced VDB ground measurement equipment (including van mounted VDB antenna) for verification of GBAS field strength coverage in complex airport environments

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10 Regulatory Framework Considerations

No regulatory impact proposed.

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11 Standardization Framework Considerations

11.1 Ionosphere monitoring and analysis

As described in section 6 the following findings and topics are recommended to be addressed in the relevant GBAS working group:

- Mitigation measures to reduce the effect of scintillation on integrity monitor continuity.
- Use of dual frequency integrity monitoring in the ground subsystem could improve GAST D performance. This will require the availability of a certified DFMC GNSS receiver, which is also needed for GAST F.
- Guidance on how to handle equatorial plasma bubbles (EPB) and scintillation for GBAS should be made available through ICAO. An activity is ongoing in the ICAO IGM ad-hoc group.

11.2 Large airports with complex environments

In SESAR context the solution has developed validation platforms comprising GBAS measurement tool, a runway coverage simulation tool, and a van-mounted VHF measurement antenna that are used to validate VDB field strength in 36ft above the landing runway (ICAO Annex 10) and the ±3dB measurement accuracy requirements (Doc. 8071 Vol II). The second requirement related to VDB field strength measurement accuracy is shown in wave 2 to be difficult to fulfil compliance to.

From a standardisation viewpoint, it is recommended to re-evaluate the ICAO Doc. 7081 Vol. II ± 3 dB measurement uncertainty requirement. This topic is to be discussed with the appropriate GBAS working groups.

11.3 GBAS Ground Station RFI Threat analysis

For GAST D, no additional recommendations relative to what is already specified in the ICAO Annex 10 and ED 114B standards are identified. Continued work on the RFI topic in the context of GAST F will contribute to further standardization work.

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12 Solution Data pack

The Data pack for this Solution includes the following documents:

- TS/IRS – D9.1.120 Final TS/IRS TRL6 GAST D Extended Scope Part I, Ed.01.03.00, Nov 2022
- TS/IRS – D9.1.120 Final TS/IRS TRL6 GAST D Extended Scope Part II, Ed.01.01.01, Aug 2022
- TVALR – D9.1.400 TVALR TRL6 GAST D Extended Scope, Ed.00.01.03, Oct 2022
- CBAT – D9.1.500 CBAT TRL6 GAST D Extended Scope, Ed.00.01.03, Oct 2022

Note that SESAR 1 15.03.06 solution #55 data pack together with the SESAR 2020 wave 1 PJ.14-03-01 D8.1 GAST D Extended Scope and wave 2 PJ.14-W2-79a D9.1 GAST D Extended Scope data packs constitute the complete TRL6 for technological solution GBAS with approach service type GAST D.

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