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Abstract

Green-GEAR aims to enable and incentivise optimum green trajectories and airspace use through new ATM procedures; to this end, it develops three new SESAR Solutions.

This present document is the Functional Requirements Document (FRD) for Solution 0406 "Vertical guidance using Geometric Altimetry" at TRL2 level, seeking to enable optimised airspace design with continuous climb and descent through the Transition Layer, as well as route separation based on vertical path performance limits. It describes the Solution functional architecture and requirements.

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Green-GEAR

GREEN OPERATIONS WITH GEOMETRIC ALTITUDE, ADVANCED SEPARATION & ROUTE CHARGING SOLUTIONS

Green-GEAR

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1 Executive summary

This document is the Functional Requirements Document (FRD) for Solution 0406 "Vertical guidance using Geometric Altimetry" targeting TRL2 maturity. It provides a high-level description of the SESAR Solution target architecture and functional requirements specification.

The Solution addresses two methods for the use of geometric altimetry for vertical guidance:

- **Concept Method 1** – Waypoint/fix altitude constraints are defined relative to geometric altitude instead of barometric.
- **Concept Method 2** – Procedural vertical paths are defined as geometric paths with Instrument Flight Procedures (IFPs) defined in 3 dimensions.

The benefits were assessed for method 2 but a composite solution of the two methods is considered to be the optimal final end state of the concept. Therefore, this FRD is built considering both methods.

Note: application of method 2 to Climb brings significant impacts on aircraft systems and operation and was not found beneficial, so it is assumed that Departure procedures would apply method 1 only.

Solution 0406 introduces significant impacts on airborne and, to a lesser extent, ground systems. They cover the entire value chain involved in designing, managing and operating the new IFPs based on geometric reference, as well as related monitoring capabilities for timely switch to fallback operation based on barometric altimetry. The technical solution also addresses the transition between barometric and geometric airspace in nominal operations.

While the Solution scope was focused on Climb, Descent and Approach phases, the use of geometric altimetry for Cruise operations was also explored. However, the use of geometric altimetry has been found not operationally suitable for Cruise phase, and thus only worth considering as part of a holistic geometric navigation solution as an enabler for other ATM Solutions (e.g., Solution 0407 / RVSM 2). So, for the purpose of this FRD, Geometric Altimetry is only applicable to airspace blocks including Climb, Descent or Approach operations (e.g., TMA and surrounding airspace).

Also, the need to mitigate the increasingly present jamming and spoofing threats and become more resilient is confirmed, but this is a transversal challenge affecting whatever ATM Solution relying on GNSS for lateral and/or vertical positioning. So, for the purpose of this FRD, it is considered as a prerequisite for the GeoAlt Solution rather than part of its scope. Solution features related to monitoring of the GeoAlt capability and fallback to barometric navigation described in this FRD are kept generic, not specifically focused on jamming and spoofing or any other particular cause of GNSS loss.

Finally, the way forward for airborne predictions computations is still to be consolidated since aircraft performance is always tied to barometric conditions and airborne systems do not currently have the capability to anticipate the pressure altitudes associated to the expected geometric altitudes. Whether the related technical solution can be standalone at airborne implementation level or would impose additional requirements on ground services such as aeronautical information management (AIM) or meteorological services (MET), is still to be assessed.

2 Introduction

2.1 Purpose of the document

The SESAR solution development lifecycle aims to structure and perform the work at project level and progressively increase the maturity of a given SESAR solution, with the final objective of delivering it for industrialisation and deployment. The Functional Requirements Document (FRD) represents one of the key technical deliverables for any SESAR Solution at TRL2 maturity level.

The FRD provides a high-level description of the SESAR Solution target architecture, together with the functional requirements specification covering not only the functions and interfaces to be implemented but also the non-functional requirements (e.g., safety, performance, etc.) to be met by the technical systems to support the target operational concept(s).

The FRD describes the 'what' is needed and not the 'how' it should be implemented. Therefore, the document does not aim at specifying the systems' physical design (which remains for the industry).

2.2 Scope

The present FRD addresses SESAR Solution 0406 "Vertical guidance using Geometric Altimetry" targeting TRL2 maturity.

The Solution addresses two methods for the use of geometric altimetry for vertical guidance:

- **Concept Method 1** – Waypoint/fix altitude constraints are defined relative to geometric altitude instead of barometric.
- **Concept Method 2** – Procedural vertical paths are defined as geometric paths with Instrument Flight Procedures (IFPs) defined in 3 dimensions.

The benefits were assessed for method 2 but a composite solution of the two methods is considered to be the optimal final end state of the concept. Therefore, this FRD is built considering both methods.

Note: application of method 2 to Climb brings significant impacts on aircraft systems and operation and was not found beneficial, so it is assumed that Departure procedures would apply method 1 only.

While the Solution scope was focused on Climb, Descent and Approach phases, the use of geometric altimetry for Cruise operations was also explored and found not operational suitable (see 5.1.1). So, for the purpose of this FRD, Geometric Altimetry is only applicable to airspace blocks including Climb, Descent or Approach operations (e.g., TMA and surrounding airspace).

2.3 Intended readership

This document is aimed at the following stakeholders:

- All Green GEAR consortium members who are contributing directly to the solution research or contributing to related solutions or work packages in the project (Airbus, DLR, EUROCONTROL, NATS, NLR, UNITS, UoW).
- Relevant SESAR R&I projects.
- Relevant SESAR transversal projects such as AMPLE3.
- SJU Programme representatives, as the owner and final approver of this document.

2.4 Background

This section presents the background on which Solution 0406 is building.

PJ.02 EARTH Solution 02-11 (2016-2020)

In SESAR 1, PJ.02-11 – Enhanced Terminal Area for efficient curved operations explored future CONOPS, including the use of geometric altitude during approach phase and the use of curved procedures.

PJ.02-11 reached V1 maturity by the end of SESAR 1 and gave recommendations on future Research and Innovation (R&I) activities linked to Advanced curved TMA operation. The Real Time Simulations that took place in PJ.02-11 addressed primarily airborne aspects and ground aspects were discussed during Expert Group meetings. The potential in using GNSS based Advanced curved TMA operation was recognised for both arriving and departing aircraft. However, it was identified that future Research and Innovation work is needed to cater for ATC aspects as well, for both the new arrival and departure concepts to mature.

PJ.02-W2 AART Solution 04.3 (2020-2023)

PJ.02-W2-04.1/2/3 was the continuation of PJ.02-11.

The Airport Airside and Runway Throughput project worked on the concept of Advanced Curved Operation in the TMA, which was linked to three SESAR Solutions, one of which was Advanced Curved Approach Operation in the TMA with the use of geometric altitude.

SESAR 2020 VLD2 ALBATROSS (2020-2023)

ALBATROSS had the aim to demonstrate how the technical and operational R&D achievements of the past years translate into fuel efficiency improvements in real operations. The Demonstration activity covered all flight phases and addressed both operational and technological aspects of aviation and Air Traffic Management (ATM).

Among the concepts demonstrated in real conditions was exercise EXE-03 where a demonstration and study were conducted to evaluate the benefits of closed-path PBN-to-ILS procedures with and without a pilot support system for energy management, compared to radar vectoring procedures to the same runway. The specific feature of EXE-03 was that the closed-path trajectory was already assigned by ATC to the pilots at the beginning of the descent when passing the IAF (Initial Approach Fix) of the STAR (Standard Instrument Arrival), avoiding tactical lateral instructions during the approach. Lateral tactical ATC instructions prevent optimised CDAs, as the distance-to-go (DTG) is crucial information to estimate the aircraft's energy state and hence decide on the energy dissipation strategy. The conclusions stressed the necessity to deploy PBN-to-xLS procedures (including RNP or LPV approaches) to as many flights as possible. Green-GEAR works especially on the vertical component of PBN-to-xLS, whose increased predictability is expected to contribute significantly to reducing the need for ATCO intervention.

SESAR 2020 PJ37-W3 ITARO (2021-2023)

ITARO project demonstrated on a larger scale several solutions in the airport environment, including procedures to enable more efficient and integrated runway throughput and terminal operations; a collaborative framework for managing delay constraints on arrivals; and improved arrival and departure operations.

Among those, a flight trial EXE-003 was conducted to increase the maturity level of Interval Management (IM) operations on RNP routes/procedures and continuous descent operations (i.e. fixed profile descents) in high density TMA environments by performing flight trials with an aircraft equipped with the RNP, VNAV and Flight-deck Interval Management (FIM) capability.

EXE-003 conducted arrival operations with frequent speed adjustments on business jet flights following closed PBN STARs with fixed descent angle of 2° or 2.5°.

The consolidated pilot feedback on the IM speed guidance aspect of the concept was that sometimes speed brakes were necessary to create sufficient deceleration, suggesting that the use of speed brakes for low-drag airliners may be needed to decelerate on RNAV routes with a fixed vertical angle.

It showed that a balance is to be found between by the procedure designer: a shallower vertical profile will require less speed brakes, but also gives less fuel/noise benefits.

That said, the use of speed brakes did not raise pilot acceptance issues, therefore the corresponding HP validation objective was assessed as OK.

2.5 Structure of the document

This Functional Requirements Document is structured as follows:

- Section 1 gives an executive summary of the FRD and provides a summary of the key information and elements contained in the document.
- Section 2 describes the purpose, scope, intended readership, background and structure of the document. It also contains a glossary of terms and a list of acronyms used in the FRD.
- Section 3 describes the functional architecture.
- Section 4 describes the functional requirements both for the airborne and ground segments.
- Section 5 describes the key assumptions taken while developing the Solution at TRL2.
- Section 6 includes the list of references used in developing the FRD.

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2.6 Glossary of terms

Term	Definition	Source of the definition
Final Approach Segment	That segment of an instrument approach procedure in which alignment and descent for landing are accomplished Below the Transition Layer	ICAO PANS OPS [25]
Geometric Altitude/ GeoAlt	Defining routes and procedures using geometric altitude. Aircraft navigation systems constructing vertical paths based on geometric altitude and navigating to geometric altitude.	Project Definition
Geometric constraints at waypoints	Flight procedures continue to constrain vertical flight profiles through the use of altitude constraints, but the constraints become geometric altitudes instead of barometric. Defined as Concept Method 1.	Project Definition
Geometric Path / Geo Path	Paradigm change in flight procedures, now being vertically defined by published geometric paths with vertical containment assumptions. Defined as Concept Method 2, with two sub-options: • Sub-option 2.1 – without V-RNP: navigation and guidance capability with vertical containment performance demonstrated at aircraft certification / ops approval level but without RNP-like onboard monitoring and alerting. • Sub-option 2.2 – with V-RNP: navigation and guidance capability with vertical containment performance supported by RNP-like onboard monitoring and alerting.	Project Definition
Initial Approach Segment	That segment of an instrument approach procedure between the initial approach fix and the intermediate fix or, where applicable, the Final Approach fix or point. Typically, below the Transition Layer	ICAO PANS OPS [25]

Term	Definition	Source of the definition
Instrument Approach Procedure / IAP	A series of predetermined manoeuvres by reference to flight instruments with specified protection from obstacles from the initial approach fix, or where applicable, from the beginning of a defined arrival route to a point from which a landing can be completed and thereafter, if a landing is not completed, to a position at which holding or en-route obstacle clearance criteria apply.	ICAO PANS OPS [25]
Instrument Flight Procedures	Instrument flight procedures (IFP) are used by aircraft flying in accordance with instrument flight rules and are designed to facilitate safe and efficient aircraft operations. It is a published procedure used by aircraft flying in accordance with the instrument flight rules which is designed to achieve and maintain an acceptable level of safety in operations and includes one or more of the following: an instrument approach procedure, a standard instrument departure (SID), a planned departure route and a standard instrument arrival (STAR).	ICAO [27] and IFATCA [28]
Intermediate Approach Segment	That segment of an instrument approach procedure between either the intermediate approach fix and the final approach fix or point, or between the end of a reversal, racetrack or dead reckoning track procedure and the final approach fix or point, as appropriate. Below the Transition Layer	ICAO PANS OPS [25]
Standard Instrument Departure / SID	A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated ATS route, at which the en-route phase of a flight commences. Typically, below or crossing the Transition Layer	ICAO PANS OPS [25]

Term	Definition	Source of the definition
Standard instrument arrival / STAR	A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced. Typically, above or crossing the Transition Layer	ICAO PANS OPS [25]
Transition Layer	The airspace between the transition altitude and the transition level, where the Transition Altitude is the altitude at or below which the vertical position of an aircraft is controlled by reference to altitudes and the Transition Level is the lowest flight level available for use above the transition altitude.	ICAO PANS OPS [25]
Vertical RNP / V-RNP	There is currently no RTCA/EUROCAE definition or standard for vertical RNP. However, for the purposes of this concept, Vertical RNP is considered to be the equivalent in the vertical plane to RNP in the lateral plane.	ICAO PBN Manual [26]

Table 1: glossary of terms

2.7 List of acronyms

Term	Definition
ADIRS	Air Data Inertial Reference System
ADS-B	Automatic Dependent Surveillance – Broadcast
AGL	above ground level
AIAA	American Institute of Aeronautics and Astronautics
AIM	Aeronautical Information Management
AirTOp	Air Traffic Optimisation [simulation software]
AIXM	Aeronautical Information Exchange Model
AoR	Area of Responsibility
APP	Approach

Term	Definition
AR	Authorisation Required
ATC	Air Traffic Control
ATCO	Air Traffic Controller / ATC Officer
ATM	Air Traffic Management
AUC	Airspace user cost efficiency [performance indicator]
AVES	Air Vehicle Simulator
BADA	Base of Aircraft Data
CAP	capacity [performance indicator]
CBA	cost-benefit analysis
CDA	Continuous Descent Approach
CLB	Climb
CONOPS	Concept of Operations
CWP	Controller Working Position
D<no.>	Deliverable <no.>
DES	Digital European Sky
DES	Descent
DISA	Delta ISA
DMP	Data Management Plan
DTG	Distance-to-Go
ENV	environment [performance indicator]
ER	Exploratory Research
ERP	Exploratory Research Plan
ERR	Exploratory Research Report
EU	European Union

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Term	Definition
EUROCAE	European Organisation for Civil Aviation Equipment
EXE	Exercise
FCU	Flight Control Unit
FDP	Flight Data Processing
FEFF	fuel efficiency [performance indicator]
FMS	Flight Management System
FOC	Flight Operations Centre
FRD	Functional requirements document
FTS	Fast-Time Simulation
GDPR	General data protection regulation
GeoAlt	Vertical Guidance using Geometric Altimetry
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
Green-GEAR	Green operations with Geometric altitude, Advanced separation & Route charging Solutions
HC	High Complexity
HE	Horizon Europe
HFOM	Horizontal Figure of Merit
HIL	Horizontal Integrity Limit
HP	Human Performance
HP	Human performance [performance indicator]
IAF	Initial Approach Fix
IAP	Instrument Approach Procedure
ICAO	International Civil Aviation Organisation

Term	Definition
ID	Identifier
IFATCA	International Federation of Air Traffic Controllers’ Associations
IFP	Instrument Flight Procedure
ILS	Instrument Landing System
ISA	International Standard Atmosphere
JU	Joint Undertaking
KPA	Key Performance Area
KPI	Key Performance Indication
LPV	Localiser Performance with Vertical guidance
M<no.>	project month <no.>
MET	Meteorological services for air navigation
MLS	Microwave Landing System
MMR	Multi-Mode Receiver
MSL	Mean Sea Level
NavDB	Navigation Database
ND	Navigation Display
NEST	Network Strategic Monitoring Tool
OBJ<no.>	objective <no.>
OPS	Operations
OSED	Operational Service and Environment Description
OPT ALT	optimum altitude [for efficient cruise flight]
PANS	Procedures for Air Navigation Services
PBN	Performance Based Navigation
PFD	Primary Flight Display

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Term	Definition
Q<no.>	(calendar) quarter <no.>
QNH	[barometric reference pressure setting to achieve MSL altitude indication in vicinity of airfield]
REC MAX	recommended maximum flight altitude
R&I	Research & Innovation
RNP	Required Navigation Performance
RTCA	Radio Technical Commission for Aeronautics
SAF	safety [performance indicator]
SBAS	Satellite-Based Augmentation System
SEN	sensitive (limited under the conditions of the Grant Agreement)
SESAR	Single European Sky ATM Research
SESAR 3 JU	SESAR 3 Joint Undertaking
SID	Standard Instrument Departure
S3JU	SESAR 3 Joint Undertaking
SJU	SESAR Joint Undertaking
SME	Subject Matter Expert
SOL	Solution
SRM	Safety Reference Material
STAR	Standard Terminal Arrival Route
STATFOR	[EUROCONTROL] Statistics and Forecasts Service
STELLAR	SESAR Tool Enabling collaborative ATM Research
Suc	Success
T<no.>	task <no.>
TA	Transversal Area

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Term	Definition
TAWS	Terrain Avoidance and Warning System
TCAS	Traffic Alert and Collision Avoidance System
TDB	Track Data Block
TMA	Terminal Manoeuvring Area
ToC	Top of Climb
ToD	Top of Descent
TRL	Technology Readiness Level
UK	United Kingdom [of Great Britain and Northern Ireland]
UKRI	UK Research and Innovation
V<no.>	version <no.>
VD	Vertical Display
VFOM	Vertical Figure of Merit
VIL	Vertical Integrity Limit
V-RNP	Vertical Required Navigation Performance
WA	Working Area
WP<no.>	Work package <no.>
xFOM	[generic abbreviation for different Figure of Merit, e.g. HFOM and VFOM]
xIL	[generic abbreviation for different Integrity Limit, e.g. HIL and VIL]
xLS	[generic abbreviation for different precision approach and landing systems, e.g. ILS, MLS, GLS]

Table 2: list of acronyms

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3 Functional architecture view

3.1 SESAR solution overview

SESAR solution ID	SESAR solution title	SESAR solution definition	Justification (why the solution matters?)
0406	Vertical Guidance using Geometric Altimetry	Airspace design based on geometric constraints and geometric vertical paths, increasing predictability and enabling continuous climb or descent ignoring atmospheric variation and the Transition Layer	Variation in localised pressure creates fuel, environmental and workload inefficiencies due to current reliance on barometric altimetry.

Table 3: Geometric Altitude Scope

The operational concept of Vertical Guidance using Geometric Altimetry is considered for both the idealised end state (fully geometric operations) as well as the transitory state (mix of geometric and barometric operations). The concept is limited to a number of key focus areas.

Two methods can be considered for the use of geometric altimetry for vertical guidance:

- **Concept Method 1** - Waypoint/fix altitude constraints are defined relative to geometric altitude instead of barometric.
- **Concept Method 2** - Procedural vertical paths are defined as geometric paths with Instrument Flight Procedures (IFPs) defined in 3 dimensions; one sub-option with a vertical tolerance established in certification; the second sub-option as a Vertical-RNP type solution with onboard performance monitoring and alerting.

The benefits were assessed for method 2 (cf. ERR [23]) but a composite solution of the two methods is considered to be the optimal final end state of the concept. Therefore, this FRD is built considering both methods.

Note: application of method 2 to Climb brings significant impacts on aircraft systems and operation and was not found beneficial, so it is assumed that Departure procedures would apply method 1 only.

While the Solution scope was focused on Climb, Descent & Approach phases, the use of geometric altimetry for Cruise operations was also explored. However, based on project outcomes described in the ERR, the use of geometric altimetry has been found not operationally suitable for Cruise phase (see 5.1.1). Consequently, geometric altimetry in cruise would only be worth considering as part of a holistic geometric navigation solution as an enabler for other ATM Solutions (e.g., Solution 0407 / RVSM 2).

Transitionary steps towards end state use of geometric altimetry are seen as follows:

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1. Step 1 – Geo Approach procedures including not only final but also initial/intermediate approach segments.
2. Step 2 – All altitude constraints within a defined airspace volume, e.g. TMA, switched from Baro to Geo Alt, with no airspace redesign.
3. Step 3 – Composite geometric solution applied within a defined airspace volume, e.g. TMA, potentially divided into a set of sequential airspace changes, e.g. airport per airport. Geo Path applied to Descents where necessary for procedural deconfliction.
4. Step 4 - Composite geometric solution applied within a larger airspace block, e.g. FIR. This solution could include geometric Cruise alongside geometric Approach, Descent & Climb, but only if it were beneficial as part of a holistic design. For example, if it enabled RVSM 2.

Under Transition Step 1, there would be an interface between barometric and geometric as the aircraft transits from the STAR to the Initial Approach Procedure. This may require an extended IAP to enable Baro to Geo capture under all meteorological conditions.

Under Transition Steps 2 & 3, a transition between Geo and Baro exists at the boundaries of the airspace volume. Cruise remains based on barometric levels meaning that there needs to either be a switch at high level Transition Layer or some form of ‘transition gates’ – for example at calculated points such as ToC and ToD or at specific waypoints that define the entry/exit points of the geometric airspace volume.

Based on outcomes from the ERR, this FRD is built under the assumption that, for the time being, the most suitable way forward is to keep Cruise phase in barometric STD reference as today. So, for the purpose of this FRD, Geometric Altimetry is only applicable to airspace blocks including Climb, Descent or Approach operations (e.g., TMA and surrounding airspace).

Research into technical resilience to loss of GNSS through GNSS Jamming and Spoofing continues outside of the project. Regardless, it is envisaged that the ultimate fallback will be to revert to barometric altimetry. Total loss of GNSS constellations (e.g., due to software failures or Kessler effect) would also necessitate a reversion to barometric. However, this would have much more far-reaching implications both within and outside of aviation.

3.1.1 Supporting reasons for this SESAR solution

Variation in localised pressure creates fuel, environmental and workload inefficiencies due to current reliance on barometric altimetry.

Outside of the Final Approach, commercial aircraft, military aircraft and general aviation rely on a barometric pressure model to determine altitude. This model requires that there be a Transition Layer between where local and standard pressure datums are used. The altitude of the Transition Layer varies from state to state and sometimes within a FIR. Setting and changing the pressure datum is reliant on manual action by the pilot and airline Standard Operating Procedures (SOPs) vary in terms of when the change is actioned.

There is a safety risk that incorrect entry of QNH will lead to an incorrect indication of onboard altitude, which could lead to insufficient terrain clearance or a level bust.

There is a capacity limitation due to pressure variations compared to STD pressure leading to loss of highest usable Altitude and lowest usable Flight Level.

There is a fuel inefficiency because flight profiles are constrained by procedural constraints that are necessary to account for the Transition Layer.

Outside of the Final Approach, vertical containment is only assured at waypoints that have altitude constraints associated with them. This enables aircraft to determine their own profile in-between the waypoints so long as they comply with the waypoint constraints. From an ATC perspective, this leads to large uncertainties about where the aircraft could be in the vertical plane in-between waypoints. Airspace design is limited by these uncertainties, for example, altitude constraints may need to be applied to ensure vertical separation for crossing tracks. In complex airspace, this can lead to long level segments of flight at low altitudes, which creates fuel inefficiency.

3.1.2 ATM capabilities addressed by the SESAR solution

This section identifies the ATM capabilities from the SESAR architecture baseline addressed by the SESAR Solution, and describes the associated updates.

SESAR solution capabilities	Comments on potential updates required at capability level
Terminal Procedure Design	Solution 0406 introduces the ability to design the whole of a TMA environment using geometric altitude and specify Departure, Arrival and Approach procedures (incl. final approach segment) using geometric altitude constraints. Solution 0406 also introduces the ability to design and specify Arrival and Approach procedures using vertical geometric paths with containment assumptions
RNP based Operations Execution	Solution 0406 introduces aircraft navigation systems constructing vertical paths based on geometric altitude and navigating to such paths.
Optimised Climb Execution	Solution 0406 introduces the ability to fly climb profiles based on geometric altitude with more efficient procedure design mitigating the effect of noise and atmospheric emissions.
Optimised Descent Execution	Solution 0406 introduces the ability to fly descent profiles based on geometric altitude with more efficient procedure design mitigating the effect of noise and atmospheric emissions.
Positioning/Navigation/Timing of Mobiles (airspace) independent of Ground Navaids	Solution 0406 introduces the ability to determine the altitude of aircraft from one or more satellite constellations (augmented as necessary and/or fused with other sources) with the required navigation performance for the actual phase of operation and weather conditions.

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SESAR solution capabilities	Comments on potential updates required at capability level
Positioning/Navigation/Timing of Mobiles in Reversionary Mode	Solution 0406 introduces the ability to determine the altitude of aircraft during interference/degradation/outage of primary navigation means, with the navigation performance required for the actual phase of operation and weather conditions.
Vertical Conversion	Solution 0406 introduces the ability to convert barometric to geometric altitudes and vice-versa. Conversion covers both aircraft present position for real time navigation, as well as procedural altitude definition for flight predictions.
Trajectory Conformance Monitoring	Solution 0406 introduces the ability to anticipate / detect deviations from trajectory agreement during execution, including for vertical geometric profiles in climb, descent and approach.
Controller Situational Awareness (airspace)	Solution 0406 introduces the ability to visualise the air traffic situation through the position and identification of aircraft, based on geometric altitude.
Separation Service Provision (airspace)	Solution 0406 introduces the ability to separate aircraft when airborne in line with the separation minima defined in the airspace design (incl. aircraft separation from incompatible airspace activity, weather hazard zones, terrain-based obstacles), based on geometric altitude.
Coordination and Transfer	Solution 0406 introduces the ability to coordinate and transfer flights between sectors, based on geometric altitude.

Table 4: SESAR Solution 0406 capabilities

3.1.3 Stakeholders impacted by the SESAR solution

This section identifies the operational stakeholders as defined in the SESAR architecture baseline impacted by the Solution and describes their expectations.

Stakeholder	Why it matters to the stakeholder
Airspace Users	Improved IFPs enabling environmental benefits. Reduction in manual pilot action reduces risk of human error.
ANSPs	Improved airspace design enabling environmental benefits and increase airspace capacity. Improved predictability reduces ATCO workload. Reduction in manual pilot action reduces safety risk.

Table 5: SESAR Solution 0406 stakeholders

3.2 SESAR solution functional view

3.2.1 Interaction(s) identification

Solution 0406 does not introduce any new Capability Configuration into the SESAR architecture baseline, it rather updates existing ones.

This section identifies the Capability Configurations from the SESAR architecture baseline addressed by the SESAR Solution, and describes the updates in the interactions between them.

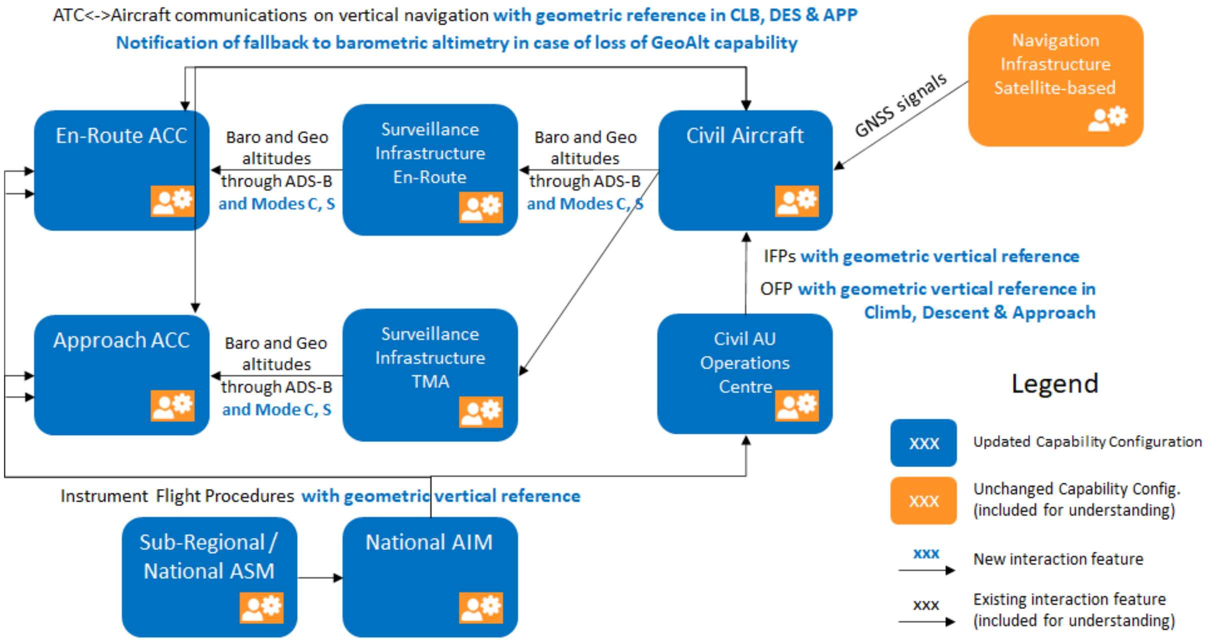

Figure 1: SESAR Solution 0406 interactions identification

Airspace Management outputs, through AIM, flight procedures based on geometric vertical reference to the ACCs (En-Route and TMA/Approach) as well as to Civil AU Operations Centre. This applies to ACCs controlling the geometric procedures/airspace as well as those interfacing with geometric procedures/airspace.

Capability of Air-Ground data and voice exchange of geometric as well as barometric altitude data relative to instrument flight procedures between the Aircraft and ACCs (En-Route and TMA/Approach).

Even if not yet fully defined at this level of maturity, technical means and operating procedures are available for both ATC and flight crew to detect the degradation or total loss of the geometric altimetry navigation capability, to communicate to each other such non-nominal condition, and to switch operation to fallback mode based on barometric altimetry.

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Ground surveillance of aircraft geometric altitude must be available not only when operating ADS-B (already capable) but also transponder Modes C or S (currently transmitting barometric altitude only), from Civil Aircraft to Surveillance Infrastructure (En-Route and TMA) to ACC (En-Route and TMA).

3.2.2 Functional decomposition

Solution 0406 does not change the functional decomposition of the existing Capability Configurations into Technical Systems and Roles with respect to the SESAR architecture baseline.

This section identifies the functional decomposition relevant to the Solution, only depicting the Technical Systems and Roles that have been identified as impacted by the Solution at this R&I stage (TRL2 target).

The description of the updates introduced by the Solution into these Technical Systems and Roles is provided in the following section.

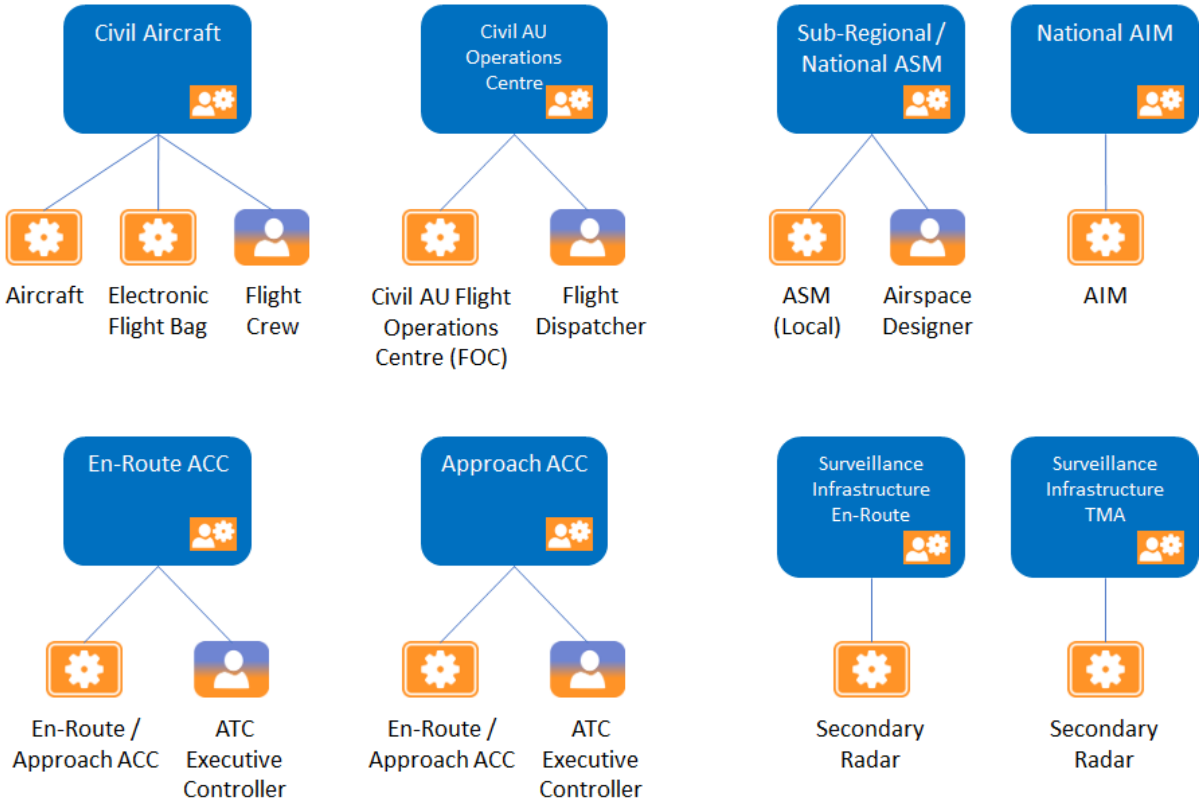

Figure 2: SESAR Solution 0406 functional decomposition

3.3 High level impact of the SESAR solution on the baseline SESAR architecture

This section describes the updates introduced by the SESAR Solution into the Technical Systems and Roles from the SESAR architecture baseline identified in the functional decomposition above.

A complete impact assessment is not yet available at this maturity level, but the outcomes of the preliminary assessment are summarised in the following table.

Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
Aircraft		Solution 0406 introduces significant aircraft systems modifications. The new capabilities are summarised hereafter. **Navigation Systems (other than FMS):** · Provision of geometric altitude for vertical navigation, selecting among the sources available onboard, one that meets the required performance in terms of accuracy, integrity, availability and continuity. · Monitoring of geometric altitude performance to detect degradation or total loss of the GeoAlt capability. **Flight Management System (FMS):** · Ability to support Departure, Arrival and Approach procedures published with geometric altitude constraints (regarding AIM data, flight plan management, vertical navigation, etc). · Ability to support Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle, and satisfy vertical containment assumptions on such segments. · Ability to compute FMS predictions (e.g., fuel, time, altitude, speed) on a flight plan with geometric vertical reference in Climb, Descent and Approach with similar accuracy to current predictions on a flight plan defined with barometric reference all along. · Automatic altitude reference (baro and geo) switching capability when reaching known transition gates such as

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Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
		ToC, ToD or transition altitude/FL (if any), as well as when a reversion from geo to baro reference is required due to unavailable or unreliable geometric altitude. **Cockpit HMI (other than FMS):** · Provision of both barometric and geometric altitudes to flight crew, with only the active altitude in the primary flight displays. · Provision of onboard monitoring and alerting means for flight crew to be informed of the status of the GeoAlt capability and to ensure conformance with the vertical containment requirements. · Provision of manual altitude reference (baro and geo) switching capability to deal with degradations of the geometric altitude capability not detected by airborne systems, as well as to enable anticipated fallback operation foreseen by ATC due to known perturbations. **Surveillance Systems:** · Provision of both barometric and geometric altitude through Transponder Mode C and Mode S, in addition to ADS-B. · Source of geometric altitude for surveillance functions as independent as possible from source used for navigation.
Electronic Flight Bag		Solution 0406 introduces the following modifications into the EFB: · Ability to support Departure, Arrival and Approach procedures published with geometric altitude constraints (regarding AIM data, flight plan management, etc). · Ability to support Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle.

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Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
	Flight Crew	In Solution 0406, the Flight Crew, supported by the Aircraft systems and the EFB, is able to: · Deal with Departure, Arrival and Approach procedures published with geometric altitude constraints (regarding AIM data, flight plan management, vertical navigation, ATC communications, etc). · Deal with Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle, and ensure compliance with vertical containment assumptions on such segments. · Monitor automatic transition or perform manual transition between geometric and barometric flight phases (and vice versa) in nominal conditions. · Manage non-nominal operation requiring fallback to barometric altimetry, including automatic or manual geo-baro reversion and related ATC communications.
Civil AU Flight Operations Centre (FOC)		Solution 0406 introduces the following capabilities into this Technical System: · Ability to support Departure, Arrival and Approach procedures published with geometric altitude constraints (regarding AIM data, flight plan management, etc). · Ability to support Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle. · Ability to compute fuel and time predictions on a flight plan with geometric vertical reference in Climb, Descent and Approach with similar accuracy to current predictions on a flight plan defined with barometric reference all along.

Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
	Flight Dispatcher	In Solution 0406, the Flight Dispatcher, supported by the FOC tools, is able to: · Deal with Departure, Arrival and Approach procedures published with geometric altitude constraints (regarding AIM information, flight plan management, etc). · Deal with Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle.
En-Route / Approach ATC		Solution 0406 introduces the following capabilities into this Technical System: · Update and distribution of flight plan data, potentially correlated with track data built from surveillance sources, based on geometric altitude of both the aircraft and the ATC sectors. · Distribution of warnings and alerts upon detection of non-conformance between aircraft behaviour and corresponding procedures defined using geometric altitude, or modelled impact of an aircraft navigating to the wrong datum. · Medium-term and tactical conflicts detection, conflicts resolution assistance and local traffic complexity assessment based on geometric altitude. · Ground-ground and air-ground exchanges of flight and environment data based on geometric altitude. · ATC terrain warning tools (e.g. MSAW, etc.) based on geometric altitude.
	ATC Executive Controller	In Solution 0406, the Executive Controller monitors the trajectory (4D and 3D) of aircraft based on their geometric altitude and according to the clearance they have received. When necessary, the controller is able to revert to fallback procedures based on barometric altitude/level.

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Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
Secondary Radar		Solution 0406 introduces the following capabilities into this Technical System: · SSR altitude (Mode C code) in both barometric and geometric. The SSR transmits signals on 1030 MHz and receives signals from the transponder on 1090 MHz. · Mode S SSR (Select) altitude in both barometric and geometric.
ASM (Local)		Solution 406 introduces the airspace design and management functions in geometric altitude, with the capability to define geometric vertical paths in descent and approach.
	Airspace Designer	Solution 406 introduces Airspace Design based on geometric altitude, with the capability to define geometric vertical paths in descent and approach.
AIM		Solution 406 introduces aeronautical data incorporating instrument flight procedures and navigation data based on geometric altitude. Procedure design based on geometric altitude, inclusive of flight path angles in descent and obstacle clearance.

Table 6: Technical Systems / Roles impacted by Solution 0406

4 Functional requirements

This section provides the functional requirements for Solution 0406 Vertical guidance using Geometric Altimetry, both for the airborne and ground segments.

The requirements identifiers are structured as follows:

"REQ-XXXX-FRD-OPxx.Yyyy", referring to:

- REQ is the object type (requirement);
- XXXX is the Solution ID, so always 0406 in this document;
- FRD because defined in the FRD
- OPxx is the applicable Concept method, with three possible reference codes:
  - OP01: applicable to Concept Method 1 only
  - OP02: applicable only to Concept Method 2 only
  - OP12: applicable to both Concept methods
- Yyyy reference number (four digits e.g., to indicate a sequence number), distinguished as follows:
  - 0yyy , starting from 0001, for airborne requirements
  - 1yyy , starting from 1001, for ground requirements

4.1 Airborne Systems requirements

4.1.1 Navigation Systems (other than FMS)

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.0001
Title	Geometric altitude source selection for Navigation – Performance
Requirement	Navigation architecture shall select, among the sources of geometric altitude available onboard, one that meets the required performance in terms of accuracy, integrity, availability and continuity in the target airspace.
Status	<in progress>
Rationale	Geometric altitude sources are already available onboard current aircraft, but they are not used for navigation outside final approach. The choice of the appropriate geometric altitude source to be used for navigation depends on availability and performance of each source as well as on airspace vertical performance requirements.
Category	<Functional>, <Safety>, <Performance>

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Identifier	REQ-0406-FRD-OP12.0002
Title	Geometric altitude source selection for Navigation – NAV/SURV independence
Requirement	Navigation architecture shall select, among the sources of geometric altitude available onboard, one that is independent of the source used in surveillance functions.
Status	<in progress>
Rationale	For surveillance functions to provide effective Safety Nets, it is necessary that errors in the altitude source used for navigation do not equally impact the altitude source used for surveillance.
Category	<Functional>, <Safety>

Identifier	REQ-0406-FRD-OP12.0003
Title	Geometric altitude status monitoring
Requirement	Navigation architecture shall be able to detect geometric altitude loss or degradation jeopardising the geometric vertical guidance capability.
Status	<in progress>
Rationale	Whether it is related to Jamming & Spoofing threats or other causes, the loss of geometric vertical guidance capability must be detected for safety reasons. This enables cockpit alerts and switching to fallback operation with barometric altitude, both described in dedicated requirements.
Category	<Functional>, <Safety>

Concept Method 2

Identifier	REQ-0406-FRD-OP02.0001
Title	Vertical Navigation System Error
Requirement	Geometric altitude estimation performance shall allow for a contribution of the Vertical Navigation System Error (VNSE) to the Vertical Total System Error (VTSE) compatible with the applicable vertical containment objective when flying Arrival or Initial/Intermediate Approach procedure segments with vertical path defined by a fixed geometric angle.
Status	<in progress>
Rationale	Vertical route separation used for airspace design is built upon aircraft vertical path containment assumptions, the VTSE. This total error can be split into three contributions: the Vertical Path Definition Error, the Vertical Navigation System Error and the Vertical Flight Technical Error. A dedicated requirement has been defined for each contribution, but a quantitative value cannot yet be specified at this maturity level.
Category	<Safety>, <Performance>

Note: Depending on each aircraft Navigation architecture, the system allocation of this VNSE requirement may be different (e.g. for some aircraft, the system responsible for the navigation positioning function is the FMS).

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Note: Green-GEAR R&D activities (TRL2 target) assumed an aircraft VTSE at 99.7% of 260ft for IFP segments with vertical path defined by a fixed geometric angle, with a vertical route separation target of 1520ft.

4.1.2 Flight Management System (FMS)

Concept Method 1

Identifier	REQ-0406-FRD-OP01.0001
Title	Management of Instrument Flight Procedures with geometric altitude constraints
Requirement	The FMS shall be able to manage Departure, Arrival and Approach procedures published with geometric altitude constraints at waypoints.
Status	<in progress>
Rationale	Outside final approach segment, current published IFPs only use barometric altitude reference. FMS needs to be able to also manage IFPs defined with geometric altitudes.
Category	<Functional>

Concept Method 2

Identifier	REQ-0406-FRD-OP02.0002
Title	Management of Instrument Flight Procedures with geometric vertical paths
Requirement	The FMS shall be able to manage Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle.
Status	<in progress>
Rationale	Outside final approach segment, current published IFPs only use barometric altitude constraints. FMS needs to be able to also manage IFPs defined with geometric reference and with fixed vertical angle outside final approach.
Category	<Functional>

Note: Current ARINC 424 standard for Navigation Database already supports a “vertical angle” field for STAR and Approach procedure segments, but its publication by ANSP and its use by FMS is only generalised for final approach segment. There are significant differences among FMS suppliers regarding the support of coded vertical angles in Arrival and Initial/Intermediate Approach segments, so a standardisation effort would be needed.

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.0004
Title	Automatic altitude reference switching capability – nominal operation
Requirement	FMS, supported by the overall Navigation architecture, should provide automatic altitude reference (baro and geo) switching capability when reaching known transition gates such as ToC, ToD or transition altitude/FL, if any.
Status	<in progress>
Rationale	To reduce flight crew workload and prevent human error (i.e. forgetting manual switching at the expected transition gate).
Category	<Functional>, <Safety>

Identifier	REQ-0406-FRD-OP12.0005
Title	Automatic altitude reference switching capability – non-nominal operation
Requirement	FMS, supported by the overall Navigation architecture, should provide automatic altitude reference (baro and geo) switching capability when a reversion from geo to baro reference is required due to unavailable or unreliable geometric altitude (e.g. due to jamming or spoofing threats or other causes).
Status	<in progress>
Rationale	To ensure continuity of safe flight.
Category	<Functional>, <Safety>

Identifier	REQ-0406-FRD-OP12.0006
Title	FMS predictions on GeoAlt flight plan
Requirement	Accuracy of FMS predictions (fuel, time, altitude and speed) on a flight plan with geometric vertical reference in Climb, Descent and Approach shall be similar to accuracy of current FMS predictions on a flight plan defined with barometric reference all along.
Status	<in progress>
Rationale	Necessary for appropriate fuel & time follow-up by the flight crew to ensure safety and business needs, as well as to anticipate compliance with published altitude and speed constraints. Depending on the use of EPP data by ATC, it might also be important for ATC operations.
Category	<Safety>, <Performance>

Concept Method 1

Identifier	REQ-0406-FRD-OP01.0002
Title	FMS vertical navigation on GeoAlt segments with altitude constraints
Requirement	When operating Departure, Arrival or Approach procedure segments defined with geometric altitude constraints, the FMS vertical navigation capabilities shall be equivalent to those existing when operating barometric procedures.

Status	<in progress>
Rationale	The introduction of geometric altitude reference should not modify the philosophy of FMS behaviour for climb (priority to speed schedule only adapting vertical speed/pitch to reach and maintain the current speed target or to level-off when reaching the current altitude target based on published constraints and pilot selection on FCU), as well as for descent & approach (priority to guidance on the vertical profile and optimised vertical profile computation following new CDA philosophy for improved speed management).
Category	<Functional>, <Design>

Concept Method 2

Identifier	REQ-0406-FRD-OP02.0003
Title	FMS vertical navigation on GeoAlt segments with fixed vertical paths
Requirement	When operating Arrival or Approach procedure segments defined with a geometric vertical path (e.g., coded with fixed geometric vertical angle), FMS behaviour shall prioritise conformance to the published vertical profile.
Status	<in progress>
Rationale	Necessary for the new airspace design principles introduced by Concept Method 2 related to vertical containment (V-RNP). Capability already existing for Final Approach segment, to be extended to Arrival and Initial/Intermediate Approach segments.
Category	<Functional>, <Safety>

Identifier	REQ-0406-FRD-OP02.0004
Title	Vertical Path Definition Error
Requirement	FMS navigation database and vertical path computation performance shall allow for a Vertical Path Definition Error (VPDE) contribution to the Vertical Total System Error (VTSE) compatible with the applicable vertical containment objective when flying Arrival or Initial/Intermediate Approach procedure segments with vertical path defined by a fixed geometric angle.
Status	<in progress>
Rationale	Vertical route separation used for airspace design is built upon aircraft vertical path containment assumptions, the VTSE. This total error can be split into three contributions: the Vertical Path Definition Error, the Vertical Navigation System Error and the Vertical Flight Technical Error. A dedicated requirement has been defined for each contribution, but a quantitative value cannot yet be specified at this maturity level.
Category	<Safety>, <Performance>

Note: Green-GEAR R&D activities (TRL2 target) assumed an aircraft VTSE at 99.7% of 260 ft for IFP segments with vertical path defined by a fixed geometric angle, with a vertical route separation target of 1520 ft.

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Identifier	REQ-0406-FRD-OP02.0005
Title	Vertical Flight Technical Error
Requirement	FMS vertical guidance performance shall allow for a Vertical Flight Technical Error (VFTE) contribution to the Vertical Total System Error (VTSE) compatible with the applicable vertical containment objective when flying Arrival or Initial/Intermediate Approach procedure segments with vertical path defined by a fixed geometric angle.
Status	<in progress>
Rationale	Vertical route separation used for airspace design is built upon aircraft vertical path containment assumptions, the VTSE. This total error can be split into three contributions: the Vertical Path Definition Error, the Vertical Navigation System Error and the Vertical Flight Technical Error. A dedicated requirement has been defined for each contribution, but a quantitative value cannot yet be specified at this maturity level.
Category	<Safety>, <Performance>

Note: Green-GEAR R&D activities (TRL2 target) assumed an aircraft VTSE at 99.7% of 260 ft for IFP segments with vertical path defined by a fixed geometric angle, with a vertical route separation target of 1520 ft.

4.1.3 Cockpit HMI

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.0007
Title	Provision of both geo and baro altitudes to flight crew
Requirement	Cockpit systems, supported by the overall Navigation architecture, shall provide both barometric and geometric altitudes to flight crew, in such a way that only the active altitude is provided in the primary flight displays while the other is available for consultation in other displays
Status	<in progress>
Rationale	Even if, at a given time, the aircraft navigation is based on geometric altimetry only, it is deemed necessary to provide the flight crew with a means to access the barometric altitude for the management of non-nominal conditions as a means of troubleshooting by checking the consistency of both altitude sources, as well as for the monitoring of aircraft barometric altitude in some operating conditions (e.g., checking baro altitude against REC MAX at the end of a full geometric climb, etc.). From a HP perspective, it would be misleading to present both altitudes to flight crew in their primary instruments (e.g. PFD), so the most appropriate solution is probably through a dedicated page in MCDU/MFD, in a similar way as today's GPS MONITOR page where the crew can find, among others, the GPS 3D position computed by the onboard receivers.
Category	<Functional>, <Safety>, <HMI>

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Identifier	REQ-0406-FRD-OP12.0008
Title	Alerting on GeoAlt capability loss
Requirement	Cockpit systems, supported by the overall Navigation and Guidance architecture, shall provide the flight crew with alerting in case of loss of the GeoAlt capability.
Status	<in progress>
Rationale	Flight crew needs to be informed of loss of the GeoAlt capability and subsequent reversion to barometric altitude.
Category	<Functional>, <Safety>, <HMI>

Identifier	REQ-0406-FRD-OP12.0009
Title	Manual altitude reference switching capability – non-nominal operation
Requirement	Cockpit systems, supported by the overall Navigation architecture, shall provide manual altitude reference (baro and geo) switching capability.
Status	<in progress>
Rationale	To deal with degradations of the geometric altitude capability not detected by airborne systems, as well as to enable anticipated fallback operation foreseen by ATC due to known perturbations. Indeed, in the latter situation, it is recommended to apply the reversion to baro reference before entering the perturbed zone.
Category	<Functional>, <Safety>, <HMI>

Concept Method 2

Identifier	REQ-0406-FRD-OP02.0006
Title	Cockpit HMI for V-RNP onboard monitoring and alerting – vertical deviation
Requirement	Cockpit systems, supported by the overall Navigation and Guidance architecture, shall provide the flight crew with an indication of the current vertical deviation with respect to the published vertical path.
Status	<in progress>
Rationale	To ensure compliance with vertical containment expectations – accuracy
Category	<Functional>, <Safety>, <HMI>

Identifier	REQ-0406-FRD-OP02.0007
Title	Cockpit HMI for V-RNP onboard monitoring and alerting – alerting
Requirement	Cockpit systems, supported by the overall Navigation and Guidance architecture, shall provide the flight crew with alerting in case of degradation of the aircraft navigation & guidance capabilities leading to risk of non-conformance with the vertical containment requirements.
Status	<in progress>
Rationale	To ensure compliance with vertical containment expectations – integrity
Category	<Functional>, <Safety>, <HMI>

4.1.4 Surveillance Systems

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.0010
Title	Altitude source selection for Surveillance – NAV/SURV independence
Requirement	Surveillance architecture shall select, among the sources of geometric altitude available onboard, one that is independent of the source used in navigation.
Status	<in progress>
Rationale	For surveillance functions to provide effective Safety Nets, it is necessary that errors in the altitude source used for navigation do not equally impact the altitude source used for surveillance.
Category	<Functional>, <Safety>

Identifier	REQ-0406-FRD-OP12.0011
Title	Altitude reporting – Modes C and S
Requirement	When reporting altitude through Transponder Mode C and Mode S, both barometric altitude and geometric altitude shall be provided.
Status	<in progress>
Rationale	Both barometric and geometric altitude are required in the ATC ground systems. Ground surveillance of aircraft geometric altitude must be available not only when operating ADS-B (already capable) but also transponder Modes C or S (currently transmitting barometric altitude only)
Category	<Functional>, <Safety>

4.1.5 Electronic Flight Bag (EFB)

Concept Method 1

Identifier	REQ-0406-FRD-OP01.0003
Title	Management of Instrument Flight Procedures with geometric altitude
Requirement	The EFB shall be able to manage Departure, Arrival and Approach procedures published with geometric altitude constraints at waypoints.
Status	<in progress>
Rationale	Altitude constraints in current published IFPs only use barometric altitude reference. EFB needs to be able to also manage IFPs defined with geometric altitudes.
Category	<Functional>

Concept Method 2

Identifier	REQ-0406-FRD-OP02.0008
Title	Management of Instrument Flight Procedures with geometric vertical paths
Requirement	The EFB shall be able to manage Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle.
Status	<in progress>
Rationale	Outside final approach segment, current published IFPs only use barometric altitude constraints. EFB needs to be able to also manage IFPs defined with geometric reference and with fixed vertical angle outside final approach.
Category	<Functional>

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.0012
Title	Management of Operational Flight Plan with geometric reference
Requirement	The EFB shall be able to manage OFP provided by AU FOC with geometric reference in Departure, Arrival and Approach.
Status	<in progress>
Rationale	Current OFPs only use barometric altitude reference. EFB needs to be able to also manage OFPs including geometric altitudes.
Category	<Functional>

4.1.6 Airspace Users Flight Operations Centre Tools

Concept Method 1

Identifier	REQ-0406-FRD-OP01.0004
Title	Management of Instrument Flight Procedures with geometric altitude
Requirement	AU FOC flight planning tools shall be able to manage Departure, Arrival and Approach procedures published with geometric altitude constraints at waypoints.
Status	<in progress>
Rationale	Altitude constraints in current published IFPs only use barometric altitude reference. Flight planning tools need to be able to also manage IFPs defined with geometric altitudes.
Category	<Functional>

Concept Method 2

Identifier	REQ-0406-FRD-OP02.0009
Title	Management of Instrument Flight Procedures with geometric vertical paths
Requirement	AU FOC flight planning tools shall be able to manage Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle.
Status	<in progress>
Rationale	Outside final approach segment, current published IFPs only use barometric altitude constraints. Flight planning tools need to be able to also manage IFPs defined with geometric reference and with fixed vertical angle outside final approach.
Category	<Functional>

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.0013
Title	Operational Flight Plan predictions on GeoAlt flight plan
Requirement	Accuracy of OFP fuel and time predictions on a flight plan with geometric vertical reference in Climb, Descent and Approach shall be similar to accuracy of current OFP predictions on a flight plan defined with barometric reference all along.
Status	<in progress>
Rationale	Necessary for appropriate fuel & time follow-up by the flight crew to ensure safety and business needs. Accuracy of other predictions such as altitude and speed profile along climb and descent are less important at OFP level than at FMS level, but it would be preferable to have them with similar accuracy as well.
Category	<Safety>, <Performance>

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4.2 Ground Systems requirements

4.2.1 Controller Working Position (CWP)

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.1001
Title	Geo and Baro altitude display
Requirement	The radar display at the CWP shall be able to display both barometric and geometric altitude on the TDB of each foreground track.
Status	<in progress>
Rationale	Under normal working modes, the controller needs to manage vertical separation using geometric altitude. However, under certain abnormal or failure modes, e.g. loss of GNSS, the controller needs to have quick access to barometric altitude information.
Category	<Functional>, <Safety>, <HMI>

Identifier	REQ-0406-FRD-OP12.1002
Title	Manual altitude reference switching capability
Requirement	The CWP shall provide manual altitude reference (baro and geo) switching capability.
Status	<in progress>
Rationale	To enable fallback scenarios, e.g. loss of GNSS or equipment failure, or for manual conformance checks. From a HP perspective, it would be misleading to present both altitudes to the controller at the same time unless the controller specifically wishes to, for example, for a manual conformance check.
Category	<Functional>, <Safety>, <HMI>

Identifier	REQ-0406-FRD-OP12.1003
Title	Conformance alerting
Requirement	The CWP shall provide an alert to the controller when a non-compliance is detected by the ground-based conformance monitor for a foreground track.
Status	<in progress>
Rationale	If the integrity of geometric altitude information is uncertain, the controller needs to be alerted so they can action accordingly.
Category	<Functional>, <Safety>, <HMI>

4.2.2 Conformance Monitoring

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.1004
Title	Geo altitude monitoring relative Baro altitude
Requirement	The ground-based conformance monitor shall be able to monitor the geometric altitude of each flight versus its corresponding barometric altitude, raising an alert to the CWP, where a non-compliance is detected.
Status	<in progress>
Rationale	Conformance monitoring to detect potential errors in the geometric altitude that could signify corruption (e.g. GNSS spoofing) or loss of the capability (e.g. onboard systems failure or GNSS jamming).
Category	<Functional>, <Safety>

Concept Method 1

Identifier	REQ-0406-FRD-OP01.1001
Title	Geo altitude monitoring relative to the procedural constraints
Requirement	The ground-based conformance monitor shall be able to monitor the geometric altitude of each flight versus relevant procedural altitude constraints, raising an alert to the CWP, where a non-compliance is detected.
Status	<in progress>
Rationale	Conformance monitoring to detect procedural compliance becomes more important in a heavily proceduralised systemisation using geometric altitude constraints at waypoints.
Category	<Functional>, <Safety>

Concept Method 2

Identifier	REQ-0406-FRD-OP02.1001
Title	Geo Path monitoring relative to the procedural profile
Requirement	The ground-based conformance monitor shall be able to monitor the geometric vertical path of each flight compared to the procedurally-defined vertical profile, raising an alert to the CWP, where a non-compliance is detected.
Status	<in progress>
Rationale	Conformance monitoring to detect procedural compliance becomes more important in a heavily proceduralised systemisation using geometric vertical paths.
Category	<Functional>, <Safety>

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4.2.3 Conflict Detection Tools

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.1005
Title	Conflict Detection
Requirement	Medium-term and tactical conflicts detection shall be able to model aircraft navigating to a geometric altitude datum
Status	<in progress>
Rationale	Medium-term and conflicts detection tools need to be able to operate based on geometric altitude for flights navigating to geometric altitude, whether on codified procedures using geometric altitude constraints or under tactical management by ATC.
Category	<Functional>

4.2.4 Safety Nets

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.1006
Title	Protection of Datum Error
Requirement	The ground-based safety net shall be able to model the impact of an aircraft navigating to the wrong datum
Status	<in progress>
Rationale	Extrapolates the profile the aircraft is on and conducts a What If the aircraft followed the right clearance but on the wrong datum. Prevents datum errors. Could run this test if the aircraft is seen to not be following the expected profile
Category	<Functional>, <Safety>

4.2.5 Flight Data Processing (FDP)

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.1007
Title	Flight coordination using geometric or barometric altitude through sector boundaries
Requirement	The flight data processing systems shall be able to coordinate flights through ATC sectors in either barometric or geometric altitude, as defined by the system operator.
Status	<in progress>

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Rationale	Under normal working modes, sector coordination is based on geometric altitude. However, under certain abnormal or failure modes, e.g. loss of GNSS, sector coordination may need to be based on barometric altitude.
Category	<Functional>

4.2.6 Surveillance Systems

Concept Method 1 & 2

Identifier	REQ-0406-FRD-OP12.1008
Title	Ground Surveillance – Modes C and S
Requirement	Mode C and Mode S receivers shall be configured to receive and interpret both barometric altitude and geometric altitude
Status	<in progress>
Rationale	Both barometric and geometric altitude are required in the ATC ground systems. Ground surveillance of aircraft geometric altitude must be available not only when operating ADS-B (already capable) but also transponder Modes C or S (currently transmitting barometric altitude only)
Category	<Functional>, <Safety>

4.2.7 Airspace Design and Aeronautical Information Management Tools

Concept Method 1

Identifier	REQ-0406-FRD-OP01.1002
Title	Airspace design based on geometric altitude constraints
Requirement	The ground-based airspace designer tools shall be able to use geometric procedural altitude constraints at waypoints.
Status	<in progress>
Rationale	Conventional airspace design is conducted using barometric constraints. Airspace design tools need to be able to also utilise geometric altitude.
Category	<Functional>

Identifier	REQ-0406-FRD-OP01.1003
Title	Aeronautical Information Management based on geometric altitude constraints
Requirement	The ground-based AIM tools shall be able to manage geometric procedural altitude constraints at waypoints.
Status	<in progress>
Rationale	Conventional airspace design is conducted using barometric constraints. AIM tools need to be able to also manage geometric altitude.
Category	<Functional>

Concept Method 2

Identifier	REQ-0406-FRD-OP02.1002
Title	Airspace design using geometric vertical paths
Requirement	The ground-based airspace designer tools shall be able to define and deconflict geometric vertical paths between waypoints in Arrival and Initial/Intermediate Approach procedure segments.
Status	<in progress>
Rationale	Conventional airspace design is conducted using barometric altitude constraints. Airspace design tools need to be able to also utilise geometric altitude and geometric vertical paths.
Category	<Functional>

Identifier	REQ-0406-FRD-OP02.1003
Title	Aeronautical Information Management using geometric vertical paths
Requirement	The ground-based AIM tools shall be able to manage geometric vertical paths between waypoints in Arrival and Initial/Intermediate Approach procedure segments.
Status	<in progress>
Rationale	Conventional airspace design is conducted using barometric altitude constraints. AIM tools need to be able to also manage geometric altitude and geometric vertical paths.
Category	<Functional>

5 Assumptions

5.1 Common assumptions for SESAR Solution 0406

5.1.1 Cruise phase

While the Solution definition is focused on Climb, Descent & Approach phases, the project has had the opportunity to conclude that the use of geometric altimetry is not operationally suitable for Cruise phase, due to significant challenges inherent to the dependency of aircraft performance on barometric conditions, particularly regarding flight envelope (e.g. maximum operating altitude) and cruise altitude optimisation.

Indeed, aircraft performance is intrinsically based on barometric conditions, including the aircraft operating ceiling which is defined in pressure altitude.

In today's operations, pilots can contribute to flight optimisation by requesting, when possible, a cruise flight level as close as possible to the optimum flight level computed by the FMS. The optimum altitude ("OPT ALT") is generally a few thousand feet below the maximum recommended altitude ("REC MAX"), which is considered as the upper limit for safe operation.

The REC MAX is computed by the FMS, not only based on the aircraft maximum certified altitude, but also on performance considerations that depend on flight and weather conditions. It is defined as the lowest of:

- Maximum altitude at maximum cruise thrust in level flight
- Maximum altitude at maximum climb thrust with 300 ft/min vertical speed
- Maximum certified altitude
- 1.3 g buffet limited altitude.

It must be highlighted that the REC MAX can be several thousand feet below the aircraft maximum certified altitude for a flight operating close to its Maximum Take-off Weight (MTOW) or in hot weather conditions (DISA>>0).

In this context, a new paradigm defining in FMS a geometric cruise altitude and guiding accordingly may lead to locally exiting the aircraft flight envelope. Indeed, if the atmosphere's isobar is descending along the flight with regard to the geo altitude, this would be perceived by the aircraft as climbing in barometric conditions, potentially above the REC MAX.

In such event, the pilot would need to request to descent to a geo cruise altitude compliant with the maximum pressure altitude. Note that this occurrence would not be predictable as avionics systems cannot currently anticipate the isobar variations.

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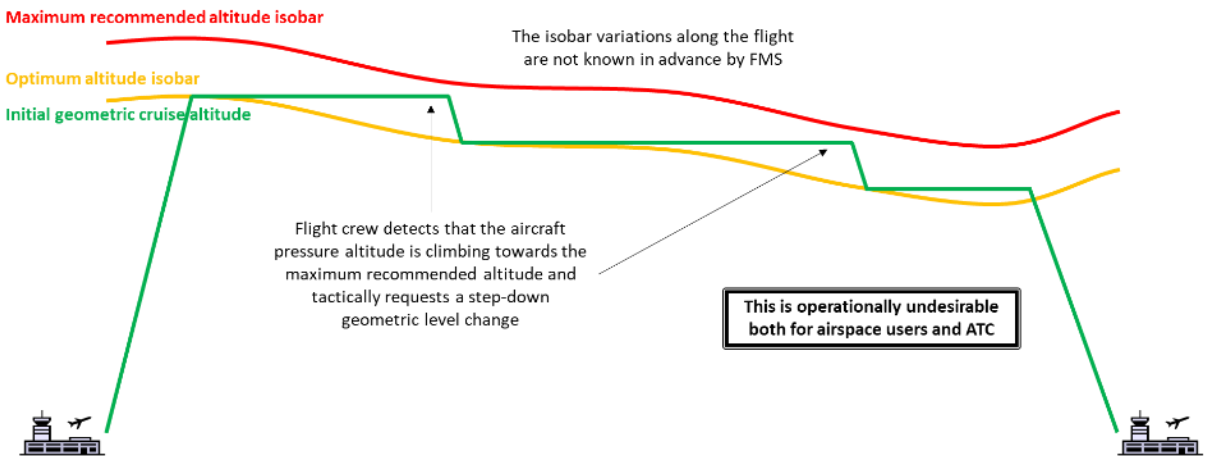

Figure 3: Geometric navigation in cruise – flight envelope and cruise altitude optimisation challenge (a)

The operational impact could be reduced by upgrading FMS and FOC flight planning tools to use meteorological data with pressure forecast grids at different geometric cruise levels (as currently done with wind and temperature at different barometric FLs) enabling anticipation and automation of the appropriate geometric level changes along the flight. However, the remaining operational complexity would still be undesirable.

An alternative mitigation would be to plan the flight geometric cruise at lower altitudes to create a buffer with respect to the maximum operating pressure altitude in order to minimise the need for safety-related step-down level changes, and briefing flight crews and briefing flight crews to limit optimisation-related level changes. However, this would bring a negative impact on environment, operational efficiency and potentially also capacity due to reduced use of the upper flight levels.

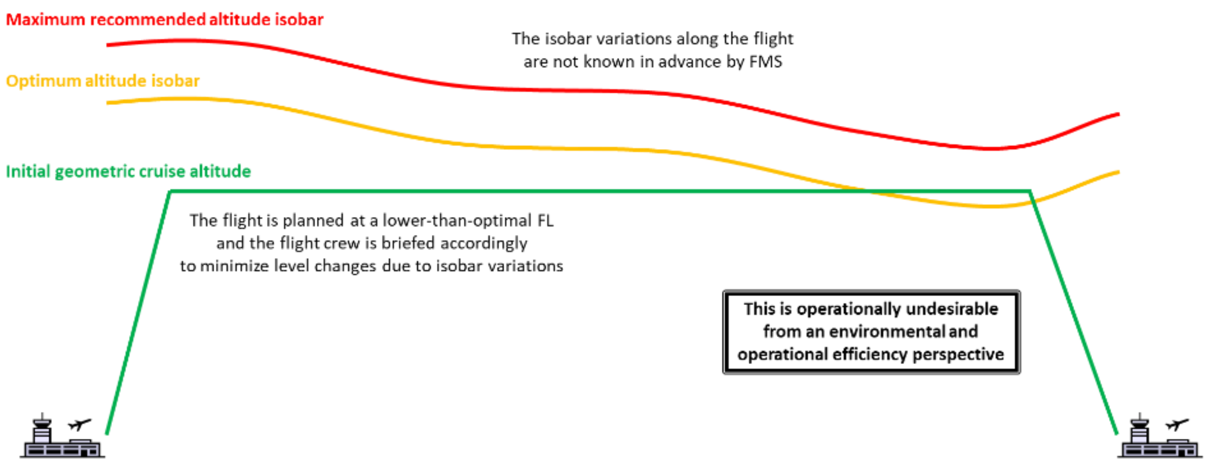

Figure 4: Geometric navigation in cruise – flight envelope and cruise altitude optimisation challenge (b)

Due to these operational challenges and the quantitative results (fuel penalty) identified during validation activities, it has been concluded that the implementation of geometric Cruise is detrimental when considered in isolation.

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Geometric Cruise could be worth considering in the future as part of a holistic geometric navigation solution, removing altitude datum transitions and potentially enabling other ATM Solutions relying on geometric altimetry in Cruise (e.g. Solution 0407 / RVSM 2), if the associated benefits were demonstrated to outweigh the drawbacks identified so far.

This FRD is built under the Solution-level assumption that, for the time being, the most suitable way forward is to keep Cruise phase in barometric STD reference as today.

5.1.2 Climb phase

From an airspace design perspective, the use of Geo Path (Concept Method 2) for Climb has been demonstrated to be practical and potentially beneficial. However, achieving a beneficial design is difficult and the level of change to the aircraft systems is significant.

Climb performance varies significantly due to aircraft type, weight, wind and temperature so any airspace design may require different SIDs for different aircraft categories to be effective or be limited to the lowest common denominator. From an airspace design perspective, Geo Path in climb offers the most predictable design in 3D. However, from an aircraft flight efficiency perspective, the more the vertical profile is constrained, the more challenging it would be for the individual flight to comply with the profile. Significant navigation system changes would be required; they would need to predict the whole climb profile instead of just the next waypoint and would need to prioritise vertical path compliance over speed schedule.

Therefore, Geo Path in Climb should only be considered for highly congested airspace, and as part of a composite solution together with Geo Path in Descent and Approach.

This FRD is built under the Solution-level assumption that the most suitable way forward for Climb phase is to use geometric altitude constraints at waypoints (Concept Method 1).

5.1.3 Loss of GNSS

One of the main non-nominal conditions that the GeoAlt solution has to deal with is the loss of GNSS, which can have different causes such as aircraft-level failures, GNSS service-level failures or external threats such as jamming and spoofing, Kessler effect (cascading destruction of satellites due to space debris), etc.

Among those, the one that currently constitutes the main risk (considering probability and severity) for the deployment of the GeoAlt Solution is GNSS jamming and spoofing.

In order to mitigate the increasingly present jamming and spoofing threats and become more resilient, the industry is planning to implement in industry airborne standards from RTCA and EUROCAE, several anti-jamming and anti-spoofing features that will provide more robust navigation capability under interference such as detection capability, return to normal after exiting the interference areas, authentication of GNSS signal (e.g. Galileo OS NMA and SBAS authentication are planned in 2030+).

Beside ongoing airborne standards evolutions, Solution validation outcomes suggest that the following mitigations to deal with the unavailability of GNSS-based altitude sources due to jamming and spoofing threats should be considered:

- A reversion to barometric altitude will be required on-board the aircraft (automatic or manual) upon detection but more likely preferable before entering the interference area.
- A reversion to barometric based airspace and management of all aircraft affected in the area by air traffic controllers such as clearance and RVSM constraints must be performed.
- A robust jamming and spoofing detection tool (on the ground and/or on-board) must be operational in order to ensure aircraft can timely and concurrently revert to barometric altitude approximately at the same locations.
- The management of the transition between an airspace managed in barometric altitude and a geometric altitude: This is already needed under normal conditions but this situation might occur very often in some regions near conflict zones, which could lead to decide to not switch to geometric altitude at all in some airspaces.
- Standardised and agreed upon phraseology and SQUAWK notices.

That said, management of GNSS loss is a transversal challenge affecting whatever ATM Solution relying on GNSS for lateral and/or vertical positioning, so for the purpose of this FRD, it is considered as a prerequisite for the GeoAlt Solution rather than part of its scope.

Solution features related to monitoring of the GeoAlt capability and fallback to barometric navigation described in this FRD are kept generic, not specifically focused on jamming & spoofing or any other particular cause of GNSS loss.

5.2 Specific assumptions for airborne predictions

The FMS is responsible for providing predictions to the flight crew from preflight to landing, among which fuel & time are the most operationally critical since these predictions are used by the crew to conduct the flight follow-up to ensure that the safety and mission needs are satisfied. Most of the FMS predicted parameters (e.g. time, altitude, speed) can be downlinked to ATC through ADS-C EPP and might also be used for ATC operations.

Note: Air-Ground exchange of ADS-C EPP data, as well as ground display and alerting of trajectory information, are mandated in Europe by CP1 from end 2027. However, such mandate is only applicable for forward fit. Few aircraft exchange ADS-C EPP data with ATC today.

The FMS predictions computation would be impacted by the switch to geometric reference as the performance of the aircraft is always tied to barometric conditions, and the FMS does not currently have the capability to anticipate the pressure altitudes associated to the expected geometric altitudes.

A simple solution could use conservative assumptions to meet safety objectives regarding fuel, such as considering a worst-case geo-baro offset based on statistical data. A worst-case offset from fuel consumption perspective would bring a lower bound of the baro altitude at a given geo altitude, which would also impact other performance computations such as speed, time, vertical profile, etc.

However, such conservative approach would degrade the accuracy of FMS predictions, leading to a negative impact on predictability, which may also degrade fuel efficiency if the airline FOC requires loading of additional fuel. Flight crew tasks and ATC operations relying on FMS predictions may potentially be also impacted.

It seems necessary to also update FOC flight planning tools, as inconsistencies between the OFP predictions and the FMS predictions are unlikely to be operationally acceptable considering that flight crew is expected to perform fuel monitoring based on FMS predictions compared to the OFP.

The impact of the simple, conservative solution mentioned above would be too high if geometric reference is used all along the flight, especially due to the cumulated error on fuel and time predictions, but it could be interesting for future R&D work to assess if the impact might remain within acceptable limits when the use of geometric reference is limited to Climb, Descent and Approach.

A more advanced solution to tackle this challenge could rely on upgrading FMS and FOC flight planning tools to use meteorological data with pressure forecast grids at different geometric altitudes, as currently done with wind and temperature at different barometric altitudes/FLs.

For the use of geometric altimetry limited to Climb, Descent and Approach, an alternative solution could be based on making the FMS and the FOC flight planning tools able to compute the pressure altitude at an expected geometric altitude by themselves, using the necessary static geographical information for conversion between geo and baro altitudes in ISA conditions, together with the dynamic local atmospheric conditions (e.g. QNH and temperature at departure and destination airports).

In addition to impacts on FMS and FOC flight planning tools, depending on the chosen way forward for airborne predictions, Solution 0406 may require further updates in the SESAR functional architecture:

a) Potential impact on MET services in case of need for providing MET aloft gridded forecast data referenced to geometric altitudes, and possibly including pressure altitude in addition to wind, temperature, etc.

b) Potential impact on AIM services in case of need for publishing static data supporting the conversion between geo and baro altitudes in ISA conditions, possibly with a similar approach as for current data supporting conversion between magnetic and true headings.

6 References

6.1 Applicable documents

This FRD complies with the requirements set out in the following documents:

SESAR solution pack

[1] SESAR DES Solution Definitions Green-GEAR V1.0, 3rd June 2024.

[2] SESAR Operation Concept Document OCD 2023, 02.00.00, 14th July 2023.

[3] SESAR DES & DSD Solutions slides 2023 (1_0).pptx

Content integration

[4] Content Integration – Executive Overview, Edition 00.01, 16th February 2023.

[5] DES Common Assumptions, Edition 00.02.01, 29th June 2023.

[6] DES Performance Framework, Edition 00.01.04, 29th June 2023.

[7] DES Performance Framework – U-space Companion Document, Edition 00.01.02, 3rd April 2023.

Content development

[8] SESAR 3 Joint Undertaking – Communication Guidelines 2022-2027, Edition 0.03, 23rd November 2022.

System and service development

Performance management

[9] Performance Assessment and Gap Analysis Report (PAGAR) 2019 – updated version, Edition 00.01.00, 20th May 2021.

[10] SESAR PJ19.04: Performance Framework (2019), 30/11/2019, Edition 01.00.01.

[11] Performance Assessment and Gap Analysis Report (2019), Edition 00.01.02, 13th December 2019.

Validation

[12] DES HE requirements and validation /demonstration guidelines, Edition 3.00, 15th September 2023.

[13] DES SESAR Maturity Criteria and sub-Criteria_01_01 (1_1).xls

Safety

[14] DES expanded safety reference material (E-SRM), Edition 1.2, 17th November 2023.

[15] Guideline to Applying the Extended Safety Reference Material (E-SRM), Edition 1.1, 17th November 2023.

Human performance

[16] SESAR DES Human Performance Assessment Process TRL0-TRL8, Edition 00.03.01, November 2022.

Environment assessment

[17] SESAR Environment Assessment Process, Edition 05.00.00, 23rd July 2024.

Security

Project and programme management

[18] Green-GEAR Grant Agreement No. 101114789, version 1, signed 11th May 2023.

[19] SESAR 3 JU Project Handbook – Programme Execution Framework, Ed. 01.00, 11th April 2022.

[20] Common Taxonomy Description (1_0).pdf, Edition 1.0, 7th February 2023.

[21] Horizon Europe ethics guidelines – essentials_1 (1_0).pptx

6.2 Reference documents

[22] Zapata, D., Vechtel, D., Bauer, T., Koloschin, A., Nelson, D.: “SESAR 3 ER 1 Green GEAR – Final OSED – Geometric Altimetry”, Deliverable D3.5, ed. 02.00, submitted 30th April 2025.

[23] Zapata Arenas, D., Rouquette, P., Nelson, T., Bauer, T.: “SESAR 3 ER 1 Green GEAR – ERR – Geometric Altimetry”, Deliverable D3.3, ed. 01.00, 28th February 2025.

[24] EUROCAE ED-75 / RTCA DO-236, Minimum Aviation System Performance Standards (MASPS), Required Navigation Performance for Area Navigation.

[25] ICAO Doc 8168, Procedures for Air Navigation Services.

[26] ICAO Doc 9613, PBN Manual, Edition 4.

[27] https://www.icao.int/safety/OPS/OPS-Section/Pages/flightprocedure.aspx.

[28] https://ifatca.wiki/kb/instrument-flight-procedures/.

[29] ED-259 - Minimum Operational Performance Standards for Galileo - Global Positioning System - Satellite-Based Augmentation System Airborne Equipment.

[30] ICAO Doc 9905, Required Navigation Performance Authorisation Required (RNP AR) Procedure Design Manual.

[31] CAP1385, PBN Enhanced Route Spacing Guidance, Edition 2, December 2022.

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