SESAR JOINT UNDERTAKING

SESAR 3 ER 1 Green-GEAR – D3.6 – ECO-EVAL – Geometric Altimetry

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Abstract

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

This document provides the economic evaluation (ECO-EVAL) of the Green-GEAR solution 0406 "Vertical Guidance using Geometric Altimetry" at TRL 2, assessing its potential benefits and costs for various stakeholders. The ECO-EVAL covers the period from 2026 to 2050 and evaluates the deployment of geometric altimetry compared to a future reference scenario.

EUROPEAN PARTNERSHIP

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Green-GEAR

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

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1 Executive summary

This document provides the economic evaluation (ECO-EVAL) related to the deployment of SESAR solution 0406 that has been matured through validation activities to TRL2.

In accordance with the ERR, the ECO-EVAL considers two options for deployment: option 1, where only the altitudes of the TMA routes (SIDs and STARs) are defined geometrically instead of barometrically, and option 2, where also geometrically fixed vertical paths are defined.

The quantitative benefits used for the ECO-EVAL have been taken from the ERR and follow the two considered options as well. As especially relevant for the economic evaluation, the validation of the solution has outlined benefits in fuel consumption during climb and descent operations in the TMA. This directly transfers in benefits in fuel costs. The assessment of additional costs, however, could only be performed in a qualitative manner as no detailed quantitative numbers have been available for all involved stakeholders. This ECO-EVAL identifies major cost drivers for all involved stakeholders, which are mainly ANSPs, airspace users and aircraft manufacturers.

The deployment of the geoAlt solution not only concerns the TMA design but is also connected to the development of aircraft capabilities. For this reason, the deployment time horizon is relatively long with a start of deployment date of 2040. Although the TMA design based on geometric altitudes would possibly be available earlier, the required development and certification effort on aircraft manufacturers side would probably take that time.

For future assessment of the solution towards higher TRLs, it is recommended to enhance the economic evaluation with a quantitative assessment of the costs of the related stakeholders. This would in the end be required to finally investigate whether the solution is not only technically feasible but also economically viable.

2 Introduction

2.1 Purpose of the document

This document defines the economic evaluation (ECO-EVAL) for SESAR Solution 0406 at TRL2.

2.2 Scope

This document provides the economic evaluation (ECO-EVAL) related to the Green-GEAR SESAR Solution 0406 at TRL2.

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

- Method 1: Waypoint/fix altitude constraints are defined relative to geometric altitude instead of barometric.
- 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.

Benefits were generally assessed for both methods. However, quantitative results have been assessed mainly for method 2 as outlined in the Exploratory Research Report (ERR) [24]. A composite solution of the two methods is considered to be the optimal final end state of the concept. Therefore, the assumptions are considered relative to both methods.

Application of geometric operations are considered relevant to all flight phases within the TMA (Climb, Descent and Approach), with the key difference being that aircraft are now required to use geometric altimetry as the primary reference for altitude reporting and vertical navigation, with GNSS as the primary navigation source. For completeness, geometric cruise operations are also considered.

The key benefits are environment, and safety, deriving primarily from removal of variation due to atmospheric conditions and the Transition Layer under normal operations and improved vertical containment.

There are a number of assumptions based around future aircraft navigation system capabilities and both air and ground conformance monitoring tools. There is also an assumption that the operation can revert to barometric altitude as a fall-back mode.

Transition state(s) are considered, Transitionary steps toward geometric altimetry are seen as follows:

1. Step 1 – Geo Final Approach & Initial Approach
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, 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.

The reference time period for the analysis is 2026-2050. The Common Assumptions [5] document gives 2026 as start year of the ECO-EVAL and 2050 as end year of the ECO-EVAL.

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 projects
- Members from PEARL
- SJU Program representatives, as the owner and final approver of this document.

2.4 Background

This section presents the background on which the Green-GEAR project 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 Arrival Route), 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)

The 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 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 ECO-EVAL Document is structured as follows:

- Section 1 gives an executive summary of the ECO-EVAL 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 ECO-EVAL.
- Section 3 describes the objectives and scope of the ECO-EVAL.
- Section 4 summarises the benefits as outlined in the ERR.
- Section 5 describes the results of the cost assessment.
- Section 6 gives recommendations for next steps in the context of the ECO-EVAL.

2.6 Glossary of terms

Term	Definition	Source of the definition
ECO-EVAL reference scenario	The scenario against which the solution is compared, i.e. the situation without the proposed SESAR solution (but including other improvements which have been implemented in the meantime).	DES transversal CBA team
ECO-EVAL solution scenario	The scenario with the proposed SESAR solution and other improvements which have been implemented in the meantime.	DES transversal CBA team
Economic evaluation (ECO-EVAL)	The economic evaluation assesses the potential benefits that an innovative idea or application under analysis by an exploratory research project could provide against an initial high-level estimation of the costs that it may imply.	SESAR 3 JU Project Handbook – Programme Execution Framework, edition 01.00, 11 April 2022
Implementation cost	All costs related to the acquisition and implementation of the SESAR solution.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02
Investment cost	The investment cost covers the pre-implementation costs (e.g. feasibility studies) and the implementation costs (e.g. system integration). Note that the pre-implementation costs shall not consider the SESAR R&I costs.	DES transversal CBA team
Operating cost	All costs related to the change in daily operations that is brought about by the SESAR solution.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02
Pre-implementation cost	All costs that need to be used up to define the needs, to develop solutions, and to decide which solution best serves the needs. Note that the SESAR R&I costs shall not be included as costs in any DES CBA/ECO-EVAL.	SESAR 16.06.06_D26_03 Methods to Assess Cost and Benefits for CBAs, ed. 00.02.02

Table 1: glossary of terms

2.7 List of acronyms

Term	Definition
ACP	Airspace Change Proposal
AIM	Aeronautical Information Management
AIS	Aeronautical Information Services
ATC	Air Traffic Control
ATCO	Air Traffic Controller / ATC Officer
ATM	Air Traffic Management
BA	Business Aviation
BIM	Benefit and Impact Mechanism
CDA	Continuous Descent Approach
CONOPS	Concept of Operations
CWP	Controller Working Position
DES	Digital European Sky
DTG	Distance-to-Go
ECAC	European Civil Aviation Conference
ECO-EVAL	Economic Evaluation
ERR	Exploratory Research Report
FIM	Flight Deck Interval Management
FIR	Flight Information Region
FL	Flight Level
FOC	Flight Operations Control
GA	General Aviation
GBAS	Ground-Based Augmentation System
GeoAlt	Vertical Guidance using Geometric Altimetry

Term	Definition
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
Green-GEAR	Green operations with Geometric altitude, Advanced separation & Route charging Solutions
HC	High Complexity
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organisation
IFP	Instrument Flight Procedure
ILS	Instrument Landing System
IOC	Initial Operating Capability
KPA	Key Performance Area
KPI	Key Performance Indication
LC	Low Complexity
MC	Medium Complexity
MET	Meteorological services for air navigation
MOPS	Minimum Operational performance Standards
NMOC	Network Manager Operations Centre
OSED	Operational Service and Environment Description
PBN	Performance Based Navigation
QNH	[barometric reference pressure setting to achieve MSL altitude indication in vicinity of airfield]
RAIM	Receiver Autonomous Integrity Monitoring
R&D	Research & Development
R&I	Research & Innovation
RNP	Required Navigation Performance

Term	Definition
SA	Scheduled Airline
SBAS	Satellite-Based Augmentation System
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
S3JU	SESAR 3 Joint Undertaking
SJU	SESAR Joint Undertaking
SLS	SBAS Landing System
SOD	Start of Deployment Date
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Route
STATFOR	[EUROCONTROL] Statistics and Forecasts Service
STD	Standard atmospheric pressure (1013 hPa)
STELLAR	SESAR Tool Enabling collaborative ATM Research
TA	Transition Altitude
TL	Transition Layer
TMA	Terminal Manoeuvring Area
TRL	Technology Readiness Level
UK	United Kingdom [of Great Britain and Northern Ireland]
UKRI	UK Research and Innovation
VHC	Very High Complexity
VNAV	Vertical Navigation

Table 2: list of acronyms

3 Objectives and scope of the ECO-EVAL

3.1 Problem addressed by the SESAR solution

Under current operations, aircraft navigate their vertical path based on barometric pressure. For the altimeter reading, a fixed relation between measured static pressure and indicated altitude is used (ICAO Standard Atmosphere barometric formula), with the assumed pressure at sea level being the only configurable parameter irrespective of the actual state of the atmosphere. The FMS, however, also uses additional configurable parameters (such as e.g. temperature) for the performance calculations. In cruise, a standard value for the barometric reference is used (STD setting of 1013.25 hPa), and the resulting vertical position indication is denoted as flight level (FL). As a consequence of the STD setting, the absolute accuracy of the indicated altitude can be several thousands of feet off but the relative accuracy is sufficient for vertical separation of traffic. Closer to the ground, obviously a large deviation of displayed altitude cannot be tolerated: here the reference value is determined such that the MSL altitude at the runway threshold is displayed correctly (QNH setting, for commercial traffic) or the runway altitude is displayed as zero (QFE setting, typically for sports aviation). It is important to note that the altitude obtained from the theoretical barometric formula and the actual altitude generally will only coincide at the reference altitude i.e. the runway threshold, which results in flight inefficiencies in a number of ways. These include, when connecting to approach procedures with geometric altitude reference (ILS/SBAS/GBAS), when flying through the so-called transition layer where the manual pressure setting is changed (local pressure - QNH/QFE to standard pressure - STD in climb and vice versa in descent), when flying along isobars in cruise due to altitude adjustment and when designing route structures due to the large blocks of uncertainty in the vertical plane.

Air traffic control (ATC) is currently unable to define Instrument Flight Procedures in three dimensions outside the final approach because there is no vertical equivalent to (lateral) Performance Based Navigation (PBN), leading to sub-optimal airspace designs and continued need for tactical intervention by the air traffic controllers. One major aspect of this is that the efficiency of climb and descent operations is degraded by the Transition Layer. Day-to-day variation in local pressure means that the Transition Level (TL) moves, necessitating a buffer of vertical airspace that limits the lowest usable flight levels and builds in vertical profile inefficiency for any standard instrument departure (SID) procedures or standard arrival (STAR) procedures transiting it. This inefficiency results in additional fuel burn and related emissions. In some cases, for example within a TMA environment, it is not practical to design SIDs or STARs through the TL because the TA/TL adds uncertainty that would unacceptably compromise either safety or capacity. Selection of the pressure datum within the cockpit is a manual process and airline standard operating procedures (SOPs) vary; some airlines will change pressure setting when crossing the TA/TL and others will change it upon receipt of a clearance through the TA/TL. This variation in SOPs, combined with the risk of human error in the form of incorrect QNH value transmission or input, can lead to safety incidents such as level busts, where the aircraft exceeds their clearance limit and ends up at a Flight Level / altitude beyond where it should be, potentially putting it in conflict with other traffic. Use of geometric vertical navigation is expected to mitigate these issues by removing the reliance on barometric pressure. With GeoAlt, no reference to pressure is required for navigation, so the vertical path is unaffected by variations in pressure or the pressure mode selection. The Transition Layer no longer has an effect on the flight profile and the risk of human error due to manual pressure mode changes is eliminated. The flight paths can be defined in 3D at all points, not just where fixes and ATC constraints are applied.

Global Navigation Satellite Systems (GNSS) equipage is commonplace and increasing, with more aircraft being equipped with Satellite Based Augmentation Systems (SBAS) sensor, and particularly with new airspace users such as drones; its use for navigation is currently limited to the lateral plane with the exception of vertical in the final approach segment at multiple locations in Europe and the US. The GeoAlt application in the TMA will thus promote the use of GNSS for the GBAS Landing Systems (GLS) and SBAS Landing System (SLS) employing the Ground-Based Augmentation System (GBAS) or respectively the Satellite Based Augmentation System (SBAS), which offer significant advantages in cost and airspace design against the conventional Instrument Landing System (ILS).

Conversely, the number of GNSS jamming occurrences is increasing around the world in particular near military theatre of operations while the GNSS spoofing threat is being considered by airworthiness authorities for future GNSS airborne receiver standards.

The capability of geometric altimetry is already on the aircraft, for example used as terrain avoidance function.

3.2 SESAR solution description

The project explored several conceptual options relating to SESAR Solution 0406. First is the target end state, where a fully geometric environment encompasses all aircraft in all flight phases reporting geometric altitude and using geometric altimetry for vertical navigation. Two options for this end state were considered with climbing and descending traffic:

- Option 1: Flight procedures continue to constrain vertical flight profiles through the use of altitude constraints, but the constraints become geometric altitudes instead of barometric.
- Option 2: Paradigm change in flight procedures, now being vertically defined by published geometric paths with vertical containment assumptions, 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.

Options 1 and 2 were assessed qualitatively from various perspectives:

- Aircraft systems and operations,
- ATC operations
- Safety
- Human factors.

Option 2 was also assessed quantitatively in terms of:

- TMA network fuel burn, emissions and capacity
- Individual flight in descent fuel burn and emissions
- Individual flight in climb fuel burn and emissions

Secondly, transition states, where there is a mixed capability, with some aircraft operating geometric altimetry and others remaining barometric, were considered in the qualitative assessments.

In addition to the two end state options considered for climbing and descending traffic, the project also assessed cruise operations using a fixed geometric altitude. The cruise phase was assessed qualitatively in terms of aircraft systems and operations, and quantitatively in terms of individual flight fuel burn and emissions.

3.2.1 SESAR solution interdependencies

There are some interdependencies between the developed GeoAlt solution 0406 and other SESAR solutions. Mainly, these interdependencies concern the DYN-MARS project and the "Separation Minima" solution 0407 from Green-GEAR.

The key interdependencies between the Green-GEAR GeoAlt solution and DYN-MARS projects are the following ones:

Shared Objectives: Both projects aim to minimise the environmental impact of flights, with Green-GEAR concentrating on geometric altimetry and route charging solutions, while DYN-MARS focuses on the dynamic management of aircraft configurations and route structures.

Complementary Approaches: Green-GEAR investigates the capabilities of geometric altimetry enabled by satellite navigation to enhance safety, support greener climb and descent operations, and optimise capacity. In contrast, DYN-MARS develops innovative avionics functions to improve the aircraft's energy management during descent and approach phases.

SESAR Program: Both projects are part of the same program and contribute to the "Aviation Green Deal" flagship initiative, which aims to promote sustainability and efficiency within European aviation.

Potential Collaboration: While there are no explicit mentions of joint activities between Green-GEAR and DYN-MARS, similar projects like GALAAD and DYN-MARS have successfully implemented structured coordination approaches, maintained regular alignment and leveraged each other's expertise. This model could serve as a potential framework for collaboration between Green-GEAR and DYN-MARS.

Another interdependency exists within the Green-GEAR project, namely towards the Separation Minima solution (SESAR Solution 0407).

Shared Objectives: Both solutions aim to minimise the environmental impact of flights by enabling more efficient flight trajectories through the use of geometric altimetry, which thus is an enabler for both. The Separation Minima solution allows aircraft to fly closer to their optimal altitude through provision of additional usable flight levels. Those stem from the reduction of the vertical separation minima which in turn require a highly accurate measurement of the altitude, which does not appear feasible to the necessary degree with barometric altimetry. Geometric altimetry is considered a possible means to provide the required measurement accuracy.

Complementary Approaches: The use of geometric altimetry in cruise, which would be a prerequisite for the reduction of vertical separation in this stage of flight, is not part of the geoAlt solution itself because of the evaluated drawbacks in aircraft operations and performance when using geoAlt in cruise without further changes. In a holistic view, however, a reduction of vertical separation minima enabled through geoAlt might prove the use case bringing the necessary benefits. Besides finer granularity of available flight levels, higher capacity would mitigate the negative effects of detours / flight level changes to avoid climate hotspots, convective weather or congestions.

Joint requirements: Both solutions use GNSS as altimetry source and have the requirement that sufficient integrity and availability of the signals is achieved. The accuracy requirements are more stringent for the Separation Minima solution though, whereas the present solution can operate with the status quo. Both solutions require a high reliability for the detection of jamming and spoofing and would initiate fall-back procedures using barometric altimetry in that case. As the Separation Minima solution employs reduced vertical separation, however, these procedures should be necessary much less often; consequently, it has higher requirements on GNSS availability and continuity. Jamming and spoofing must be suppressed here through system design as far as possible (multi-frequency and multi-constellation receivers, message authentication, improved RAIM algorithms) and reliably detected if not, where the timely detection as such might suffice for the present solution. Both solutions acknowledge the existence of (external) technological threads working on improved robustness of onboard systems to jamming and spoofing.

SESAR Program: Both solutions are part of the same program and contribute to the "Aviation Green Deal" flagship initiative, which aims to promote sustainability and efficiency within European aviation.

Collaboration: Both solutions, geoAlt and separation minima, are connected in the framework of the Green-GEAR project, and have collaborated especially as the mutual enabler GNSS and its problems (mainly jamming and spoofing) are concerned.

3.3 Objectives of the ECO-EVAL

The objective of this TRL2 ECO-EVAL is to help build an assessment of whether SESAR solution 0406 is worth deploying, across ECAC, from an economic perspective for the involved stakeholders. This ECO-EVAL provides a consolidated assessment of the costs and benefits of deploying SESAR solution 0406 in TMA operations included in the ECO-EVAL solution scenario (see section 3.5.2).

This ECO-EVAL includes the evidence gathered to estimate the benefits and costs of the solution. The output is an overview of the high-level impact of costs and benefits per stakeholder group, recommendations and next steps.

3.4 Stakeholder identification

Stakeholder	Deployment locations (or sub-operating environments)	Cost drivers	Benefits in operations	Involvement in the ECO-EVAL analysis
ANSP	Improved airspace design enabling environmental benefits and increasing airspace capacity. Improved predictability reduces ATCO workload. Reduction in manual pilot action reduces safety risk.	Invest in airspace change, tools to support, training and regulatory changes.	ATCO workload reduction and neutral safety impact	Provided input
Airport operators	Airspace changes	Invest in update to procedure design tool	none	Not involved
Network manager	Sectorisation changes	Invest in flight planning tools	none	Not involved
Scheduled airlines (mainline and regional)	Improved IFPs enabling environmental benefits. Reduction in manual pilot action reduces risk of human error.	Invest in aircraft capability equipage (retrofit and linefit), EFB update, pilot training, FOC flight planning tools update and flight dispatcher training	Reduced fuel consumption and safety benefit	Not involved
Business aviation	Same as scheduled airlines	Same as scheduled airlines	Same as scheduled airlines	Not involved
Rotorcraft	Not applicable	Not applicable	Not applicable	Not involved
General aviation IFR	Same as scheduled airlines	Same as scheduled airlines	Same as scheduled airlines	Not involved
General aviation VFR	Not applicable	Not applicable	Not applicable	Not involved
UAS operators	Not applicable	Not applicable	Not applicable	Not involved
Military	Not applicable	Not applicable	Not applicable	Not involved
Common information service provider (CISP)	Not applicable	Not applicable	Not applicable	Not involved
U-space service provider (USSP)	Not applicable	Not applicable	Not applicable	Not involved

Stakeholder	Deployment locations (or sub-operating environments)	Cost drivers	Benefits in operations	Involvement in the ECO-EVAL analysis
Aircraft manufacturers	The need to develop aircraft capabilities to enable the concept for potential benefits to their airline customers.	Solution pre-implementation cost related to new airborne capabilities	Not applicable	Provided input
Avionics suppliers	The need to develop avionics and Flight Management System capabilities to enable the concept for potential benefits to their airline customers.	Solution pre-implementation cost related to new airborne capabilities	Not applicable	Not involved
Academic/Industrial research groups	Further development of airspace concepts that derive future benefits to aviation stakeholders.	Investment cost for research	Not applicable	Provided input
Communities neighbouring airports	Potential reduction in noise impact.	Not applicable	Not applicable	Not involved

Table 3: SESAR solution 0406 ECO-EVAL stakeholders and impacts

3.5 ECO-EVAL scenarios and assumptions

This section describes the scenarios that are compared in the ECO-EVAL. The aim is to reflect the delta (difference) between the ECO-EVAL reference scenario (where the SESAR solution is not deployed, bottom box in Figure 1) and the ECO-EVAL solution scenario (reflecting the proposed deployment of the SESAR solution across ECAC, upper box in Figure 1). The comparison between the ECO-EVAL scenarios considers the point in time when the solution is available to be deployed and hence differs for each solution. The delta approach means that the focus is on identifying the impact of the changes between the ECO-EVAL reference and ECO-EVAL solution scenarios. For example, new systems to be deployed, training requirements or changes in operating costs.

Defining the ECO-EVAL reference scenario has proven to be challenging because of the assumptions that need to be made regarding the 'ongoing deployments' that are relevant for the solution and their impacts.

To avoid being blocked by this issue, some elements of this TRL2 ECO-EVAL focus on the difference between the current situation and the ECO-EVAL solution scenario. This is reflected in the following scenario descriptions.

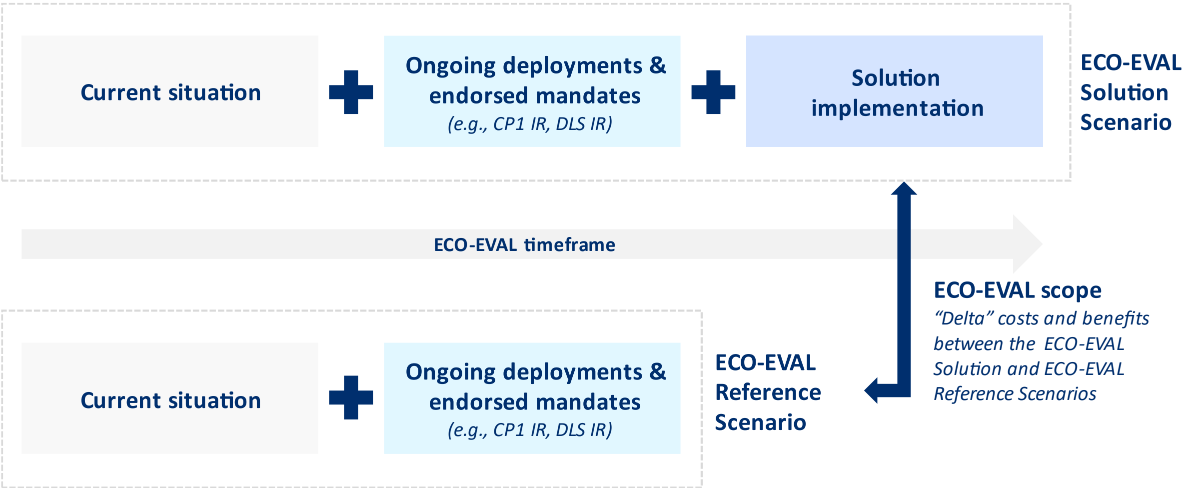

Figure 1: ECO-EVAL scenario overview

3.5.1 ECO-EVAL reference scenario

The reference scenario covers the current situation of traffic operations in London TMA.

3.5.2 ECO-EVAL solution scenario

The solution scenario covers the introduction of the SESAR solution 0406 in London TMA until transition Step 3. This scenario represents a composite solution where in the TMA, geometric altitude constraints are used exclusively together with the geometric definition of vertical flight paths for descent and approach operations (where necessary for procedural separation).

ECO-EVAL timeline

The ECO-EVAL covers the period from 2026 to 2050 as defined in the common assumptions [5]. This mean that the net present value is calculated by discounting the cash-flows back to 2026 (the end of DES wave 1).

Table 4 lists the key dates used in the ECO-EVAL and Figure 2 shows them over a timeline. Please note that the timeline relates to the full deployment capabilities of all stakeholders. The TMA design using geometric altitudes would possibly be available earlier than the start of deployment as outlined below. However, the development and certification of the aircraft capabilities inherent to the GeoAlt Solution (see FRD) as well as the pre-requisite improvements related to GNSS integrity and availability, would probably not be available earlier than the dates outlined below. For this reason, the SOD is relatively late.

Dates	SESAR solution 0406
Start of deployment date (SOD): the start of investments for the first deployment location	2040
End of deployment date: the end of the investments for the final deployment location, same as FOC	2050
Initial operating capability (IOC): the time when the first benefits occur following the *minimum deployment* necessary to provide them. Costs continue after this date as further deployment occurs at other locations.	2045
Final operating capability (FOC): maximum benefits from the *full deployment*[2] of the SESAR solution at applicable locations. Investment costs are considered to end[3] here although any operating cost impacts would continue.	2050

Table 4: ECO-EVAL investment and benefit dates

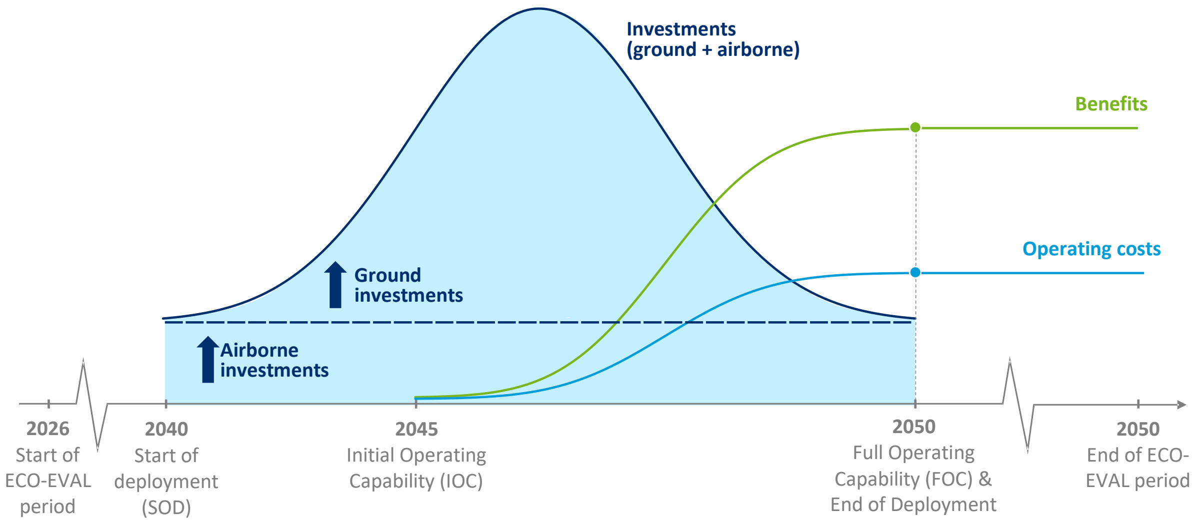

Figure 2: overview of ECO-EVAL dates

Figure 2 shows that:

- Investment costs are the addition of the (i) ground investment costs (spread following a bell curve[4] between the start and end of deployment dates), and (ii) airborne investment costs (spread linearly between the start and end of deployment dates);

[2] Where ***full deployment*** means deploying the SESAR solution in all the locations where it makes sense to deploy it (i.e. it does not mean it has to be deployed everywhere)

[3] The basic assumption is that infrastructure does not need to be replaced during the ECO-EVAL period.

[4] The bell curve is based on the diffusion of innovation theory (see Investopedia for further reference).

- Benefits ramp-up following an 'S' adoption curve[4] between IOC and FOC and then continue up to the end of the ECO-EVAL period;
- Operating cost impacts (increases or decreases) would also start at IOC and ramp-up following an 'S' adoption curve to FOC before continuing for the rest of the ECO-EVAL duration.

3.5.3 Assumptions

For the ECO-EVAL, only some additional assumptions have been made on top of the DES common assumptions.

The following local assumptions have been made for the ECO-EVAL:

- It is assumed that the equipage rate of aircraft is 100 % for the solution scenario. This is in accordance with the benefit analysis, where also an equipage rate of 100 % is assumed.
- 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 ECO-EVAL, it is considered as a prerequisite for the GeoAlt solution rather than part of its scope. In particular, it is assumed that any development that might possibly be required regarding GNSS jamming & spoofing is already available before the deployment of the geometric altimetry and, consequently, it would have no impact on costs for the deployment of the solution. Solution features related to monitoring of the GeoAlt capability and fallback to barometric navigation are described in the FRD [27] generically, not specifically focused on jamming & spoofing or any other particular cause of GNSS loss.

4 Benefits

The description of benefits follows the benefits impact mechanisms (BIM) as presented in the OSED [28]. The benefits are described in detail in the ERR [24] and in three internal documents [29][30][31].

4.1 Benefits overview

The benefits impact mechanisms (BIM) as presented in the OSED [28] outline several benefits / impacts from the introduction of geometric altimetry. These are mainly:

- Improved vertical profiles on SID, STAR and IAP procedures lead to fuel and CO_2 reduction
- The reduced reliance on manual datum switching reduces the risk of Level Busts
- The reduced reliance on manual data entry reduces the risk of mis-entry of QNH
- Additional usable levels enable more efficient procedures whilst maintaining capacity
- The improved design options enable more efficient procedures whilst maintaining capacity
- Assigning vertical accuracy requirements forces aircraft to more tightly adhere to the IFP profile, which in turn reduces the fuel and CO_2 efficiency for the individual flight and increases the risk of energy or speed management issues for the pilot to manage in descent

4.2 Benefit summary

Table 5 summarises the solution benefits showing the benefit impact mechanisms (BIMs) impact (positive, negative or neutral). It explains how the solution provides estimates. In accordance to the OSED [28], the two options referred to here are:

- Option 1: IFPs defined using Geometric Altitude
- Option 2: OFPs defined in 3 dimensions

KPI / PI	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
CAP1 TMA throughput in challenging airspace per unit time	=	Additional usable flight levels enable more efficient procedures whilst maintaining capacity. Also, the improved design options enable more efficient procedures whilst maintaining capacity.
FEFF1 Average fuel burn per flight	Option 1: - Option 2: +	Option 1: Improved vertical profiles on SID, STAR and IAP procedures leads to fuel reduction. Option 2: Assigning vertical accuracy requirements forces aircraft to more tightly adhere to the IFP profile, which reduces the fuel efficiency for the individual flight.
ENV1 Average CO_2 emissions per flight	Option 1: - Option 2: +	Option 1: Improved vertical profiles on SID, STAR and IAP procedures leads to CO_2 reduction. Option 2: Assigning vertical accuracy requirements forces aircraft to more tightly adhere to the IFP profile, which reduces the CO_2 efficiency for the individual flight.
SAF1 Safety	Option 1: + Option 2: +/-	Option 1: The reduced reliance on manual datum switching reduces the risk of Level Busts. The reduced reliance on manual data entry reduces the risk of mis-entry of QNH. Option 2: Assigning vertical accuracy requirements forces aircraft to more tightly adhere to the IFP profile, which increases the risk of energy or speed management issues for the pilot to manage in descent.
HP1 Human Performance	Option 1: + Option 2: +/-	Option 1: The reduced reliance on manual datum switching reduces the risk of Level Busts. The reduced reliance on manual data entry reduces the risk of mis-entry of QNH. Option 2: Assigning vertical accuracy requirements forces aircraft to more tightly adhere to the IFP profile, which increases the risk of energy or speed management issues for the pilot to manage in descent.

Table 5: solution performance benefits

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4.3 Airspace capacity (CAP1)

Overall, no capacity increase was indicated through the proxy metrics analysed. However, there was no conclusive significant detriment to capacity either.

SECTOR ENTRIES

The average sector entries per hour vary by sector due to different traffic flows entering or not entering a sector in the Reference scenario and Solution scenario. This is because climb and descent rate change because some traffic flows climb above while others remain below certain sectors. Overall, the trend between the models is similar with no difference to traffic levels spread across the day. For the 2035 traffic sample, across all hours of the day, there are on average 36 hourly sector entries in the reference scenario compared to 33 hourly sector entries in the solution scenario.

SECTOR OCCUPANCY

In terms of sector occupancy, on average, flights spend an extra 7 seconds longer across all the sectors in the solution scenario compared to the reference scenario in 2035. This is due to the less steep 7% climb profiles than statistically observed at 8% on the SIDs. This is more noticeable in the EGTTLAM, EGTTJAC and EGTTSAB sectors where the aircraft are spending longer climbing in these sectors. Overall, there has been a marginal increase in occupancy times between the reference and solution scenarios.

TRAFFIC INTERACTIONS

The analysis has indicated that the overall number of interactions between aircraft in the Solution Scenario has increased by 27% compared to the Reference Scenario for the 2035 traffic sample. This is mainly due to increased interactions between Heathrow arrivals levelling off at higher levels for the BNN hold interacting with Stansted NUGBO and Heathrow WOBUN departures in the EGTTBNN sector. It was determined that these interactions were caused by shortcomings of the airspace design rather than the concept itself; these would be caught and resolved through standard iterative airspace design processes.

4.4 Fuel efficiency (FEFF1) and CO_2 (ENV1)

Overall, a significant fuel benefit was indicated based on the difference in vertical profile and lateral track distance between Reference and Solution Scenarios. This demonstrates that airspace designers can use geometrically-defined vertical paths to create greater flight efficiencies at a TMA, or network, level, than can be achieved using current day (barometric) principles.

For STARs and IAPS, 5% (3°) descent gradients were used throughout with aircraft modelled to strictly adhere to the gradient.

For SIDs, below 3000ft, the climb rates were kept the same as in the barometric model; this is to allow aircraft to achieve minimum speed and climbs to get airborne from the runway and comply with local noise profile restrictions. Between 3000ft and the end of the SID (up to 17,000ft maximum), a constant 7% climb rate is modelled. Above the end of the SID, typical aircraft performance climb rates are used as per the barometric model.

Using geometric altimetry in the TMA as described above, the cumulative results of this project analysis provided a net benefit overall for fuel & emissions at 2035 traffic levels:

- Climb: c.2 kg fuel disbenefit per flight
- Descent and Approach: c.24k g fuel benefit per flight
- TOTAL (net): c.23kg[5] fuel benefit per flight

See also the results from Exercise #04 (Section 4.2.3 of [26]), which show similar outcomes: significant potential fuel benefit for Geometric Path in descent but minimal to negative fuel benefit for Geometric Path in climb.

	ARRIVALS			DEPARTURES		
	Fuel Burn (T)	CO2e (T)	% change	Fuel Burn (T)	CO2e (T)	% change
2023	-4,833	-15,224	-1.6%	-331	-1,042	-0.1%
2035	-5,949	-18,739	-1.8%	302	952	0.1%

Table 6: Combined summary of arrival and departure total fuel/CO2e in UK FIR.

	ARRIVALS + DEPARTURES		
	Fuel Burn (T)	CO2e (T)	% change
2023	-5,164	-16,266	-0.8%
2035	-5,647	-17,787	-0.8%

Table 7: Overall Green Gear Total fuel benefit in UK FIR

The size of the benefit only shows a potential scale of benefit as there were limitations with the modelling capability because speed profiles could not be adjusted according to the climb or descent rate. Therefore, the calculated fuel differences between Reference and Solution Scenarios are based on the difference in the vertical profiles and lateral track distance.

Fuel and CO_2 analysis has been carried out on the proposed Green-GEAR model. The fuel and CO_2 calculations for this analysis have been based solely on the affected routes and the traffic utilising those routes. Any routes that have not changed as part of the Green-GEAR model and remain as current day operations have not been included.

Routes have been cut to the UK FIR boundary, and all calculations are based on the segments of the routes between UK FIR boundary and runway or vice versa for arrivals and departures respectively.

In the results of the descent analysis, several different effects are visible. The change of the altimetry type influences the fuel savings by a very small amount and can be positive or negative depending on the QNH. In an optimised descent scenario, the differences would not cancel out each other in a long-term scenario with varying weather conditions, but a noticeable advantage for the geometric altimetry would remain. For the shown example scenario, the change from the baseline descent profile to the solution descent profile results in fuel savings of approximately 23 kg, which is about 6.6% of the fuel

[5] These summary fuel figures are rounded to the nearest integer value, hence the value of 23kg as opposed to 22kg for the total.

consumption for this scenario. Even though these fuel savings are mostly not a direct result of the geometric altimetry, if the optimised descent profile in the solution scenario is considered to be enabled by the usage of geometric altimetry, then the change of the altimetry type indirectly enables these fuel savings. Also, the usage of geometric altimetry reduces the variance of the fuel consumption and therefore improves the predictability.

In the climb scenario, the influence of the altimetry type on the fuel savings is similar to the influence in the descent scenario: it can be positive or negative depending on the QNH. For the shown example scenario, the change from the baseline climb profile to the solution climb profile results in fuel savings of approximately 2 kg, which is only about 0.25% of the fuel consumption for this scenario and therefore much lower than the benefit in the descent scenario. The reasons for the only very low fuel savings are the two counteracting effects in the optimisation of the climb profile: the removal of the level-off segment in the solution scenario has a positive influence on the fuel savings while forcing the aircraft to fly a fixed climb gradient has a negative influence on the fuel savings. In total, a small positive benefit remains. Even though these fuel savings are not a direct result of the geometric altimetry, if the optimised climb profile in the solution scenario is considered to be enabled by the usage of geometric altimetry, then the change of the altimetry type indirectly enables these fuel savings. In contrast to the descent scenario, the usage of geometric altimetry in the climb scenario increases the variance of the fuel consumption and therefore decreases the predictability.

For the TMA analysis, it can be concluded that geometric altimetry has a direct positive effect on the fuel consumption because, in contrast to barometric altimetry, the flight level constraints are at fixed geometric altitudes and are therefore not moved away from the optimal profile when the QNH is changing. This direct effect, however, only exists when flying an optimised profile. Also, geometric altimetry has an indirect positive effect on the fuel consumption by enabling an optimisation of the climb and descent profiles. The optimisation of the climb profile in the solution scenario results in small fuel savings but leaves potential for further improvement while the optimisation of the descent profile in the solution scenario already results in significant fuel savings of about 6.6% of the fuel consumption from the top of descent until the ILS intercept.

The results on fuel consumption as outlined above can be directly transferred into CO_2 emissions.

4.5 Safety (SAF1)

To address the primary objective on whether GeoAlt could enable the safe removal of the transition later, controllers indicated that removing the transition layer in a fully geometric environment would be feasible and pose minimal hazards to the operation, in the context of the current day operation prior to airspace systemisation. This positive feedback suggests that removing the transition layer, from a controller point of view, would simplify altitude management without introducing significant operational challenges. Removing the transition layer associated with pressure datum changes between QNH and standard pressure eliminates the need for pilots to adjust altimetry mid-flight or the potential for the wrong QNH given. No major safety hazards were identified with the move to GeoAlt and the removal of the transition layer, additional consideration and analysis will be required for the transition to a systemised airspace on top of the transition to GeoAlt.

4.6 Human Performance (HP1)

Human Performance assessment was conducted mainly regarding ATCOs operation. Some results of the airborne impact assessment are related to flight crew operation, but no dedicated HP assessment has been conducted with pilots. The following description of human performance assessment results is only applicable to ATCOs.

To address the validation objective of assessing human performance, no critical showstoppers were identified, primarily, for the scenario which would introduce geometric operations by changing barometric altitude constraints at waypoints for geometric, i.e. without a significant change to ATC MOPS. Controllers felt that transitioning to this configuration would require minimal adjustments to existing procedures.

By contrast, the majority of human performance impacts were associated with the airspace scenarios, where a shift to geometric altimetry is coupled with a more systemised airspace that is more tightly defined in both the vertical and lateral planes, incorporating fixed vertical and lateral geometric paths. While an increase in a more systemised airspace, whether using barometric or geometric altimetry, entails changes such as a shift in controller roles to a system monitoring role, the introduction of GeoAlt presents additional consideration, for example it would require controllers to adjust to a new way of interpreting altitude information. However, this report focuses specifically on the implications of GeoAlt within a systemised airspace, rather than examining systemisation within barometric altimetry. Transitionary factors, particularly in mixed-mode operations, require significant attention as the controllers emphasised the importance of clear visual indicators and consistent phraseology to distinguish between barometric and geometric operations, especially when in failure scenarios. Training will play a critical role in ensuring controllers and pilots are equipped to manage new procedures effectively.

Overall, while GeoAlt presents opportunities and benefits to the operation, a careful phased approach to its implementation will be essential to address any human performance issues as well as establishing the appropriate airspace design. Whilst no significant HP issues were identified, it should be noted that this was an early theoretical assessment that encompassed of several use cases and airspace environments. A switch from barometric to geometric constraints without changing the airspace was considered to be relatively simple and may result in managing less complex and easier interactions. However, with the development of an airspace change to a more optimised airspace, this in turn impacts the severity of the effect on roles, technology, communication and training for the controller. This highlighted the need to adjust the transitionary steps of geometric altimetry to the following:

1) Geo Initial Approach

2) Lateral Path + Geo Alt constraints (no airspace change)

3) Geo TMA (Approach, Descent & Climbs), potentially through a set of smaller changes, e.g. airport per airport, i.e. could be a mix of Geo Alt constraints and Geo Vertical Path.

4) Airspace block (Cruise, Approach, Descent & Climbs)

With the progression to a more systemised airspace, every step of this transitionary period would require an in-depth human performance and safety assessment to further investigate the impact. Such a transition would, in the end, involve significant changes in controller roles and responsibilities, require advancements in technology, updates to communication and teamwork, as well as extensive training requirements, as such influencing the impact on human performance. While further investigation into these specific details of these changes may uncover potential challenges, the controllers did not identify any major showstoppers during the workshop that would halt the progression of the project from an ATC human performance perspective at this stage when working under the assumptions outlined. However, further established mitigations and protocols will be required for fallback scenarios, emergencies and failures.

5 Cost assessment

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
ANSPs	Investment cost	Yes	see sections below	VHC, HC, MC, LC TMA airspace
	Operating cost	Yes	see sections below	
Airport operators	Investment cost	Yes	see sections below	S, M, L, VL airports
	Operating cost	No	-	
Network manager	Investment cost	Yes	see sections below	NMOC
	Operating cost	No	-	
Airlines and other airspace users	Investment cost	Yes	see sections below	SA (aircraft fleet), BA, GA
	Operating cost	Yes	see sections below	
Military	Investment cost	Yes	see sections below	n.a.
	Operating cost	Yes	see sections below	
U-space Stakeholder	Investment cost	No	-	n.a.
	Operating cost	No	-	
Other stakeholders	Investment cost	No	-	n.a.
	Operating cost	No	-	

Table 8: identification of solution's cost drivers and deployment locations

Because of the relatively low TRL of 2, the identified costs per stakeholder can only be expressed in a qualitative way. In the following sections, operational and investment costs for the related stakeholders are identified and outlined. A quantitative assessment of each cost category cannot be performed here.

5.1 ANSPs costs

Investment Costs:

- Update to Airspace design tools
- Airspace change (not necessary for Step 2 but for Step 3 – differential between geo and baro airspace change)
- Change in ACP – part of airspace change but CAA will likely make it more complex
- Update to Procedure Design tools
- IFP chart changes
- AIS / AIM changes
- ATCO Training based on GeoAlt

- Ground system conformance monitoring system development
- Conflict Detection Tool development
- Safety Net system development
- Flight data processing based on GeoAlt
- CWP to manage and display GeoAlt
- Updating procedures, safety cases, etc.
- Project delivery of GeoAlt: inc. Safety and HF assessment, regulatory oversight

Operating Costs:

- ATCO fallback training for Baro Fallback

5.2 Airport operators costs

Investment Costs:

- Airspace change (not necessary for Step 2 but for Step 3 – differential between geo and baro airspace change)
- Change in ACP – part of airspace changes but CAA will likely make it more complex
- Update to Procedure Design tools
- IFP chart changes

5.3 Network manager costs

Investment Costs:

- Flight planning tools to be geo capable
- Sectorisation changes

5.4 Airlines and other airspace users costs

Although the assessment of SESAR solution 0406 has been performed focusing mainly on scheduled airline traffic, the following costs related to the introduction of the solution also apply to other civil airspace users, such as business or general aviation.

Operational Costs:

- Recurrent pilot training
- Maintenance of equipment and systems (effect on existing maintenance items, e.g. if in case of option 2, spoilers would be used more frequently, or even additional maintenance items on new hardware / software functions)
- Recurrent flight dispatcher training

Investment costs:

- Aircraft equipment costs (retrofit and linefit)
- EFB software update
- Initial pilot training

- FOC flight planning software update
- Initial flight dispatcher training

5.5 Military costs

As Green-GEAR deals with the civil application of geometric altimetry, this is not applicable in the context of Solution 0406. However, in case of a military use of airspace applying geometric altimetry, military airspace users could be treated in the same way as civil airspace users in terms of their costs.

5.6 U-space stakeholder costs

Green-GEAR addresses mainly operations of commercial transport aircraft. Also, unmanned aircraft typically use geometric altimetry for navigational purposes anyway. For this reason, this is not applicable in the context of Solution 0406.

5.7 Other relevant stakeholders

There are no other stakeholders relevant for the ECO-EVAL.

6 Recommendations and next steps

At the current TRL of 2, a quantitative assessment of costs cannot be performed. The evaluation of benefits has been performed quantitatively, but the cost assessment could only be performed in a qualitative way. It is therefore highly recommended to perform a quantitative cost assessment to improve the economic evaluation if the solution is to be further developed for higher TRL. In order to do so, quantitative input is required from the involved stakeholders regarding their respective cost drivers.

It is also recommended to enlarge the regional scope of the solution towards a deployment beyond London TMA. Currently, the benefit assessment was based on a deployment of geoAlt in London TMA only. Although the qualitative cost assessment is more or less generic for the involved stakeholders, the benefit assessment could be influenced by the deployment region. This should be further investigated in the future.

As the cost assessment could only be performed in a qualitative manner, no recommendations can be made towards a deployment of the solution from the cost-benefit perspective. Here, further research is required to conclude whether the solution is also viable not only from a technical perspective, but also from the cost benefit perspective.

At the current stage of the solution development (TRL 2), some technical developments in the field of mitigation of jamming/spoofing are considered as necessary prerequisites. These necessary developments are not considered as part of the geoAlt solution as such. However, the future development of those means for jamming/spoofing mitigation is likely to result in additional costs. This should also be considered for future development of the solution.

Also, depending on the chosen way forward for airborne predictions, in addition to impacts on Airspace Users (see FRD), Solution 0406 may have an impact on additional stakeholders, which have not been considered at the current TRL. This is:

- 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.
- 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.

If such potential impacts on MET and/or AIM stakeholders were confirmed in further maturity phases, the associated costs would need to be captured in the cost-benefit analysis.

7 References

7.1 Applicable documents

This ECO-EVAL 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 Solution Cost Benefit Analysis (CBA) Quick Start Guide (1_0), Edition 01.00.00, 1st February 2024.

[11] SESAR ECO-EVAL Quick Start Guide (1_0).docx.

[12] SESAR Guidelines for Producing benefit and Impact Mechanisms, PJ16.06.06, ed. 03.00.01, 23rd June 2016.

Validation

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

[14] DES SESAR Maturity Criteria and sub-Criteria_01_01 (1_1), Edition 01.01, 15th February 2024.

System engineering

Safety

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

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

Human performance

[17] SESAR DES Human Performance Assessment Process TRL0-TRL8, Edition 00.04.02, January 2024.

Environment assessment

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

Security

Programme management

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

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

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

[22] Horizon Europe ethics guidelines – essentials_1 (1_0), Edition 01.00.01, 26th June 2024

[23] Project Reviews 2024_guidance for IR1 & ER1 (1_0).pptx

7.2 Reference documents

Green-GEAR Project Documents

[24] Zapata, D.; Vechtel, D.; Bauer, T.; Koloschin, A.; Nelson, D.: “SESAR 3 ER 1 Green GEAR – Initial OSED – Geometric Altimetry”, Deliverable D3.1, ed. 01.00, 28th June 2024.

[25] Zapata Arenas, D.; Bauer, T.; Koloschin, A.; Vechtel, D.; Donaghey, R.; Godsell, J.; Melendez, J.; Nelson, D: "SESAR 3 ER 1 Green GEAR – ERP – Geometric Altimetry V1", Deliverable D3.2, ed. 01.00, 22nd November 2024.

[26] Nelson, D.; Donaghey, R. M.; Melendez, J.; Zapata Arenas, D., Rouquette, P., Vechtel, D., Koloschin, A.; Bauer, T.: "SESAR 3 ER 1 Green GEAR – ERR – Geometric Altimetry", Deliverable D3.3, ed. 01.00, 28th February 2025.

[27] Zapata Arenas, D., Rouquette, P., Nelson, D., Bauer, T.: "SESAR 3 ER 1 Green GEAR – FRD – Geometric Altimetry", Deliverable D3.4, ed. 01.00, 30th April 2025.

[28] Zapata Arenas, 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, 30th April 2025.

[29] Hough, D., Hung, S.: "SESAR 3 ER 1 Green GEAR – ATC and Route Design Impact Report", internal Deliverable iD3.1, ed. 01.00, 20th December 2024.

[30] Azoulai, L., Zapata Arenas, D., Rouquette, P., Pastre, T.: "SESAR 3 ER 1 Green GEAR – Aircraft Systems and Architecture Impact Report", internal Deliverable iD3.2, ed. 01.01, 6th January 2025.

[31] Vechtel, D., Koloschin, A.: "SESAR 3 ER 1 Green GEAR – Flight Performance and Procedures Report", internal Deliverable iD3.3, ed. 1.0, 20th December 2024.

Appendix A Maturity criteria (self-assessment)

The only maturity criterion identified as relevant for the ECO-EVAL is PER.TRL2.3.

Does the TRL2 ECO-EVAL contain a qualitative (order of magnitude) description of the costs and benefits of the solution that allows the different impacted stakeholders to have confidence on the continuation of further research for the proposed ATM solution?

Yes, costs as well as benefits have been outlined qualitatively. Given the low TRL of 2, quantitative numbers for costs could not be evaluated.

Are the following elements clearly described in the TRL2 ECO-EVAL:

(1) scope of the solution (in particular considering the cost-drivers).

Yes, the scope of the solution is described in section 2.2 and cost-drivers are described in section 5.

(2) interdependencies with other solutions.

Yes, interdependencies with other solutions are described in section 3.2.1.

(3) implementation/deployment options.

Yes, implementation and deployment options are described in section 3.5.

(4) identification of the impacted stakeholders.

Yes, the impacted stakeholders have been identified and described in section 3.4.

(5) qualitative description of the benefits, in line with the BIMs in the OSED TRL2, including the most impacted KPAs and KPIs.

Yes, the benefits have been described in accordance with the BIM and related to the investigated KPIs (see section 4)

(6) identification of cost drivers.

Yes, the major cost drivers have been identified and described in section 5.

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