Green-GEAR

Green-GEAR – Common assessment methods

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

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1 Executive summary

The Green-GEAR project is developing three Solutions: Vertical Guidance using Geometric Altimetry (GeoAlt), Separation minima (SM), and Green route charging (GRC), the goal of which is to help decrease aviation's climate impact in the short to medium term. The three Solutions address different flight phases and environments, but the planning and the requirements of specific experiments apply the same approach to definition of research hypotheses, definition of experimental/validation scenarios, reliability, sensitivity and validity of exercises, generalisation of the exercise results and their transfer to the operational environment. This paper details the approach taken in definition of scenario choices, performance assessment, validation methods and the steps to be taken in economic evaluation.

2 Introduction

The goal of this white paper is to describe the application of scientific best practices within the Green-GEAR project, in the definition of the experimental approach and validation results analyses. The choice of research questions, objectives, hypotheses and methods for the three Green-GEAR Solutions are described. The ultimate objective is to facilitate the Solution assessment and have a coordinated approach, following the open science principles. The three Solutions aim to reach TRL2 by the end of the project.

The Green-GEAR Solutions are expected to contribute to the environment, capacity, safety, security and cost-effectiveness key performance areas (KPAs). Not all the Solutions will address the same KPAs, but the assessment plans are made jointly between the Solutions that do.

2.1 Green-GEAR Solutions

The Green-GEAR is developing three Solutions to jointly address enabling of optimum green trajectories, acceleration of decarbonisation and decrease of climate impact of flights:

- Vertical Guidance using Geometric Altimetry (GeoAlt),

- Separation minima (SM), and

- Green route charging (GRC).

Green-GEAR Synergies. The GeoAlt Solution will determine the feasibility of using geometric altimetry instead of barometric altimetry in various phases of flight and for various aircraft types. This is a key input for the definition of the proposed Solution and concept in the SM Solution. The SM Solution in turn will determine the feasibility of reducing separation minima in various flight phases and will propose flight trajectories for new entrants & new aircraft types. This is a key input for the GRC Solution. The combined approach to these Solutions by Green-GEAR ensures that the respective performance assumptions are valid and the concepts of operation are harmonised.

2.1.1 Vertical Guidance using Geometric Altimetry

Definition of GeoAlt Solution (406): The idealised end state is where all airspace users operate Geometric altimetry for vertical navigation in all flight phases, i.e. there is a single common datum for aircraft height in use under nominal operations. This would enable better integration of emerging airspace users (such as drones/UAS, eVTOL / air taxis and High-Altitude Operations) with incumbent ones.

There are two potential methods to apply Geometric altimetry for vertical navigation;

(1) Defined lateral path + altitude constraints: Conceptually, Geometric altimetry could be used for vertical path construction and navigation, with vertical separation provided by height constraints at waypoints as per today's operation, forgoing changing of today's airspace or instrument flight procedures. Reporting Geometric height (in parallel with Barometric height) is a current aircraft capability but not yet used for constructing and navigating to a vertical path.

Potential benefits include safety (avoiding the need for manual pressure datum change when crossing the Transition Layer), environment (consistency of altitude, which at low level, could offer performance and noise benefits) and capacity (no loss of Flight Levels due to the Transition Layer).

(2) Defined lateral & vertical path: Conceptually, Geometric altimetry could be used for vertical path construction and navigation, with vertical separation assured against the Geometrically-constructed path as a form of Vertical RNP. This would enable Instrument Flight Procedures to be constructed and separated much more efficiently in 3 dimensions than today, maximising the benefits of airspace and procedure design. ATC tools would need to evolve, including surveillance and safety nets (e.g. Mode-S CFL/SFL checking and a Barometric Alerting Tool).

This method offers a significant improvement in containment which would allow procedure designers to optimise route efficiency through a truly 3-dimensional airspace design.

2.1.2   Separation minima

Definition of SM Solution (407): The solution aims to transition from 1000 ft to 500 ft minimum vertical separation in reduced vertical separation minimum (RVSM) airspace (FL 290 to 410), enabled by increased height measurement accuracy through geometric altimetry. In addition, geometric altimetry does not suffer from the same degradation in accuracy with increasing height as barometric altimetry. It is therefore expected to allow the extension of the upper limit of RVSM airspace to FL 600, whereas today the minimum vertical separation above FL 410 is 2000 ft.

Reduced vertical separation will increase capacity, allowing more aircraft to fly closer to their optimal flight level and thus reducing CO_2 emissions. It can also be an enabler to limit the length of detours that are flown to avoid regions of high climate impact.

The study will focus on the safety aspects, most notably the collision risk, wake turbulence risk, and an overall safety case, where the EUR RVSM region will serve as a test case. It is part of the research effort to determine whether advanced modes of separation (e.g. dynamic and/or geometry-dependent horizontal separation) would be needed to ensure the safety of operations. The concept is applicable to civil and military aircraft and will allow the integration of novel concepts such as UAS and HAO aircraft which can use geometric altimetry much more easily.

2.1.3   Green route charging

Definition of GRC Solution (408): The GRC solution is designed to encourage airspace users to reduce the environmental impact of aircraft operations while maintaining economic and capacity effects.

En-route charges, proportional to the costs of providing en-route air navigation services, are collected from airspace users. The current charging scheme allows for the modulation of charges to incentivise desired behaviours.

The GRC solution is scalable, with a two-step implementation corresponding to different levels of ambition and complexity. Initially, the solution is designed to reduce CO_2 emissions and congestion through the use of modulation of charges. Ultimately, it aims to mitigate the effects of non-CO_2 emissions as well.

The Solution will eliminate flight inefficiencies resulting from the route charging scheme itself (e.g., detours due to unit rate differences) and incentivise environmentally friendly trajectory planning. Revenue neutrality will be maintained through the appropriate recalibration of charges. The principles

set forth in the ICAO Document 9082 need to be maintained, particularly those pertaining to gradual changes in charges and the modulation of charges.

3   Common assessment methods for Solutions

3.1   Baseline scenario choice

The planned Green-GEAR Solutions address different, but related topics. The planning and the requirements of specific experiments needed, having the same approach to definition of research hypotheses, definition of experimental/validation scenarios, reliability, sensitivity and validity of exercises, generalisation of the exercise results and their transfer to the operational environment, is secured through this approach. As a part of this, the common baseline was envisioned across the Solutions. The preliminary choices for the baseline scenario dates for the three Solutions was September 2019, as the 2023 traffic numbers were still catching up with the 2019 ones, but creating much higher air traffic flow management delay, which is one of the indicators that the ATM situation was still in the recovery mode in 2023. As the years 2020-2022 were still under direct pandemic impact, we believed that the best choice for the baseline traffic data is year 2019.
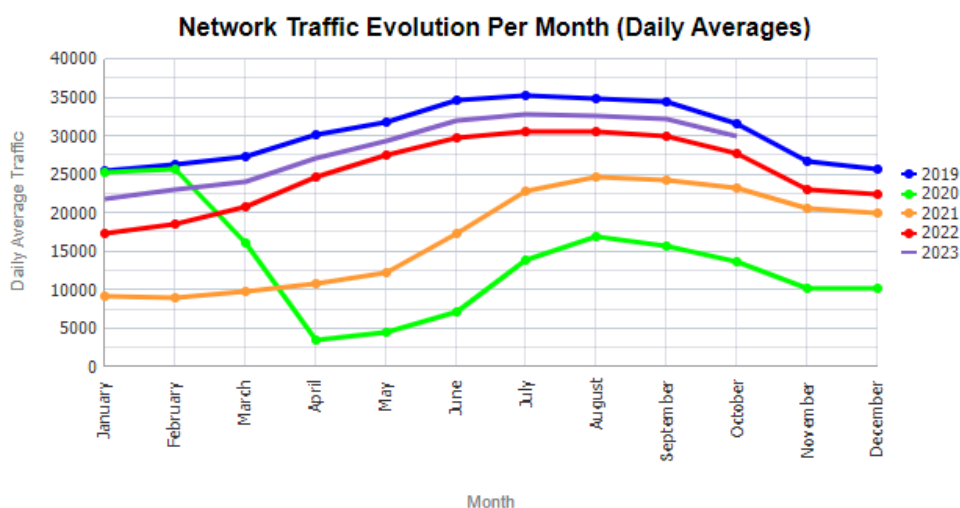

Figure 1. Network traffic 2019-2023 (source: EUROCONTROL's Network Dashboard).

For the GRC and SM Solution the traffic and weather data (and other datasets, if needed) will be sourced for 2019. For the ECAC[1] area modelling, the traffic from September 2019 is chosen, as it contains busy traffic, delays are not excessive, and the autumn weather conditions can facilitate the creation of contrails (which is one of the negative environmental impacts of aviation).

However, the terminal maneuvering area (TMA) simulations will need to take 2023 as a baseline year due to the significant change in traffic mix using the London TMA pre- and post-pandemic. Examples include: heavy quad-engined jets have largely been retired, the loss of Dash 8s, and many airlines have taken the opportunity to bring in new fleets. Furthermore, there has also been a major airspace change affecting the north London TMA since 2019.

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[1] European Civil Aviation Conference – is a pan-European organisation, it is composed of 44 Member States.

As the GeoAlt Solution depends on the aircraft characteristics and their equipage, it has been decided to use 2023 London TMA traffic in the exercises (for baseline, and building the future scenarios).

3.2 Performance assessment KPAa

The Green-GEAR Solutions are expected to contribute to the environment, capacity, safety, security and cost-effectiveness key performance areas (KPAs), as listed in Table 1.

Table 1. KPAs and indicators addressed.

KPA	GeoAlt	SM	GRC
Capacity	CAP1	CAP2	CAP2
Cost-efficiency	AUC4	N/A	AUC3 AUC1
Operational efficiency	FEFF1	FEFF1 TEFF6	FEFF1 TEFF6
Safety	SAF1	SAF1 SAF1.1	N/A
Environment	ENV1	ENV1	ENV1
Human performance	HP1	N/A	N/A

Capacity is important for all Green-GEAR Solutions, even if the exact indicators differ. The GeoAlt is focusing on the impact of geometric altimetry in the TMA, assuming that the removal of the Transition Layer will enable the use of more flight levels (FLs) and thus increase capacity of TMA. As the focus is on TMA, the appropriate capacity indicator is CAP1 – TMA throughput in unit of time. The SM and GRC Solutions are looking at the changes in en-route airspace, and as such the CAP2 - The total number of movements per volume of En-Route airspace per hour for specific traffic mix and density at peak demand hours – as appropriate indicator. The initial assumptions are that the SM could increase en-route capacity by further reduction of vertical separation, and that the GRC will be able to redistribute traffic to take the en-route capacity in account, thus reducing the need for demand-capacity balancing measures.

Cost-efficiency KPA is addressed in GeoAlt and GRC, and is not applicable in SM. By using GeoAlt Solution, there is potential for cost efficiency benefit through engine wear reduction due to thrust consistency, which is measured through AUC4 indirect operating costs for an airspace user). The GRC will asses AUC3 (the impact on direct costs related to the aeroplane and passengers) and AUC1 (the minutes of strategic delay saved with the Solution), as the initial assumptions are that the fuel costs and minutes of delay could be reduced (on average, on network level).

Operational efficiency KPA is important from the efficiency, but also from the environmental point of view. The Green-GEAR Solutions are aiming to reduce the fuel consumption, on average. As such, the

Solutions will asses the FEFF1 (the total amount of planned fuel burnt divided by the number of flights) in the airspace under evaluation (i.e., TMA for GeoAlt, and en-route for SM and GRC). Furthermore, SM and GRC will assess TEFF6 (the average of the distribution of actual en-route durations), as the initial assumptions are that these two Solutions will help reduce the en-route durations.

Safety is paramount concern for SM Solution, and an important indicator for GeoAlt. The SM will quantify the mid-air collision risk in the en-route flight segment. A hypothetical reduction of minimum vertical separation under barometric altimetry in itself would obviously increase the collision risk; this is counteracted by the increased accuracy of geometric altimetry. The latter is a mixed blessing though: while collision risk of aircraft properly separated decreases with higher accuracy altimetry, the collision risk of aircraft that are erroneously on the same flight level increases. The investigation will quantify the collision risk according to an adaptation of the ICAO RVSM methodology, measured by SAF1. Other safety indicators will be looked at as well (SAF1.1, SAF1.10.2, SAF1.10.3). The GeoAlt Solution would reduce the risk of capturing the glideslope from above in hot weather conditions, which could otherwise cause energy management issues or potentially lead to a missed Approach, also to be measured by SAF1. The GRC Solution will divise new route charging mechanism, but will not change the way the flights are operated, and as such safety is not applicable.

Environment is the main KPA for all the Green-GEAR Solutions, as all three Solutions are looking at fuel consumption reduction through flight optimisation. All the Solutions will assess ENV1 indicator (the amount of fuel burnt x 3.15 (CO_2 emission index) divided by the number of flights).

Human performance will be assessed, qualitatively, for the GeoAlt Solution, via HP1 indicator. The aim is to investigate the high-level key human performance risks and/or impacts the Solution may have on roles and responsibilities, human and system, teams and communication. The initial assumptions are that the reduced reliance on manual datum switching reduces the risk of level busts and the reduced reliance on manual data entry reduces the risk of mis-entry of QNH.

Each Solution will assess indicators that are not part of the SESAR's Performance Framework, but that will help create a full picture of the Solutions' impact. For example, the GRC solution will assess the impact of the new route charge mechanism on the revenue neutrality for air navigation service providers, as revenue neutrality is mandated by the current regulations.

3.3 Validation methods

The three Green-GEAR Solutions address different topics under the Green Deal flagship. As such, the validation methods to be applied vary across the Solution and validation exercises. Table 2 lists the validation exercises and main methods applied;

Table 2. Validation exercises and methods applied.

Solution	Validation exercise and method
GeoAlt	Benefit assessment of a fully geometric TMA: Fast-time simulation of a fully geometric TMA compared with a fully barometric TMA to determine the relative benefits and disbenefits of geometrically-defined instrument flight procedures at a network level (addressing Operational Efficiency, Environment, Capacity).

	Safety and Human Performance assessment: Safety and Human Performance assessment carried out through workshops as a paper exercise to identify the key features for ATC in a fully geometric environment. Assessment will cover both nominal conditions and fallback due to GNSS loss or spoofing, which are seen as the major risk with geometric operations (addressing Safety, Human Performance)	
	Aircraft Performance & Procedures: Simulation study for the assessment of the effects from the use of geometric altimetry instead of barometric altimetry on aircraft performance and flying procedures. The objective is to evaluate the effect on fuel consumption and other aircraft-performance-related parameters (addressing Operational Efficiency, Environment, Cost Efficiency).	
	Aircraft functions, architecture and cockpit systems: Assessment using expert judgement to address the impact of the GeoAlt concept of operations as described in the Initial OSED on aircraft functions, architecture and cockpit systems, focused on large commercial aircraft (Airbus families), addressing technical feasibility.	
SM	Collision Risk RVSM 2: Height deviations are considered as an important hazard in the safety case exercise which could potentially lead to mid-air collisions. Therefore, a collision risk assessment is performed. The collision risk assessment is based on the ICAO collision risk models as described in the ICAO *Manual on airspace planning methodology for the determination of separation minima,* addressing safety.	
	Wake Turbulence Risk RVSM2: A wake turbulence risk analysis will be performed in order to determine the influence of RVSM2 on the probability and severity of wake vortex encounters. Therefore, a previously developed software toolbox will be adapted and used for a statistical evaluation of the wake vortex encounters in a traffic scenario. Also, a hazard assessment of these encounters will be performed. If the risk of hazardous wake vortex encounters due to the introduction of RVSM2 will be assessed as unacceptably high, then additional methods of risk mitigation will be suggested, addressing safety.	
GRC	Modelling of Green Route Charge schemes: Verify the proper functioning of the models for GRC assessment. Monitoring the behaviour of the GRC models and checking for their feasibility.	

	Execution of Green Route Charge schemes:
	Validation of the GRC Solution by running the GRC models and assessing the performance in respect to capacity, cost efficiency, operational efficiency and environment.

The Solutions apply different methods, based on their focus. The assessment of the indicators listed in the section 3.2 will give the values for listed indicators, but will also strive to give a distribution of the indicator, to be able to better assess its impact. For example, the TEFF6, which by its definition is an average value, may stay the same across several settings. However, it is important that the Solution does not end in the state where the distribution of en-route times spreads in such a way that the long flight times end up being longer.

3.4 Economic evaluation

Next step is to build a high-level assessment of whether the Green-GEAR Solutions are worth deploying, across ECAC, from an economic perspective for the involved stakeholders, listing recommendations and next steps.

The aim of economic evaluation is to reflect the difference between the (reference) scenario where the Solution/s is/are not deployed, and the scenario where the Solution/s are deployed across ECAC, at the point in time when the Solution/s is/are available for deployment. Care should be taken when creating these scenarios as they should include other ongoing developments.
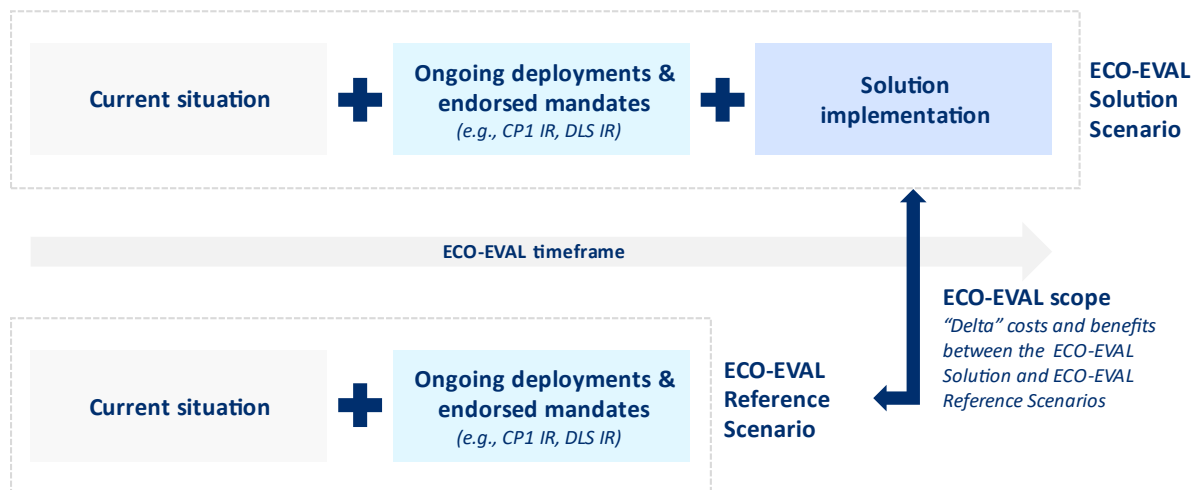

Figure 2. ECO-EVAL scenario overview, taken from [3].

This evaluation should cover the period from 2026 to 2050 as defined in the SESAR common assumptions [5], and include the assessed benefits and assumed costs.

The three Green-GEAR Solutions identified the stakeholders that will be impacted, benefits mechanisms and the applicable operational environments. The validation exercises (currently ongoing) are assessing the feasibility of the Solutions as well. As such, the economic evaluation scenarios and evaluation itself are currently being developed, based on the validation results.

4 Applicable documents

[1] SESAR 3 ER 1 Green-GEAR – D3.1 – Initial OSED – Geometric Altimetry, Edition 01.00, 28 June 2024

[2] SESAR 3 ER 1 Green-GEAR – D4.1 – Initial OSED – Separation minima, Edition 01.00, 28 June 2024

[3] SESAR 3 ER 1 Green-GEAR – D5.1 – Initial OSED – Green RC, Edition 01.00, 28 June 2024

[4] ICAO, Doc 9082 ICAO's Policies on Charges for Airports and Air Navigation Services, ninth edition 2012

[5] SESAR 3 ER 1 Green-GEAR – D5.2 – ERP – Green Route Charging V1, Edition 01.00, under review

[6] SESAR 3 ER 1 Green-GEAR – D4.2 – ERP – Separation Minima V1, Edition 01.00, under review

[7] SESAR 3 ER 1 Green-GEAR – D3.2 – ERP – Geometric Altimetry V1, Edition 01.00, under review

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

[9] DES HE SESAR solution XXX ECO-EVAL template for TRL2, Edition 00.01

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

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

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

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

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

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

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

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

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

5   List of acronyms

Acronym	Description
ATC	air traffic control
ATM	air traffic management
GeoAlt	geometric altimetry
GRC	green route charging
KPA	key performance area
QNH	atmospheric pressure at mean sea level
RVSM	reduced vertical separation minimum
SM	separation minima
TMA	terminal maneuvering area
TRL	technology readiness level

Table 3. List of acronyms

AIRBUS

DLR

EUROCONTROL

NATS

nlr

UNIVERSITY OF WESTMINSTER

UNIVERSITÀ DEGLI STUDI DI TRIESTE