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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.

The “Separation Minima” Solution assesses the feasibility of reducing the vertical separation minima to 500 ft in upwards-extended Reduced Vertical Separation Minima (RVSM) airspace with the use of improved altitude keeping expected with GNSS altimetry, also named the RVSM 2 concept. This report describes the functional architecture and requirements for the RVSM 2 concept at TRL 2.

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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 defines the functional requirements (FRD) for the 'Separation Minima' solution at TRL2. The goal of this document is to present the functional requirements that have been identified through the validation exercises (Collision Risk Analysis, Wake Turbulence Risk Analysis and FHA/Safety Case) that are required for the RVSM 2 concept to be successfully and safely introduced.

The RVSM 2 concept aims to reduce vertical separation minima to 500 ft in upwards-extended RVSM airspace (i.e. FL290 to FL600 inclusive), from previously 1000 ft and 2000 ft below and above FL410 respectively, with the use of geometric altimetry. Here, geometric altimetry is defined as a geometric altitude reference with altimetry based on GNSSs, provided by some yet-to-be-determined system (e.g. GPS, Galileo, multi-constellation, dual frequency, etc.) The reduction in vertical separation minima is facilitated by the increased accuracy of geometric altimetry as compared to barometric. It is assumed that all airspace users have sufficient capabilities, routes could be free or fixed, and the fleet is comparable to today. The European airspace is taken as a test case, even though the concept would likely be introduced on a global scale.

The RVSM 2 airspace is expected to provide increased capacity through the added available flight levels. In addition, efficiency is expected to be increased by allowing aircraft to fly closer to their preferred flight levels through the finer granularity and increased capacity, and by reducing the need for climate-inefficient detours to avoid capacity bottlenecks.

ATM capabilities are identified that are applicable to the RVSM 2 concept, and are in accordance with the SESAR architecture. Examples of such capabilities are Positioning / Navigation / Timing of Mobiles (airspace) independent of Ground Navaids, Mid-Air Collision Avoidance and Navigation performance monitoring.

The functional requirements are organised following the structure of the Safety Case, in three major domains: the airborne domain (i.e. aircraft), the ground domain (i.e. ANSPs) and the altitude information domain (i.e. GNSS constellation(s) and additional infrastructure).

During the Green-GEAR project, several assumptions are made, the most important of which are the following. First, SESAR solution 407 assumes the EUR RVSM airspace region as test case, that is, the safety studies performed in the WP and the resulting requirements are based on figures that are typical of the European airspace. Also, air traffic complexity and passing frequencies in the RVSM 2 airspace is comparable to the current airspace complexity. In addition, the fleet in the RVSM 2 airspace is assumed to be comparable with today's fleet. This assumption is particularly important concerning propulsion systems under development such as electric- and hydrogen-powered propulsion. Finally, all RVSM 2 airspace users use geometric altimetry and all aircraft entering the airspace are capable of doing so.

2 Introduction

2.1 Purpose of the document

This document defines the functional requirements (FRD) for Separation Minima Solution 0407 at TRL2. The goal of this document is to present the functional requirements that have been identified through the validation exercises (Collision Risk Analysis, Wake Turbulence Risk Analysis and FHA/Safety Case) that are required for the RVSM 2 concept to be successfully and safely introduced. These functional requirements serve as further input for the design process, to be included in the Final OSED, and serve as a starting point in further efforts to mature the concept.

2.2 Scope

In the Final OSED (deliverable D4.6)[21]) the concept for a reduced RVSM airspace (RVSM 2) is outlined. The scope of this document is the reduction of vertical separation minima with the use of geometric altimetry. Even though it is unavoidable that some aspects regarding geometric altimetry are included, the introduction of geometric altimetry itself would require a more elaborate and detailed description of the functional requirements of its own.

It will be assumed that all airspace user will be using a single mode of altimetry (i.e. geometric). A mixed mode between barometric and geometric altimetry will not be considered. In addition, the transition phase from current operations to RVSM 2 is considered out of scope.

Even though, if RVSM 2 were to be introduced, this would likely happen at a global scale, the 'Separation Minima' solution of the Green-Gear project focuses on the European airspace as a test case.

2.3 Intended readership

The intended readership of this report is the Green-GEAR Consortium and the SESAR 3 JU. Further groups potentially benefitting from reading this document are the key stakeholders involved in the Green-GEAR Advisory Board in particular, relevant SESAR 3 projects especially those from the Green Deal Flagship, and finally the aviation community in general.

2.4 Background

Existing and planned research on the reduction of separation minima has been analysed, including work done and foreseen for SESAR, ICAO, EASA, European Commission and EUROCONTROL. This has resulted in a newly proposed Solution for reducing vertical separation minima.

Worldwide aircraft separation standards are laid down in ICAO Doc 4444 (Procedures for Air Traffic Management) [22], ICAO Annex 2 (Rules of the Air) [23] and ICAO Annex 11 (Air Traffic Services) [24]. These standards ensure safe separation from the ground, from other aircraft and from protected airspace:

- Vertical separation is achieved by requiring aircraft to use a prescribed altimeter pressure setting within designated airspace, and to operate at different altitude or flight levels;
- Lateral separation is achieved by reference to different geographical locations (position reports) or by requiring aircraft to fly on specified tracks separated depending on type of navigation aid;
- Longitudinal separation for aircraft on the same track is applied through speed control/ instructions so that the spacing between aircraft is never less than a specified minimum when passing over a specific point in the airspace.

Wake turbulence separation standards are applied in various flight phases to ensure that following aircraft are not endangered by effects of wake vortex turbulence generated by a preceding aircraft. Aircraft are categorised according to their Maximum Take-Off Mass (MTOM) and minimum separation times or distances so that aircraft following a higher MTOM category aircraft are given a greater minimum spacing.

EUROCONTROL and NLR are responsible for pre-implementation and post implementation safety studies of RVSM in ICAO's European and Africa Indian Ocean Regions respectively. These studies analyse data on the height keeping performance of aircraft to ensure that the risk of collision between aircraft is sufficiently low and properly mitigated. Collision risk models and tools endorsed by the ICAO Separation and Airspace Safety Panel (SASP) are used by EUROCONTROL and NLR.

Reduction of wake turbulence separation standards has been studied extensively by consortium partners (EUROCONTROL, Airbus, NATS, DLR, NLR) in European Commission research for the last 20 years (e.g. S-Wake, ATC-Wake, I-Wake, FAR-Wake, C-Wake, CREDOS) and by SESAR/EUROCONTROL (Time Based Separation, RECAT-EU, WIDAO, R-Wake). Under contract to EASA, NLR has reviewed the safety cases that were brought forward to the ICAO Wake Turbulence Study Group for approval.

While many opportunities exist for further reduced separation minima, Green-GEAR will focus on Reduced Vertical Separation Minima to 500 ft (RVSM 2) in a geometric altimetry environment.

Table 1 below lists past projects on which the consortium builds the R&I work. Moreover, the experience and expertise gained in those will be used in overcoming barriers and achieving impacts listed above.

Project name	Expertise
ICAO AFI RVSM	Implementation of 1000 ft Reduced Vertical Separation Minimum (RVSM) in the Africa - India Ocean (AFI) Region, using collision risk models (NLR)
Time Based Separation (TBS)	New operation for reducing separation between aircraft by time during strong headwind conditions, instead of distance, developed by EUROCONTROL and NATS, and deployed at Heathrow.
RECAT	Wake Turbulence Recategorisation (RECAT) is a decrease in wake turbulence separation standards between certain aircraft pairs to improve airport capacity. EUROCONTROL, NATS, NLR involved.
USEPE (SESAR)	Exploring potential separation methods to ensure the safety of UAS operations in urban environments (enabled by U-Space), DLR.

Project name	Expertise
S-Wake, ATC-Wake, CREDOS	EC research projects at TRL1 to TRL4 dedicated to the safety analysis and development of concepts for reduced separation in the airport environment. NLR and EUROCONTROL coordinated the projects, with participation by DLR.

Table 1: Green-GEAR partners' expertise in relevant past international projects.

2.5 Structure of the document

This document is split into several chapters. First, Chapter 3 presents the functional architecture view. This is done by first presenting the SESAR Solution overview in section 3.1, and next the SESAR Solution functional view in section 3.2.

Next, Chapter 4 introduces the functional requirements. These are split into the three main domains, namely the airborne requirements (section 4.1), ground requirements (section 4.2), and the altitude information requirements (section 4.3).

Finally, Chapter 5 discusses the assumptions made in the project. This is split up in common assumptions for the Solution (section 5.1) and specific assumptions for functions in the Solution (section 5.2).

2.6 Glossary of terms

Term	Definition	Source of the definition
Geometric Altitude / Geo Alt	Mode of altimetry where altitude is determined relative to a fixed reference system such as WGS 84.	Project definition (WP3 / Solution 0406)
RVSM 2	The concept studied in WP4, where vertical separation minima are set to 500 ft in en-route airspace (FL290 – FL600 inclusive), where altitude is determined through geometric altimetry, and separation is managed through geometric altitudes.	Project definition
Target level of Safety	The level of risk considered to be the maximum tolerable value for a safe system.	ICAO
Wake Encounter Resistance	Ability of an aircraft, due to geometry, mass and moment of inertia on one hand and flight control capabilities on the other, to safely limit the effects of a wake encounter on aircraft accelerations, changes of attitude and flight state as well as flight path excursions.	Project Definition

Term	Definition	Source of the definition
Climate Hotspot	A volume of airspace where the atmospheric conditions are such that flying through it creates much higher climate impact than in the other areas.	Project Definition (WP5 / Solution 0408)

Table 2: glossary of terms

2.7 List of acronyms

Term	Definition
ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
AFI	Africa - India ocean
ANSP	Air Navigation Service Provider
ASE	Altimetry System Error
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
AU	Airspace Users
CRA	Collision Risk Analysis
DES	Digital European Sky
EASA	European Union Aviation Safety Agency
ICAO	International Civil Aviation Organisation
FHA	Functional Hazard Assessment
FL	Flight Level
FOC	Flight Operations Centre
FRD	Functional Requirements Document
FTE	Flight Technical Error
GA	Grant Agreement

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Term	Definition
GBAS	Ground Based Augmentation System
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
Green GEAR	Green Geometric altitude, Advanced separation and Route charging
HAO	High Altitude Operations
HE	Horizon Europe
ID	Identifier
LPV	Localiser Performance with Vertical Guidance
MET	Meteorological (Services/Information)
METSP	Meteorological Services Provider
OSED	Operational Service and Environment Description
PMUA	Procedure Multi Unable Altimetry
PS	Performance Specification
PSUA	Procedure Single Unable Altimetry
RNP AR	Required Navigation Performance Authorisation Required
RVSM	Reduced Vertical Separation Minima
SARPS	Standards and Recommended Practices
SBAS	Satellite Based Augmentation System
SESAR	Single European Sky ATM Research
SESAR 3 JU	SESAR 3 Joint Undertaking
SPS	[GPS] Standard Positioning Service
SSR	Secondary Surveillance Radar
TMA	Terminal Manoeuvring Area
TRL	Technology Readiness Level

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Term	Definition
TVE	Total Vertical Error
UAS	Unmanned Aircraft Systems
WGS 84	World Geodetic System 1984
WP	Work Package
WTRA	Wake Turbulence Risk Analysis

Table 3: list of acronyms

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3 Functional architecture view

3.1 SESAR solution overview

Green-GEAR Work Package (WP) 4 assesses the feasibility of reducing the vertical separation minima to 500 ft in upwards-extended Reduced Vertical Separation Minima (RVSM) airspace with the use of improved altitude keeping expected with Global Navigation Satellite System (GNSS) altimetry, also named the RVSM 2 concept, in the "Separation Minima" Solution. The main focus here is on the safety aspects of the concept, and the work is structured by considering the technical (nominal) risk and the operational (non-nominal) risk separately, which add up to the total, or overall risk. In short, iD4.1 Collision Risk Analysis (CRA) [25] focuses on the nominal collision risk, iD4.2 Wake Turbulence Risk Analysis (WTRA) [26] focuses on the nominal wake turbulence risk, and D4.3 RVSM 2 Safety Case performed a Functional Hazard Assessment (FHA) that considers the non-nominal risk, and in addition provides an over-arching perspective on the risk of the three parts as a whole [27]. From these three deliverables, functional requirements are deduced that have to be fulfilled to safely implement the RVSM 2 concept. These functional requirements are outlined in this Functional Requirement Document (FRD).

GNSS is nowadays used by most aircraft for horizontal positioning, at least in commercial air transport. GNSS is also used for altimetry but only occasionally in specific flight procedures, such as LPV, GBAS and RNP AR approach procedures. The Green-GEAR project researches the possibility to use GNSS for vertical navigation in aviation more broadly, as this potentially offers several benefits. In Green-GEAR WP3 for example, the feasibility of GNSS altimetry in a Terminal Manoeuvring Area (TMA) environment is studied, which would allow for the removal of the barometric transition layer. This would require the introduction of a geometric altimetry system including agreements and coordination about the definition of the altitude coordinate in a geodetic reference (that is, so to speak: a vertical coordinate geometrically attached to the Earth, such as in WGS 84, as used by GPS).

If aircraft use GNSS for vertical navigation and if such a geometric altimetry system is introduced, it might be feasible to reduce the currently applied vertical separation minima. A reduction of the vertical separation minima would increase capacity and would allow aircraft to fly closer to their preferred altitude, thereby possibly offering efficiency, cost and environmental benefits. The possibility to operate with reduced vertical separation minima is the main topic of Green-GEAR WP4. There are basically two reasons why this might indeed be feasible. The main reason is that GNSS altimetry is supposed to be more accurate than barometric altimetry, and the related margins in spacing might therefore be reduced. The second reason is that the accuracy of GNSS altimetry is not dependent on altitude to the same degree as barometric altimetry. The currently applied vertical separation minima of 2000 ft above FL410 could then be reduced, even if GNSS altimetry is only as accurate as barometric altimetry on lower altitudes.

The RVSM 2 concept thus focuses on an upwards-extended RVSM airspace, from FL290 to FL600 (inclusive). Altitude estimates of the airspace users are to be provided through one or multiple GNSSs and aircraft are separated through a geodetic reference. The vertical separation minimum will be reduced to 500 ft from 1000 ft and 2000 ft minimal separation below and above FL410 respectively. All airspace users are assumed to be only navigating on geometric altimetry. Considering the European focus of this project, the European RVSM airspace will serve as a test case. The concept is further described in the initial Operational Service and Environment Definition (OSED) [29] and is further updated in the final OSED [21].

3.1.1 Supporting reasons for this SESAR solution

The higher accuracy of geometric altimetry and the fact that the accuracy does not degrade appreciably with increasing altitude might allow for the Separation Minima to be reduced to 500 ft between FL290 and FL600. This significantly increases the airspace capacity, as more aircraft can fly in a certain block of airspace, by doubling the number of available flight levels. Furthermore, with more flight levels available, aircraft will be able to fly closer to their optimal cruise altitude, and the increased capacity will allow more aircraft to fly closer to their preferred altitude, thereby saving fuel and cutting back emissions.

3.1.2 ATM capabilities addressed by the SESAR solution

This section shows in Table 4 the ATM capabilities from the SESAR architecture baseline [35] addressed by the SESAR solution, and describes the associated updates.

SESAR solution capabilities	Comments on potential updates required at capability level
Optimised cruise execution	The ability to fly optimised cruise profiles will be enabled by the reduced separation minima.
Positioning / Navigation / Timing of Mobiles (airspace) independent of Ground Navaids	The ability to determine the position, velocity, and time of aircraft from one or more satellite constellations (augmented as necessary and/or fused with other sources) with the required navigation performance.
Positioning / Navigation / Timing of Mobiles in Reversionary Mode	The ability to determine the position, velocity, and time 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	The ability to convert barometric to geodesic heights and vice-versa
Mid-Air Collision Avoidance	The last resort collision avoidance between mobile airborne vehicles that will have to be updated in order to be compatible with 500 ft separation.

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SESAR solution capabilities	Comments on potential updates required at capability level
Separation service provision (airspace)	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).
Wake encounter detection and forecasting	The ability to detect/predict wake turbulence encounters (incl. severity, likelihood).
Wake turbulence separation provision	The ability to provide separation between aircraft pairs which takes into account wake turbulence strength (anticipated, measured).
Traffic information provision in support of operations	The ability to provide traffic information for user situational awareness coming from any kind of monitoring.
Navigation performance monitoring	The ability to monitor the performance of the navigation service and act accordingly. The navigation performance will likely have to be monitored on both aircraft, ANSP and GNSS provider levels, such that in case of insufficient performance contingency procedures can be instigated.
Enhanced ACAS	Mid-air collision avoidance by given alerts if nearby aircraft are not properly separated.

Table 4: SESAR solution 0407 capabilities

3.1.3 Stakeholders impacted by the SESAR solution

Table 5 shows the stakeholders that are impacted by a reduction of the vertical separation minima to 500 ft. Furthermore, it is outlined why this impacts the stakeholders.

Stakeholder	Why it matters to the stakeholder
Research organisations	Understanding of the safety effects of transitioning to GNSS altimetry and 500 ft minimal vertical separation in the en-route part of the flight.

Stakeholder	Why it matters to the stakeholder
Airspace Users	Generally: understanding of the potential of the Solution for more cost efficient and environmentally friendly operations. Understanding the practical implications of using geometric altimetry. Specifically emerging users, such as unconventional configurations / drones / HAOs: understanding of the potential of easier access to upper airspace.
Air Navigation Service Providers	Understanding of the safety effects of the Solution and its potential for a capacity increase in RVSM 2 airspace. Understanding of the needs for navigation performance monitoring, understanding the need for new ATM procedures.
Aircraft manufacturers	Understanding of the implications on aircraft systems architecture (such as ACAS) and assessment of the need to develop aircraft capabilities to enable the concept for potential benefits to their airline customers.
Pilot organisations	Understanding new procedures and airspace rules.
Regulators	Assessment of the impact of a possible implementation of the Solution on regulatory documents; acceptability and feasibility on international level.
Standardisation bodies	Analysis of the potential of Solution and identification of the need for amendment or development of standards.

Table 5: SESAR solution 0407 stakeholders

3.2 SESAR solution functional view

3.2.1 Interaction(s) identification

This section discusses the interactions between capability configurations and technical systems in the RVSM 2 environment. The interactions are taking place between the ground, altitude information and airborne domain. An overview of these interactions is given in Figure 1.

From the figure it can be seen that satellite-based navigation structure (i.e. GNSS signals provided by e.g. GPS and Galileo) is responsible for providing GNSS signals for altitude determination. These signals, and when necessary a lack of altimetry integrity message, are sent to civil aircraft in the RVSM 2 airspace. Furthermore, GNSS signals are provided to ACC so that the GNSS performance can continuously be monitored.

Civil aircraft in their turn provide geometric and barometric altitudes to the surveillance infrastructure en-route. This tracks aircraft in the RVSM 2 airspace and provides information to ACC so that ACC can separate aircraft appropriately. The ATM-MET provides weather forecasting to both aircraft and ACC.

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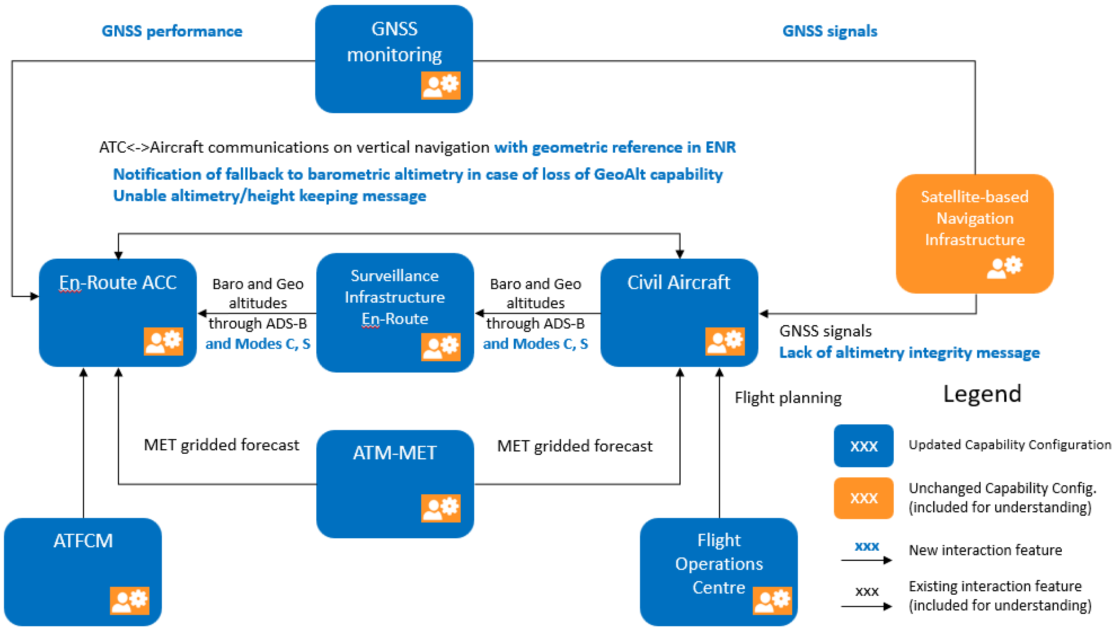

Figure 1: Schematic overview of interactions in solution 0407.

3.2.2 Functional decomposition

The functions discussed in section 3.2.1 can be decomposed into subfunctions, which is shown in Figure 2.

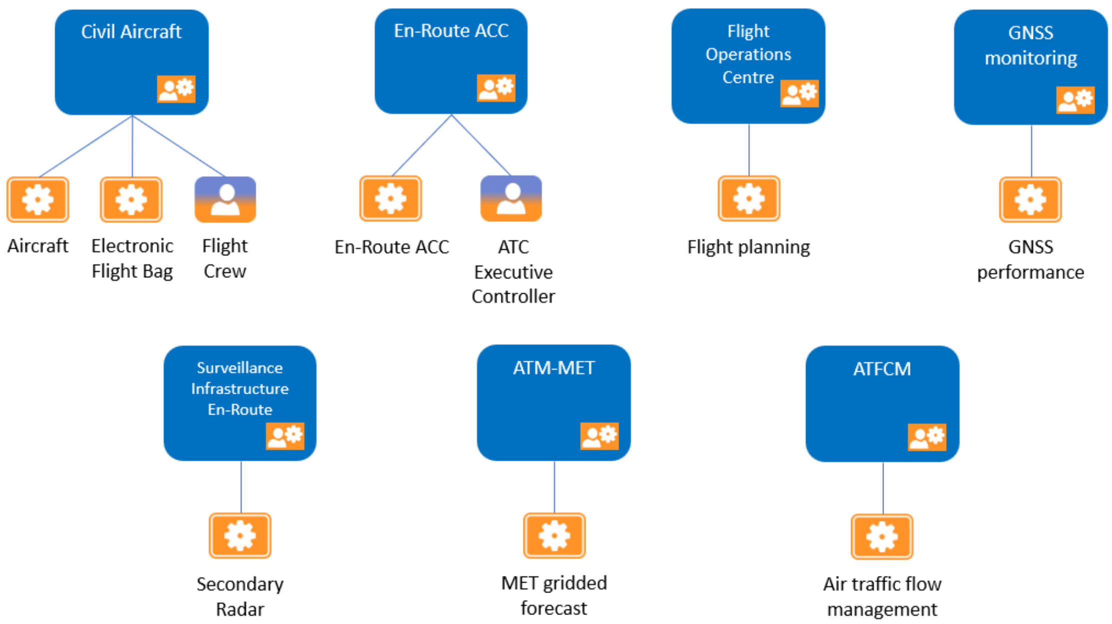

Figure 2: Schematic overview of the functional decomposition of solution 0407.

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

This section presents the impact of the Green-GEAR solution on technical systems. The technical systems are defined by EUROCONTROL [32]. An overview of the relevant systems is given in Table 6.

Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
Civil Aircraft		On-board systems such as ACAS and GNSS receivers require an evaluation and should be updated to the requirements of an RVSM 2 airspace. Aircraft will have to 'fly according to' geometric altitudes and aircraft systems will have to support this.
	Flight crew	New flight rules and (contingency) procedures will be implemented and should be known by the flight crew.
Air Traffic Flow and Capacity Management (ATFCM)		SESAR definition: "Supports the regional, sub-regional and local Air Traffic Flow and Capacity Management functions." [32] In the RVSM 2 setting, the airspace changes and more available FLs are present. To accommodate for this, the respective information in the ATFCM systems will likely have to be updated.
Civil Airspace Users (AU) Flight Operations Centre (FOC)	Flight Operations	SESAR definition: "Supports Airspace Users performing manned or unmanned flight operations of civil aircraft (as defined by ICAO). The FOC Technical System represents the 'Flight Operations' domain as part of the whole operations of the Airspace User. The domain 'Flight Operations' covers all activities that deal with the flights operated by the Airspace Users. These activities refer to the medium- and short-term

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Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
		planning and the execution phases of the flights.” [32] Implementing RVSM 2 will change the airspace layout and thus impact flight planning. Furthermore, the flight execution can differ when using geometric altimetry, due to new (contingency) procedures. More precise optimisation of vertical profiles will be possible.
En-Route / Approach ATC		SESAR definition: “Gathers the ground based automated means, used in En-Route and Approach ATC Centres, to support the air traffic controllers in the provision of the following main Air Traffic Services: · Update and distribution of flight plan data, potentially correlated with track data built from surveillance sources (mode 3/A code or 24 bit ICAO address - Aircraft Identification (Mode S or ADS-B), when available) · Distribution of warnings and alerts upon detection of danger areas / separation criteria infringement, or on non-conformance between aircraft behaviour and corresponding flight plan data, · Medium-term and tactical conflicts detection, conflicts resolution assistance and local traffic complexity assessment · Sequencing of arrival aircraft on aerodromes or groups of aerodromes, · Ground-ground and air-ground exchanges of flight and environment data” [32] Separation criteria infringement will be different in an RVSM 2 setting and will have to be adjusted accordingly.
GNSS monitoring		SESAR definition: “A system to collect, process and assess data of operational core constellations to assess

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Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
		performances with respect to ICAO SARPS and referenced material (e.g. GPS SPS PS)." [32] The performance criteria of GNSS when flying with geometric altimetry will be stricter and have to be monitored continuously. In addition, jamming and spoofing will have to be monitored for.
Secondary radar		SESAR definition: "SSR is used for En-Route and Approach surveillance. It provides the position (range and bearing) of the Aircraft as well as its identity (Mode A code) and altitude (Mode C code). The SSR transmits signals on 1030 MHz and receives signals from the transponder on 1090 MHz. Mode S SSR (Select) has been replacing the classic Mode A/C interrogation/reply scheme by identifying each Aircraft using a unique 24 bit address. This mode allows downloading additional airborne data from the Aircraft for elementary and enhanced surveillance." [32]
MET gridded forecast		SESAR definition: "This service will be provided by the METSP (MET Service Provider). The METSP is an organisation designated to provide MET services supporting international air navigation. - This service will enable the local OUE stakeholders to be provided with all nominal MET information for an airport and its approach areas they require. It contains two main sub-parts being the information on surface elements (like e.g. wind, temperature, QNH) as well the aloft elements (e.g. wind and temperature). The required elements should be selectable by the stakeholder.

Technical systems impacted by the SESAR solution	Functions / roles impacted by the SESAR solution	Comments on required updates
		- This service will enable the sub-regional OUE stakeholders to be provided with selectable MET aloft elements (temperature, wind). - This service will enable the network OUE stakeholders to be provided with selectable MET aloft elements (temperature, wind). A special feature of the network service could be the possible selection of ensemble MET information, next to the deterministic information. This service could possibly be split up between observation and forecast MET information." [32] In the RVSM 2 setting, there is a need for MET gridded forecast including pressure values at geometric altitudes along the flight.

Table 6: Systems impacted by SESAR solution 0407

4 Functional requirements

This chapter presents the functional requirements that have to be fulfilled in the RVSM 2 airspace. The requirements are divided into requirements concerning the airborne, ground and altitude information domains. The requirements are partially from the CRA [25], WTRA [26] and Safety Case [27].

4.1 Airborne Domain Functional Requirements

Identifier	**REQ-ARB-01**
Title	Estimated geometric altitude
Requirement	The aircraft shall receive the altitude information and provide estimates of the altitude of each individual aircraft in a continuous way.
Status	<in progress>
Rationale	The RVSM 2 concept aims to provide separation based on geometric altimetry, thereby necessitating GNSS altitude estimates.
Category	<Functional>

Identifier	**REQ-ARB-02**
Title	Assigned altitude reception
Requirement	The airborne domain shall receive assigned altitudes from the ground domain according to **REQ-GRD-01** and make each individual aircraft fly according to the assigned altitude.
Status	<in progress>
Rationale	To avoid aircraft from flying at non-desired altitudes.
Category	<Functional>

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Identifier	**REQ-ARB-03**
Title	Lack of altimetry integrity reception
Requirement	Aircraft flying in or close to the RVSM 2 airspace shall receive a 'lack of altimetry integrity' message from the altitude information domain, according to **REQ-AI-03**.
Status	<in progress>
Rationale	To create awareness of the lack of integrity so that pilots are ready to react if necessary.
Category	<Functional>

Identifier	**REQ-ARB-04**
Title	Monitoring performance parameters
Requirement	The aircraft shall monitor the availability, accuracy and integrity of the altitude estimate of each individual aircraft in the RVSM 2 airspace.
Status	<in progress>
Rationale	To keep track of the reliability of the altitude estimate.
Category	<Functional>

Identifier	**REQ-ARB-05**
Title	Own altitude signal
Requirement	The airborne domain shall transmit 'own geometric altitude' signals for each individual aircraft in a continuous way.
Status	<in progress>
Rationale	To be transparent about the altitude each individual aircraft is flying at.
Category	<Functional>

Identifier	**REQ-ARB-06**
Title	Unable altimetry message
Requirement	The airborne domain shall transmit an 'unable altimetry' message if a lack of availability, accuracy or integrity of the altitude estimate of an aircraft is detected.
Status	<in progress>
Rationale	To alert aircraft flying in the vicinity of the aircraft that transmits the signal.
Category	<Functional>

Identifier	**REQ-ARB-07**
Title	Unable height keeping message
Requirement	The airborne domain shall transmit an 'unable height keeping' message, if an aircraft is not able to maintain the assigned altitude for other reasons than lack of availability, accuracy or integrity of the altitude estimate.
Status	<in progress>
Rationale	To alert aircraft flying in the vicinity of the aircraft that transmits the signal.
Category	<Functional>

Identifier	**REQ-ARB-08**
Title	Execution of the PSUA
Requirement	The airborne domain shall be able to execute a Procedure Single Unable Altimetry (PSUA) when a geometric altitude estimate with sufficient accuracy is not available for an individual airspace user such that separation is maintained.
Status	<in progress>
Rationale	When a single aircraft in the RVSM 2 airspace cannot meet the required accuracy, a contingency procedure has to be executed. This will be initiated by the ground domain.
Category	<Functional>

Identifier	**REQ-ARB-9**
Title	Execution of the PMUA
Requirement	The airborne domain shall be able to execute a Procedure Multiple Unable Altimetry (PMUA) when a geometric altitude estimate with sufficient accuracy is not available in a large part of the airspace such that separation is maintained.
Status	<in progress>
Rationale	When multiple aircraft in the RVSM 2 airspace cannot meet the required accuracy, a contingency procedure has to be executed. This will be initiated by the ground domain according to **REQ-GRD-11**.
Category	<Functional>

Identifier	**REQ-ARB-10**
Title	Vertical navigation performance
Requirement	Aircraft are certified such that the 1σ Total Vertical Error (TVE) shall not exceed 34 ft if Laplace, or 58 ft if Normal distributed.
Status	<in progress>
Rationale	If the TVE were to be higher the collision risk would exceed the TLS for the technical risk.
Category	<Functional>

Identifier	**REQ-ARB-11**
Title	Dual Frequency receivers
Requirement	Aircraft in RVSM 2 airspace shall use Dual Frequency (DF) receivers.
Status	<in progress>
Rationale	To minimise disturbances of unintended interference. Furthermore, a higher accuracy and integrity is achieved with DF receivers.
Category	<Functional>

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Identifier	**REQ-ARB-12**
Title	PSUA initiative
Requirement	The aircrew that received a lack of altitude information message conforming to **REQ-AI-03** shall *not* initiate a PSUA.
Status	<in progress>
Rationale	ATC is in control of initiating contingency procedures. The aircrew is kept informed with the lack of altitude information messages to be able to act immediately when necessary.
Category	<Functional>

4.2 Ground Domain Functional Requirements

Identifier	**REQ-GRD-01**
Title	Assign altitude
Requirement	The ground domain shall assign an altitude to each individual aircraft such that it is vertically separated if not horizontally separated.
Status	<in progress>
Rationale	To insure vertical separation between all aircraft.
Category	<Functional>

Identifier	**REQ-GRD-02**
Title	Lack of altimetry integrity reception
Requirement	The ATC units providing service in or close to the RVSM 2 airspace shall receive 'lack of altimetry integrity' messages from the altitude information domain operating in the vicinity, according to **REQ-AI-03**.
Status	<in progress>
Rationale	To be aware of the lack of integrity and be ready to react for example by initialising a contingency procedure.
Category	<Functional>

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Identifier	**REQ-GRD-03**
Title	Own altitude signal reception
Requirement	The ATC units providing service in or close to the RVSM 2 airspace shall receive the ‘own geometric altitude’ signals, transmitted by aircraft according to **REQ-ARB-05**.
Status	<in progress>
Rationale	To monitor whether the own altitude corresponds with the assigned altitude of each individual aircraft.
Category	<Functional>

Identifier	**REQ-GRD-04**
Title	Unable altimetry message reception
Requirement	The ATC units providing service in or close to the RVSM 2 airspace shall receive the ‘unable altimetry’ messages, transmitted by aircraft according to **REQ-ARB-06**.
Status	<in progress>
Rationale	To monitor whether the ground domain should intervene and separate aircraft at least 1000 ft vertically.
Category	<Functional>

Identifier	**REQ-GRD-05**
Title	Unable height keeping message reception
Requirement	The ATC units providing service in or close to the RVSM 2 airspace shall receive the ‘unable height keeping’ messages, transmitted by aircraft according to **REQ-ARB-07**.
Status	<in progress>
Rationale	To monitor whether the ground domain should intervene and separate aircraft at least 1000 ft vertically.
Category	<Functional>

Identifier	**REQ-GRD-06**
Title	Altitude information inadequacy detection
Requirement	The ground domain shall detect inadequacy of the altitude information in (part of) the RVSM 2 airspace.
Status	<in progress>
Rationale	Doing integrity checks will make sure that the ground domain is always aware of the ability of 500 ft vertical separation.
Category	<Functional>

Identifier	**REQ-GRD-07**
Title	Contingency spacing
Requirement	The ground domain shall separate aircraft in the RVSM 2 airspace by 1000 ft from aircraft that cannot meet the accuracy requirements for 500ft separation.
Status	<in progress>
Rationale	If the accuracy requirements for 500 ft separation are not met, larger spacing should prevent safety from being compromised.
Category	<Functional>

Identifier	**REQ-GRD-08**
Title	Inadequacy detection jamming and spoofing
Requirement	The ground domain shall detect inadequacy of the altitude information domain due to jamming and spoofing
Status	<in progress>
Rationale	In order to assure safe operations in the RVSM 2 airspace, any inadequacy in altitude information, such as jamming and spoofing of the GNSS signals, should be detected.
Category	<Functional>

Identifier	**REQ-GRD-09**
Title	Aircraft altitude deviation
Requirement	The ground domain shall detect when several aircraft deviate from their assigned altitude in a part of the airspace.
Status	<in progress>
Rationale	To be able to initiate the PSUA, the ground domain should be up to date about any aircraft deviating from the assigned altitude.
Category	<Functional>

Identifier	**REQ-GRD-10**
Title	Send out possible PMUA
Requirement	The ground domain shall inform all aircraft in the airspace about a possible PMUA when it detects that there is a possibility that the altitude information in a part of the airspace is inadequate.
Status	<in progress>
Rationale	Making the airborne domain aware of a possible PMUA improves efficiency and thus safety in the RVSM 2 airspace.
Category	<Functional>

Identifier	**REQ-GRD-11**
Title	Initiate PMUA
Requirement	The ground domain shall initiate a PMUA if an ATC unit has confirmation that altitude information in part of the airspace is inadequate.
Status	<in progress>
Rationale	If the altitude information is inadequate, it is no longer safe to fly using GNSS signals only and a PMUA should be initialised.
Category	<Functional>

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4.3 Altitude Information Domain Functional Requirements

Identifier	**REQ-AI-01**
Title	Altitude information provision
Requirement	The altitude information domain shall provide altitude information in the entire airspace in a continuous way.
Status	<in progress>
Rationale	So that the airborne domain can estimate the altitude.
Category	<Functional>

Identifier	**REQ-AI-02**
Title	Satellite Navigation System
Requirement	A Global Satellite Navigation System (GNSS) is available that offers signals of sufficient quality such that geometric altimetry can be estimated.
Status	<in progress>
Rationale	GNSS is the intended candidate for determining geometric altitude in the RVSM 2 concept.
Category	<Functional>

Identifier	**REQ-AI-03**
Title	Lack of altimetry integrity message
Requirement	The altitude information domain shall provide a 'lack of altimetry integrity' message in the RVSM 2 airspace, when the integrity requirements are not met.
Status	<in progress>
Rationale	In case of uncertainty about the accuracy, the lack of altimetry message warns the users of the altitude information signal.
Category	<Functional>

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4.4 Other requirements

Identifier	**REQ-OTH-01**
Title	Frequency of lack of altitude information
Requirement	The frequency of occurrence of altitude information being inadequate in a significant part of the airspace shall be less than once in ten years.
Status	<in progress>
Rationale	Inadequacy of altitude information leads to the initiation of contingency procedures, which is highly disruptive for operations and thus not desired to occur often. A significant part of the airspace in this context could be considered as the case that the lack of altitude information poses a serious disruption of air traffic, multiple, if not all aircraft in an airspace are affected and the duration of the disruption is such that contingency procedures need to be activated. Sector-wide disruptions or larger would fit these criteria.
Category	<Functional>

Identifier	**REQ-OTH-02**
Title	Rate of failure GNSS altimetry
Requirement	GNSS altimetry systems shall have a similar maximally allowed rate of failure as current barometric altimetry systems.
Status	<in progress>
Rationale	To not reduce safety in the RVSM 2 airspace with respect to current operations.
Category	<Functional> <Safety>

Identifier	**REQ-OTH-03**
Title	Wrong assigned altitude
Requirement	The maximally allowed occurrence rate of an aircraft not having an altitude assigned to it such that separation is maintained shall be the same as in current operations.
Status	<in progress>
Rationale	To keep the same level of safety with current operations.
Category	<Functional> <Safety>

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Identifier	**REQ-OTH-04**
Title	Flying at 'wrong' altitude
Requirement	In RVSM 2 an aircraft not flying to its assigned altitude shall have a similar maximally allowed rate as in current RVSM operations.
Status	<in progress>
Rationale	To not reduce safety in the RVSM 2 airspace with respect to current operations.
Category	<Functional> <Safety>

Identifier	**REQ-OTH-05**
Title	ACAS-based avoidance barrier
Requirement	The combined visual- and ACAS-based avoidance barrier is to have an effectiveness of at least 93%.
Status	<in progress>
Rationale	Without the ACAS barrier, meeting the TLS is not possible. With RVSM 2, the time to solve conflicts is reduced, leading to lower effectiveness.
Category	<Functional>

Identifier	**REQ-OTH-06**
Title	ACAS redesign
Requirement	ACAS shall be redesigned such that no alerts or resolution advisories are given with 500 ft separation.
Status	<in progress>
Rationale	Current ACAS would give alerts and even resolution advisories at 500 ft, which is not desired in RVSM 2.
Category	<Functional>

Identifier	**REQ-OTH-07**
Title	Controlled airspace
Requirement	Controlled airspace-based operations are required in order to provide the ATC collision prevention barrier.
Status	<in progress>
Rationale	Since 93% allowed effectiveness of the ACAS barrier is based on the availability of ATC collision prevention.
Category	<Functional>

Identifier	**REQ-OTH-08**
Title	Wake vortex encounter avoidance
Requirement	A predictive capability shall be available at the airborne domain, and/or the ground domain and communicated to the airborne domain where necessary, to detect the possibility of a severe wake vortex encounter and initiate a safe and timely avoidance manoeuvre.
Status	<in progress>
Rationale	The wake turbulence risk analysis shows an increase in the wake turbulence encounter risk against the status quo.
Category	<Functional>

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5 Assumptions

This chapter lists the assumptions that are applicable to the 'Separation Minima' Solution, and that have an impact on the functional requirements that were defined in Chapter 4.

5.1 Common assumptions for SESAR Solution 0407

This section covers assumptions that are common to the different functions across the Solution.

5.1.1 Operational

- SESAR Solution 0407 assumes the EUR RVSM airspace region as testing ground.
- Air traffic complexity and passing frequencies in the RVSM 2 airspace are comparable to the current RVSM airspace.
- The fleet in the RVSM 2 airspace is assumed to be comparable with today's fleet. This assumption is particularly important concerning propulsion systems under development such as electric- and hydrogen-powered propulsion.
- All RVSM 2 airspace users use geometric altimetry and all aircraft entering the airspace are capable of doing so.
- Altitudes are defined geometrically, with reference to the WGS 84, and there is no mix with pressure altitudes.
- A transition time between current operations and a fully functioning RVSM 2 operation, relying on geometric altimetry is not considered in SESAR Solution 0407.
- Altitude keeping accuracy (Flight Technical Error, FTE) is influenced by the characteristics of the altitude source and the performance of the flight control system, but not by the propulsion concept.
- It is assumed that SSR to enable conformance monitoring and real-time ground-airborne communications (via R/T or CPDLC) to solve conflicts by the ATCOs remain available.
- Separation modes are initially assumed to be unchanged, meaning that as per Doc 4444 [21] the separation requirement is fulfilled if either vertical or horizontal separation is ensured.
- Any non-conventional future aircraft configurations are assumed to have at least the same attitude control power as existing conventional ones, meaning it is a conservative assumption to apply the same weight-dependent resistance to wake encounters.
- Contingency procedures are developed in case a single aircraft is not able to determine its altitude (PSUA) and in case multiple aircraft are not able to determine their altitude (PMUA).

- A suitable tool, airborne or ground-based, is available to detect the danger of an impending severe wake vortex encounter and advise the concerned aircraft of corrective / avoidance action.

5.2 Specific assumptions for functions

This section covers assumptions that are particular to a given domain and functions.

5.2.1 Airborne

- It is assumed that ACAS is capable of functioning with 500 ft vertical separation minima. It is clear that the system needs to be modified to be able to do so.
- Aircraft are appropriately equipped to be able to continuously receive GNSS signals of a given accuracy.
- Aircraft in a certain airspace block use the same mode of GNSS altimetry.

5.2.2 Ground

No assumptions specifically related to the ground domain have been identified.

5.2.3 Altitude information

- The GNSS that will be used in the RVSM 2 airspace is able to provide continuous signals.

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 Solution Cost Benefit Analysis (CBA) Quick Start Guide (1_0).docx

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

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

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).xls

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 00.03.01, November 2022.

Environment assessment

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

Security

Project and 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.

6.2 Reference documents

[21] Jonk, P.; Boshuizen, I.; Koloschin, A.; Klein Obbink, B.; Smeltink, J., Bauer, T.: "SESAR 3 ER 1 Green-GEAR – D4.6 – Final OSED – Separation Minima". Version 02.00, submitted 30th April 2025.

[22] ICAO: Doc 4444, Procedures for Air Navigation Services (PANS) – Air Traffic Management. 16th Edition, 2016.

[23] ICAO: Annex 2 to the Convention on International Civil Aviation. Rules of the Air. 12th Edition, 2005.

[24] ICAO: Annex 11 of the Convention on International Civil Aviation, 2011.

[25] Jonk, P.; Klein Obbink, B.; Smeltink, J.W. and Boshuizen, I.T.: "Green-GEAR – iD 4.1 – Separation Minima – Collision Risk Analysis". Project internal report, v1.0, 31st January 2025.

[26] Bauer, T. and Koloschin, A.: "Green-GEAR – iD 4.2 – Separation Minima – Wake Turbulence Risk Analysis". Project internal report, v1.0, 31st January 2025.

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[27] Jonk, P.; Klein Obbink, B.; Smeltink, J. and Boshuizen, I.: “SESAR 3 ER 1 Green-GEAR – D4.3 – RVSM 2 Safety Case”. Version 01.00, 28th February 2025.

[28] Bauer, T.; Koloschin, A.; Jonk, P.; Boshuizen, I.; Smeltink, J. and Klein Obbink, B: “SESAR 3 ER 1 Green-GEAR – D4.2 – ERP – Separation Minima v1“. Version 01.00, 31st July 2024.

[29] Jonk, P.; Boshuizen, I.; Koloschin, A.; Klein Obbink, B.; Smeltink, J.: “SESAR 3 ER 1 Green-GEAR – D4.1 – Initial OSED – Separation Minima”. Version 01.00, 28th June 2024.

[30] Bauer, T.; Koloschin, A.; Jonk, P.; Boshuizen, I.; Klein Obbink, B; Smeltink, J.: “SESAR 3 ER 1 Green-GEAR – D4.4 – ERR – Separation Minima“. Version 01.00, 30th May 2025.

[31] Bauer, T.; Jonk, P., Boshuizen, I. and Castelli, L.: “SESAR 3 ER 1 Green-GEAR – D4.7 – ECO-EVAL – Separation Minima. Version 01.00, 28th May 2025.

[32] EUROCONTROL, technical systems, 2025. https://atmmasterplan.eu/data/systems.xls, retrieved on 27 March 2025.

[33] ICAO European and North Atlantic Office, Guidance material on the implementation of a 300 m (1000 ft) vertical separation minimum in the European RVSM airspace, 2001.

[34] Smeltink, J. and Moek, G.: Pre-Implementation Collision Risk Assessment for RVSM in the Africa Indian Ocean Region, 2005.

[35] SESAR: Solution - Capabilities - 05-12-2024.xlsx, 2024.

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