# SESAR 3 ER 1 Green-GEAR – D4.6 – Final OSED – Separation Minima


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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 is the updated Operational Service and Environment Description (OSED) that describes the RVSM 2 concept at TRL2.

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## Copyright statement



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# Green-GEAR

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

Green-GEAR

This document is part of a project that has received funding from the SESAR 3 Joint Undertaking under grant agreement No 101114789 under European Union's Horizon Europe research and innovation programme. UK participants in Green-GEAR have received funding from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee [grant numbers 10087714 (NATS) and 10091330 (University of Westminster)].

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# 1 Executive summary

This document describes the Final Operational Service and Environment Description (OSED) of the Green-GEAR 'Separation Minima' solution 0407 at Technology Readiness Level (TRL) 2. This OSED serves as an update of the initial OSED (D4.1) and focusses on the concept of further reduced separation minima in the (upwards-extended) Reduced Vertical Separation Minima (RVSM) airspace in the European (EUR) Regional Monitoring Agency (RMA) region.

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 reference, 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. The Key Performance Indicators (KPIs) this solution is aimed to improve are the capacity, efficiency and a reduction in harmful emissions. The stakeholders that are affected by the work in this document are research organisations, airspace users, Air Navigation Service Providers (ANSPs), aircraft manufacturers, pilot organisations, regulators and standardisation bodies.

During the Green-GEAR project, several assumptions are made. Some important assumptions are that air traffic complexity and passing frequencies in the RVSM 2 airspace are comparable to the current airspace complexity and the relevant characteristics of the fleet in the RVSM 2 airspace are assumed to be comparable with today's fleet (even though new entrants may be present, such as electric- and hydrogen-powered propulsion aircraft). This assumption is particularly important concerning propulsion systems under development such as electric- and hydrogen-powered propulsion, and that all RVSM 2 airspace users use geometric altimetry and all aircraft entering the airspace are capable of doing so.

Some important issues identified in the work (Collision Risk Assessment (CRA), Wake Turbulence Risk Assessment (WTRA) and Safety Case) are that more accurate characterisations of the relevant parameters is necessary to be conclusive, even though the current height keeping system performance seems to be just sufficient to meet the Target Level of Safety (TLS) for the collision risk. In addition, matters regarding GNSS liability and responsibility may pose a barrier to the introduction of the concept and will have to be clarified further. In addition, current ACAS systems are incompatible with a 500 ft vertical separation scenario. ACAS will have to be updated to prevent (nuisance) warnings at separations that are allowed under the RVSM 2 concept, and the updated ACAS systems will still need sufficient efficacy to prevent accidents from occurring. Furthermore, the WTRA shows that a significant increase of wake encounter risk is expected under the new separation, if nothing else is changed. Here either a predictive function / warning system would need to be further developed, or the applicability of 500 ft separation could be made dependent on aircraft pairing and/or the weather situation.

# 2 Introduction

## 2.1 Purpose of the document

This document defines the Operational Service and Environment Description (OSED) for Separation Minima 0407 at TRL2. The goal of this document is to specify the characteristics of the operational environment in which a vertical separation of 500 ft could be introduced as enabled by geometric altimetry. Green-GEAR Work Package (WP) 4 serves both as a feasibility study as well as a reference for later research. The technical background that is important to geometric altimetry-based operations will be discussed.

This final OSED is an update of the initial OSED (D4.1 [21]) and describes the operations and operational challenges in an RVSM 2 airspace, building on the results of the research conducted in the collision risk assessment (iD4.1 [22]), the wake turbulence risk analysis (iD4.2 [24]) and the safety case, including a Functional Hazard Assessment (FHA) (D4.3 [25]).

## 2.2 Scope

The final OSED serves as an update of the initial OSED (D4.1 [21]) and focusses on the concept of further reduced separation minima in en-route airspace in the EUR RMA region. 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 warrant a more elaborate OSED of its own.

It will be assumed that all airspace users will be using a single mode of altimetry (i.e. geometric). A mixed mode in nominal operations 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 might happen at a global scale, the 'Separation Minima' solution of the Green-Gear project focuses on the European airspace as a reference.

## 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 during various phases of flight.

Worldwide aircraft separation standards are laid down in ICAO Doc 4444 (Procedures for Air Traffic Management) [26], ICAO Annex 2 (Rules of the Air) [27] and ICAO Annex 11 (Air Traffic Services) [28]. 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 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 focussed on Reduced Vertical Separation Minima to 500 ft (RVSM 2) in a geometric altimetry environment.

Table 1 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. |
| **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: Past projects relevant to Green-GEAR Work Package 4.**

## 2.5 Structure of the document

The remainder of this chapter will explain the terms and acronyms used in the rest of the document. After that, a summary of the concept is given in chapter 3, and subsequently a detailed description of the operational environment. Here factors such as the airspace, route structure aircraft and traffic characteristics are discussed. After that, roles and responsibilities are discussed, as well as the CNS/ATS description, standards and regulations, and more. The use case is described from the SESAR perspective, and finally in chapter 4 the key assumptions are listed.

## 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 |

| Term | Definition | Source of the 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 |
| **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 |
|---|---|
| **AAD** | Assigned Altitude Deviation |
| **ACAS** | Airborne Collision Avoidance System |
| **ADS-B** | Automatic Dependent Surveillance in Broadcast Mode |
| **ANS** | Air Navigation Services |
| **ANSP** | Air Navigation Service Provider |
| **ASE** | Altimetry System Error |
| **ATC** | Air Traffic Control |
| **ATCO** | Air Traffic Controller / ATC Officer |
| **ATM** | Air Traffic Management |
| **ATS** | Air Traffic Service |
| **AU** | Airspace User |
| **CNS** | Communication, Navigation and Surveillance |
| **CPDLC** | Controller Pilot Data Link Communications |
| **CRA** | Collision Risk Analysis |



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| Term | Definition |
|---|---|
| **DES** | Digital European Sky |
| **DF** | Dual Frequency |
| **EASA** | European Union Aviation Safety Agency |
| **EC** | European Commission |
| **EGNOS** | European Geostationary Navigation Overlay Service |
| **EUR** | European |
| **FHA** | Functional Hazard Assessment |
| **FIR** | Flight Information Region |
| **FL** | Flight Level |
| **FLOS** | Flight Level Orientation Scheme |
| **FRD** | Functional Requirement Document |
| **FTE** | Flight Technical Error |
| **GBAS** | Ground Based Augmentation System |
| **GEO** | Geostationary Earth Orbit |
| **GeoAlt** | Vertical Guidance using Geometric Altimetry |
| **GNSS** | Global Navigation Satellite System |
| **GPS** | Global Positioning System |
| **Green-GEAR** | Green operations with Geometric altitude, Advanced separation & Route charging Solutions |
| **HAO** | High Altitude Operations |
| **HE** | Horizon Europe |
| **ICAO** | International Civil Aviation Organisation |
| **IFR** | Instrument Flight Rules |
| **KPI** | Key Performance Indicator |
| **LPV** | Localiser Performance with Vertical guidance |



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| Term | Definition |
| --- | --- |
| **MTOM** | Maximum Take-Off Mass |
| **OSED** | Operational Service and Environment Description |
| **PMUA** | Procedure Multi Unable Altimetry |
| **PSUA** | Procedure Single Unable Altimetry |
| **RMA** | Regional Monitoring Agency |
| **RVSM** | Reduced Vertical Separation Minima |
| **SBAS** | Space Based Augmentation System |
| **SERA** | Standardised European Rules of Air |
| **SESAR** | Single European Sky ATM Research |
| **SF** | Single Frequency |
| **SM** | Separation Minima |
| **SSR** | Secondary Surveillance Radar |
| **TBS** | Time Based Separation |
| **TCAS** | Traffic alert and Collision Avoidance System |
| **TLS** | Target Level of Safety |
| **TMA** | Terminal Manoeuvring Area |
| **TRL** | Technology Readiness Level |
| **UAS** | Unmanned Aircraft Systems |
| **UEE** | User Equipment Error |
| **VFR** | Visual Flight Rules |
| **VPE** | Vertical Position Error |
| **WGS 84** | World Geodetic System 1984 |
| **WP** | Work Package |
| **WTRA** | Wake Turbulence Risk Analysis |

**Table 3: list of acronyms**



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# 3 Operational service and environment definition (OSED)

## 3.1 Green-GEAR reduced vertical separation: a summary

Traditionally vertical separation minima have been set to 1000 ft up to FL290. Because of the decreasing accuracy of barometric altimeters with increasing height the separation minima from FL290 to FL410 were set at 2000 ft. In order to increase capacity above FL290 the Reduced Vertical Separation Minima (RVSM) program was introduced, resulting in the reduction to 1000 ft minimal vertical separation between FL290 and FL410. [21]

In the current operation commercial, military and general aviation mainly rely on barometric measurements for determining the altitude of the aircraft. Even though aircraft are equipped with GNSS receivers and broadcast both geometric and barometric altitudes for surveillance purposes, navigation is usually done using barometric altimetry. [21]

Geometric altimetry can achieve greater accuracy (i.e. lower Altimetry System Error (ASE), see Figure 3-1) at high altitudes than barometric altimetry, as it is not sensitive for local weather and is not impacted by the low atmospheric pressure. Green-GEAR's Separation Minima solution therefore investigates whether the use of geometric altimetry would allow a reduction of the SM from the current 1000 ft in RVSM airspace (FL290 – FL410), or 2000 ft (FL410 – FL600) to 500 ft. As the added altimetry system errors of two passing aircraft are assumed to be less than 500 ft in the current standard, a reduction by this margin is not straightforward even in the hypothetical case of perfect altimetry. [21]

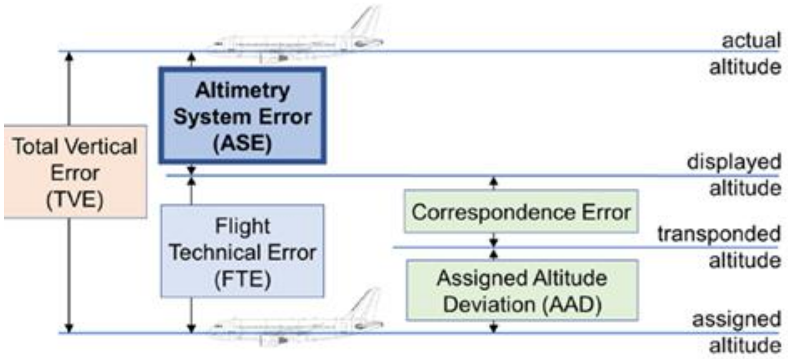


**Figure 3-1: Vertical errors definition (drawn after ICAO Doc 9574).**

The main goals of the Green GEAR project (Green Geometric altitude, Advanced separation and Route charging) are to enable optimum green trajectories, accelerate decarbonisation and decrease the climate impact on flights, which is summarised in Table 4. The present Solution consists of two parts:

1. Separation Minima (SM) aiming to reduce $CO_2$ emissions and increase capacity by further reducing separation minima at various phases of flight, while keeping the level of safety of operations at least as it is today. The reduction of separation includes aircraft currently in

service, zero emissions aircraft and other new entrants, such as Unmanned Aircraft Systems (UAS) and High-Altitude Operations (HAO) aircraft. [19][21] This RVSM 2 concept results in an airspace as shown in Figure 3-2.

2. Flying with geometric altimetry (i.e. the determination of altitude by GNSS measurements), instead of barometric altimetry as used in current operations.

| SESAR solution ID | SESAR solution title | SESAR solution definition | Justification (why the solution matters?) |
| --- | --- | --- | --- |
| Solution 0407 | 'Separation Minima' | The solution aims to transition from 1000 ft to 500 ft minimum vertical separation in RVSM airspace (FL 290 to 410), enabled by increased height measurement accuracy through geometric altimetry. 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 far more easily.<br><br>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.<br><br>The feasibility study of the concept at TRL2 level focused on the safety aspects, most notably the collision risk, wake turbulence risk, and the operational (or non-nominal risk), and a limited cost-benefit analysis. | Reducing vertical separation minima increases the capacity in the airspace, while allowing aircraft to fly closer to their optimal altitude, thus reducing $CO_2$ emissions. |

**Table 4: Green-GEAR solution scope**

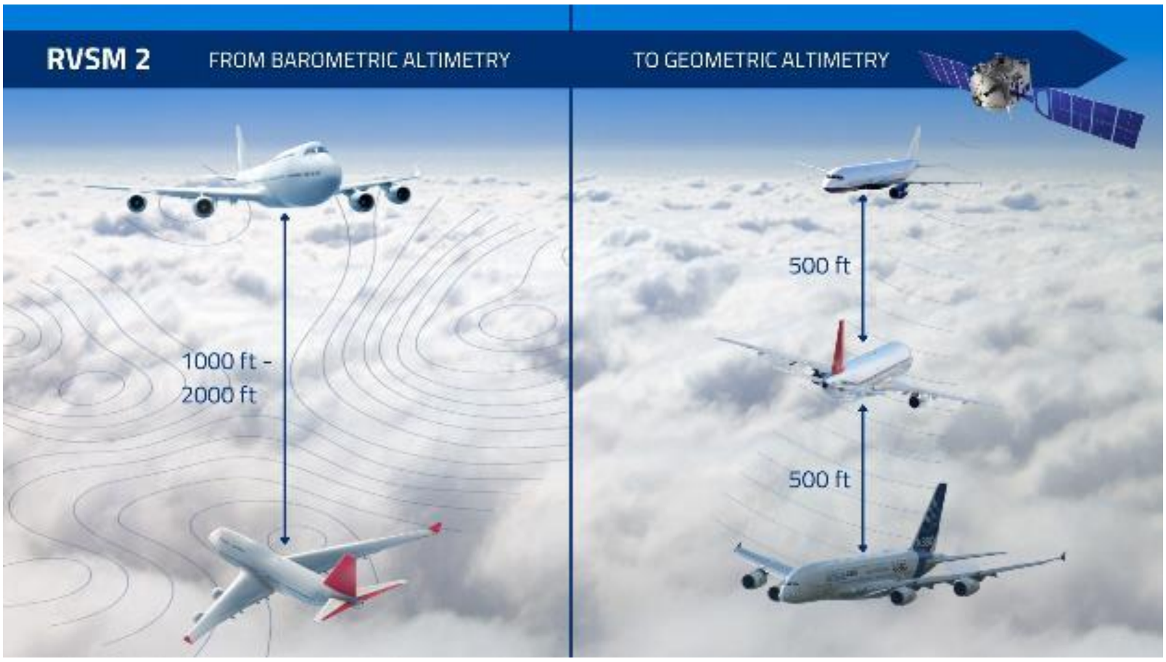


**Figure 3-2: Artist's impression of current operations and the RVSM 2 concept.**

The present Solution addresses upper airspace only, but the use of geometric- instead of barometric altimetry is also relevant for air vehicles whose configuration complicates the measurement of static air pressure, such as many types of drones. Furthermore, HAO aircraft could benefit due to the decreasing pressure gradient with increasing height: the same absolute error in measuring the static air pressure translates into a larger vertical error with increasing height. It is therefore investigated whether geometric altimetry could allow extending RVSM airspace upwards up to FL600. [21]

As the technical risk of loss of separation is dependent on the characteristics of the traffic, which varies by airspace, results of an investigation would not be universally applicable but dependent on the region chosen (see RVSM manual). Green-GEAR therefore addresses European (EUR) region en-route airspace (FL290 – FL600). [21]

### 3.1.1 Deviations with respect to the SESAR solution definition

The tentative Solution Definition for the Solution, which has been written at the beginning of the work, has been slightly updated since the Initial OSED [21] and reads as follows now: The solution aims to transition from 1000 ft to 500 ft minimum vertical separation in 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 feasibility study of the concept at TRL2 focusses on the safety aspects, most notably the collision risk, wake turbulence risk, and an overall safety case, where the EUR RVSM region serves 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) and/or the (further) development of safety nets would be needed to ensure the safety of operations. The goal is to study the feasibility of the concept from a safety perspective, to identify possible bottlenecks, and to possibly derive vertical height keeping performance requirements.

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.

A further update will be made for the Maturity Gate.

## 3.2 Detailed operational environment

### 3.2.1 Operational characteristics

#### 3.2.1.1 Airspace

The airspace under consideration for the RVSM 2 concept is an upwards-extended RVSM airspace, spanning from FL290 to FL600 inclusive. Even though most commercial air traffic does not operate extensively above the current limit of RVSM airspace of FL410, this part of the airspace is permitted as geometric altimetry is not expected to degrade with increasing altitude. Arguably, the introduction of 500 ft separation may only be sufficiently beneficial if it is deployed worldwide. From a practical perspective, however, this study will focus on the EUR RVSM region for the initial validation of the concept. Similar to the Collision Risk Assessment, studies on RVSM concepts are typically done at the continental scale. If the results of this study show that the deployment of RVSM 2 in the EUR RVSM region is indeed viable, the approach can be extended in future studies to cover the rest of the world. A map of the RVSM Regional Monitoring Agencies (RMAs) and their member Flight Information Regions (FIRs) is shown in Figure 3-3.

When reducing the vertical separation between aircraft to 500 ft, requirements must be established. When doing so, the current RVSM airspace is taken as a reference. Common requirements for RVSM are therefore adopted, such as the aircraft should be RVSM approved, appropriate pilot training, etc. In addition, additional RVSM 2 specific requirements will be needed, part of which are identified in the CRA [22] and Safety Case, and subsequently listed in the Functional Requirements Document (FRD) [23].

The CRA and Safety Case are based on the condition that all airspace users are ‘RVSM 2 approved’, or comply with the requirements that were identified in these documents. If a given airspace user does not comply with these requirements, it would either have to be prevented from entering the airspace, or would require special guidance from ATC where it would be vertically separated by 1000 ft (RVSM approved) or 2000 ft (non-RVSM approved) from other airspace users.

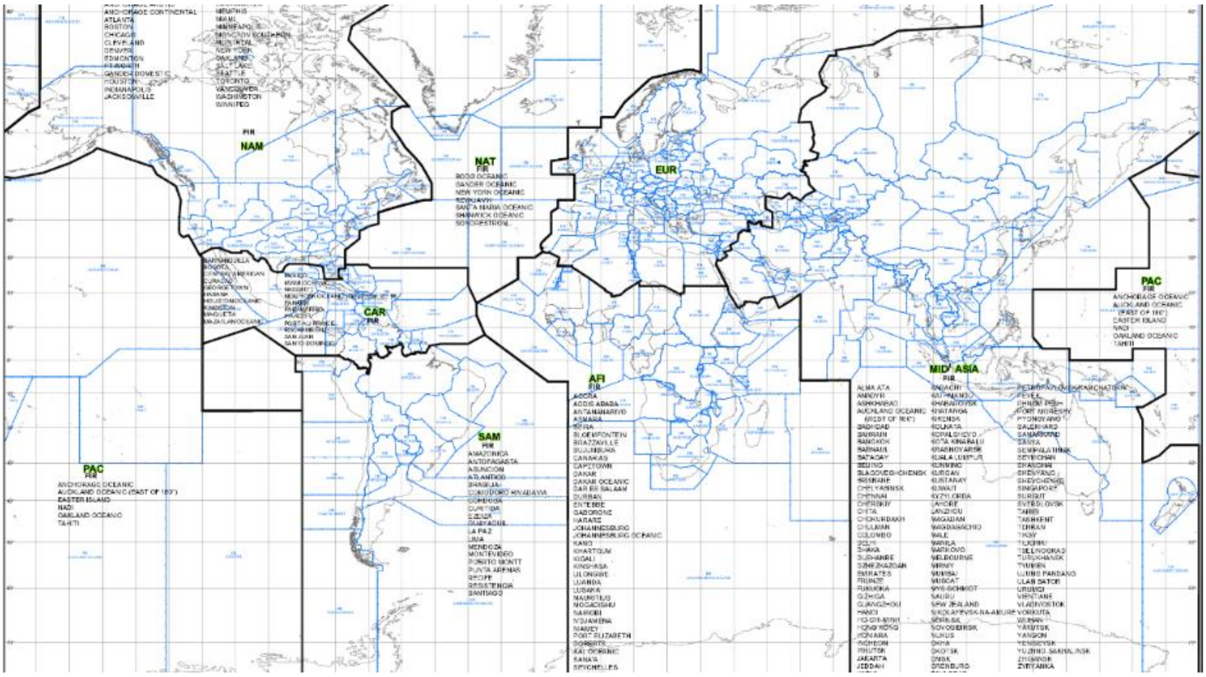


**Figure 3-3: Chart of the RMAs and the member FIRs. [30]**

A 500 ft vertical separation airspace should be a demarcated, controlled (class A, B, C, D, E, where Air Traffic Control (ATC) has the authority to grant or deny access. Initially the airspace will be from FL290 to FL600.

The airspace should be fully covered by a GNSS configuration. What this exact configuration should be is not yet known, but it should comply with a certain level of accuracy, integrity, continuity and availability, for which the CRA and Safety Case have identified the most relevant requirements. The GNSS to be used could possibly include, a single- or multi-constellation system, single- or dual frequency and SBAS augmentation [22].

### 3.2.1.2 Route structure

When comparing to the old Flight Level Orientation Scheme (FLOS) [31], transitioning from 1000 ft to 500 ft separation in RVSM airspace results in 12 additional flight levels within the FL290 to FL410 altitude limits of current RVSM airspace. In addition, 6 flight levels are reversed. When the upper limit of RVSM airspace is extended from FL410 to FL600, an additional 38 flight levels above FL410 are available. The new FLOS is shown in Table 5. The heading of the aircraft determines the available flight levels, where aircraft with a heading between 000 and 179 degrees (or 090 to 269 in the FIRs or UIRs of Italy, France, Portugal and Spain) are eastbound. Aircraft with a heading of 180 to 359 degrees (or 270 to 089 in the FIRs or UIRs of Italy, France, Portugal and Spain) are westbound.

**Table 5: Orientation of flight levels with 500 ft separation. Marked FLs (*) are reversed with respect to the RVSM airspace.**

| Westbound flights (180-359°M) | Eastbound Flights (000-179°M) | Remarks |
|---|---|---|
| | FL600 | |
| … | … | Similarly, 38 extra flight levels above FL410. |
| | FL410 | |
| FL405 | | |
| | **FL400 *** | |
| FL395 | | |
| | FL390 | |
| FL385 | | |
| | **FL380 *** | |
| FL375 | | |
| | FL370 | |
| FL365 | | |
| | **FL360 *** | |
| FL355 | | |
| | FL350 | |
| FL345 | | |
| | **FL340 *** | |
| FL335 | | |
| | FL330 | |
| FL325 | | |
| | **FL320 *** | |
| FL315 | | |

| Westbound flights (180-359°M) | Eastbound Flights (000-179°M) | Remarks |
|---|---|---|
| | FL310 | |
| FL305 | | |
| | **FL300 *** | |
| FL295 | | |
| | FL290 | |
| | | FL285 not used |
| FL280 | | Non-RVSM level |

Note that the suggested flight orientation scheme is made for the entire EUR airspace. However, there can be local deviations that conflict with this scheme. For example, in France military traffic operates at flight level multiples of five (e.g. FL305, FL310, FL365). To avoid conflicts, discussions with the relevant stakeholders are necessary to determine whether this would actually pose a problem, and if so, how this could be prevented.

When RVSM was implemented, the route structure did not have to be modified. To ensure safety within the RVSM airspace, a fixed route structure was presumed. This was preferred because of the increased workload of the Air Traffic Control Officer (ATCO) while adapting to a new operational environment. [31] In the meantime, however, free routing airspace has become more common and therefore RVSM 2 will allow FIRs to adopt free routing structures.

#### 3.2.1.3 Transition zones

Like in the introduction of 1000 ft RVSM, the areas just within the EUR RVSM area will be designated as transition airspace when RVSM 2 is introduced [31]. For RVSM 2 the transition zone may have to take two parameters into account: the separation minimum (as was the case in RVSM transition zones) and the altimetry mode (i.e. geometric or barometric.)

When the neighbouring airspace operates under geometric altimetry and only the separation minimum changes, the transition will be from 500 ft to 1000 ft or 2000 ft, and vice versa. Aircraft entering the RVSM 2 airspace will be allowed to be separated by 500 ft vertically in case both are RVSM 2 approved. Non-RVSM 2 approved aircraft will either have to be denied access, or will have to be given special considerations by ATC regarding separation. Aircraft leaving the RVSM 2 airspace will have to be separated by a minimum of 1000 ft or 2000 ft depending on the rules of the adjacent airspace, which would entail a reduction in the number of available flight levels. This means that aircraft that fly on a discontinuous flight level must either climb or descend to an available flight level in the transition zone. This must be done in a structured way, as it must be prevented that two planes climb/descend to the same flight level, causing collision risks.

In addition to the change in separation minima that is similarly present in RVSM transition zones, RVSM 2 transition zones may also require a change in altimetry mode (i.e. from geometric to barometric or vice versa).

When the adjacent airspace operates under barometric altimetry, additional challenges arise on top of the possible reduction in the number of available flight levels. Geometric flight levels are not directly equal to barometric flight levels. A transition between the two zones could require aircraft to stay in level flight, and in doing so would require a conversion to get the barometric and geometric altitudes that are equivalent. Another option would be that in the transition zone, aircraft stay at equal flight levels (e.g. FL300 barometric becomes FL300 geometric, thereby likely requiring a climb or descent) or that new flight levels get assigned by ATC. Both these options require close coordination or monitoring by ATC. The higher complexity of the transition procedures, the larger the transition zone that may be required.

#### 3.2.1.4 Aircraft characteristics

Aircraft flying in the 500 ft vertical separated airspace should fulfil standard airworthiness criteria and be fully certified to operate. There will not be any requirements concerning aircraft performance, nor will there be limitations to aircraft mix or general characteristics, such as dimensions or speed keeping performance. All performance related requirements and standards are comparable with the current situation.

Nonetheless, there will be some additional technological requirements. Aircraft be able to use geometric altimetry. Besides technological requirements, adjustments of the current technology must be made. Aircraft will have to be equipped (e.g. receiver, antenna, etc.) such that they can determine their position with sufficient accuracy from GNSS signals. The ASE should be such that the 1σ Total Vertical Error (TVE) shall not exceed 34 ft if Laplace, or 58 ft if Normal distributed. Considering the Flight Technical Error (FTE) in current operational practice, this would likely result in an ASE of lower than about 20 ft as the certification standard. In order to minimise factors like unintended interference, the aircraft will likely have to be equipped with dual-frequency receivers [25]. These factors are not completely within the control of aircraft equipment, as it would also depend on factors like the signal quality.

Nowadays, aircraft are usually equipped with an Airborne Collision Avoidance System (ACAS) which reduces the risk of mid-air or near mid-air collisions. As of 1 January 2005, all turbine-engine aeroplanes of a maximum certificated take-off mass in excess of 5,700 kg, or authorized to carry more than 19 passengers shall be equipped with ACAS II, but it is recommended for all aeroplanes [32]. The altitude threshold of the currently only commercial implementation TCAS v7.1 is more than 500 ft at all altitudes [33], meaning that resolution advisories will be triggered when aircraft are nominally separated at 500 ft. Therefore, ACAS algorithms have to be adjusted to not give warnings when aircraft are vertically separated by 500 ft, while still being sufficiently effective.

Novel aircraft concepts such as HAO (High Altitude Operations) aircraft and UAS will be allowed to enter the RVSM 2 airspace, provided they meet the standards for height keeping ability and GNSS.

For the wake vortex risk analysis, there are also some aircraft characteristics of particular importance. A detailed description about wake vortices in general can be found in [34]. The two main influencing factors of the wake generating aircraft besides airspeed are the aircraft mass and its wingspan. An aircraft with a larger mass requires its wings to generate more lift and thus it generates stronger wake vortices. Also, the self-induced downwards motion of the wake vortices is faster when the vortices are stronger. Thus, simply using the maximum take-off weight of the aircraft type as a conservative assumption is not desirable because the weight also influences the downward motion of the wake vortices and thus a prediction of a possible wake encounter might result in a false negative if a too high aircraft mass is assumed.

Therefore, the estimation of the aircraft mass should be as precise as possible in order to not only allow a precise calculation of the wake vortex strength but also of the vortex motion. The wingspan of the leader aircraft is also of particular importance because an aircraft with a smaller wingspan requires a higher circulation in order to generate the required lift and thus it generates stronger wake vortices. This also influences the motion of the wake vortices and therefore a precise knowledge of the wingspan is important. However, in contrast to the aircraft mass, the wingspan remains constant (with rare exceptions for certain military types) and is precisely known for a given aircraft type.

In addition to the mentioned characteristics of the generator aircraft, the characteristics of the aircraft that encounters the wake vortex also need to be considered. This aircraft is typically referred to as the "follower aircraft" even though this aircraft can also encounter the wake vortex in crossing or opposite direction. Generally, the mass and wingspan of the follower aircraft are important as well because these parameters influence the susceptibility of the aircraft to wake vortices. Moreover, the control effectiveness of the control surfaces is important for determining whether it would be possible to counteract the disturbance due to the wake vortex encounter or whether an unwanted aircraft motion would occur that could not be compensated even by full deflections of the control surfaces.

The relevance of a control surface depends on the encounter geometry. For example, when encountering a wake vortex in longitudinal direction, as is typically the case when both aircraft are on the same route (and also during approach or departure, which is out of scope for the present Solution), the rolling moment due to the wake vortex is mostly relevant and thus the aileron effectiveness is the relevant parameter for counteracting this external disturbance. In contrast, when crossing a wake vortex in lateral direction, the pitching moment and the vertical load factor, and thus the elevator effectiveness are mostly relevant. In general, when encountering a wake vortex in an arbitrary direction, the effectiveness of several control surfaces needs to be considered.

Even though alternative propulsion systems are being researched (i.e. electric or hydrogen-based propulsion), this is deemed outside the scope of Green-GEAR. For the time being and at the current TRL, we assume that altitude keeping accuracy is influenced by the characteristics of the altitude source and the performance of the flight control system but not by the propulsion concept. In view of the expected introduction of electrical aircraft in the future, it is quite conceivable that they will have more responsive propulsion (both as regards physical capability as willingness to modulate power in view of wear and tear issues) to counteract atmospheric disturbances so this appears a conservative assumption.

### 3.2.1.5 Traffic

In terms of traffic in the RVSM 2 airspace, it is assumed that air traffic complexity and passing frequencies in the RVSM 2 airspace are comparable to the current RVSM airspace. The values of these parameters that were used can be found in the CRA [22].

Furthermore, it is assumed that the fleet in the RVSM 2 airspace is comparable to the current fleet in the sense especially that possible future all-electric or hydrogen-powered transport aircraft will have comparable cruise speeds and physical dimensions. As an example, in the case of hydrogen-powered aircraft, the fuselage size very probably will increase but the vertical size of the aircraft, which is relevant for the collision risk, is still determined by the height of the vertical tailplane.

#### 3.2.1.6 Contingency procedures

In case that 500 ft vertical separation is no longer possible in the RVSM 2 airspace, a contingency procedure has to be initialised. This can be due to lack of required GNSS performance for a single aircraft, or for multiple aircraft in the airspace. Therefore, two different contingency procedures are determined. [24]

The first contingency procedure, referred to as *Procedure Single Unable Altimetry* (PSUA), is applied if it is detected that one aircraft is not able to derive an altitude estimate with sufficient accuracy in a continuous way or if it is detected that one aircraft does not have sufficient capabilities to maintain assigned altitudes. The procedure aims to maintain sufficient spacing between this aircraft and all other aircraft. For this, there are two options:

- Option 1, typically applied if the ground domain does not actively control the air traffic (i.e.; there is procedural control, without full surveillance and communication coverage, and the ground domain is for example not receiving the *own altitude* signals for each individual aircraft and neither the *unable altimetry* messages). The PSUA is then executed by the aircraft that is not able to derive an altitude estimate or is not able to keep its assigned altitude. The aircraft might then need leave the RVSM 2 airspace.
- Option 2, typically applied if the ground domain is actively controlling the air traffic with full surveillance and communication coverage, receiving the *own altitude* signals from each individual aircraft and receiving *unable altimetry* messages. The PSUA then possibly involves standardised communication between ground and airborne domain and might involve dedicated communication between aircrew and controller, for example about the cause of the lack of altimetry capabilities. This ground domain might then maintain horizontal separation or provide vertical spacing with respect to other aircraft with large margins.

The second contingency procedure, referred to as *Procedure Multiple Unable Altimetry* (PMUA) is applied if it is detected that the provided altitude information is not adequate in the entire airspace, or in a part of it. *Not adequate* in this context is not yet precisely defined but includes situations such as: the information is not available for some period, the estimates derived from it are rather inaccurate for some period and the estimates derived from it are incorrect for some period. The procedure aims to maintain sufficient spacing between all aircraft in the relevant part of the airspace.

The two contingency procedures are not further developed than described in this section, due to the TRL 2 maturity of the Green-GEAR project. Additional research should be conducted into the safe implementation of the procedures. This research should include, but is not limited to the transition from geometric altitude to barometric altitude, both for PSUA and PMUA, the transition back to geometric altitude when the required GNSS performance is available again, both for PSUA and PMUA, the safety of the procedures, and the responsibilities of initialising a contingency procedure (ATC or pilots).



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### 3.2.2 Roles and responsibilities

In the Green-GEAR solution, research is conducted to the feasibility of an RVSM 2 airspace, given that aircraft are properly equipped and pilots are properly trained. Therefore, within roles and responsibilities, no further detail is given concerning for example aircraft manufacturers and air traffic management. However, the roles and responsibilities of ATC and the aircrew are outlined.

First, ATC should grant or deny access to the airspace. This should be based, among other things, on geometric altimetry capabilities of the aircraft. If an aircraft does not fulfil the requirements, ATC will either have to deny access or will have to provide additional separation to other airspace users. Furthermore, ATC is in charge of flight conformance monitoring, including height keeping, and giving tactical instructions to the aircrew.

Second, the aircrew is responsible for reporting the lack of geometric altimetry capabilities. The aircrew should report if the required accuracy cannot be met when entering the airspace. Likewise, during in-flight contingencies where the vertical navigation performance of the aircraft cannot be met, aircrew shall inform ATC. ATC gives the aircrew a revised clearance, after which the aircrew can deviate from the earlier route. Whenever RVSM 2 is suspended for whatever reason, ATC applies a minimum vertical separation of 1000 ft or 2000 ft to all aircraft in the region.

### 3.2.3 CNS/ATS description

This section discusses the communication, navigation and surveillance services (in that order) that have to be provided in the RVSM 2 airspace by comparing the situation with the current operation.

#### 3.2.3.1 Communication

In terms of communication technology, there are no significant changes in the RVSM 2 airspace. R/T frequency or Controller Pilot Data Link Communications (CPDLC) is used for aircrew voice communication. ATC is free to use the same frequency as that is used in current operations.

Because of the increase in capacity however, an increase in throughput may occur locally on the order of 70% (the number of available flight levels doubles). If frequencies are scarce this might cause congestion, but further investigation is required to be conclusive.

#### 3.2.3.2 Navigation

The crucial difference between current operations and the RVSM 2 airspace concerns navigation. This section outlines the components that influence the performance of GNSS for aircraft in the RVSM 2 airspace.

##### 3.2.3.2.1 GNSS performance

The Collision Risk Analysis (CRA) elaborates on the topic on GNSS performance metrics. In short, it is assumed that availability, continuity and integrity are all sufficient and that accuracy is the crucial parameter for the feasibility of the RVSM 2 concept from a collision risk perspective. In particular, the Vertical Positioning Error (VPE) is the parameter of interest that is taken to represent the ASE. In addition, there is a specified, or ‘promised’ performance, and an actual measured performance that exceeds the former. As stated in the Aircraft characteristics section, 3.2.1.4, the ASE should be such that the 1σ Total Vertical Error (TVE) shall not exceed 34 ft if Laplace, or 58 ft if Normal distributed. Considering the Flight Technical Error (FTE) in current operational practice, this would likely result in an ASE of lower than about 20 ft as the certification standard.

The specified or 'promised' performance for GPS single frequency, and Galileo single and double frequency, have a VPE of 13 m (or 43 ft) and 8 m (or 26 ft) respectively at average user locations. Even though there are no guarantees, the actual performance in practice typically exceeds this. These figures are more representative however of the space segment contributions to the errors, as propagation and user contribution errors are purposefully excluded, and would result in worse performance figures when taking into account all error contributions. Nevertheless, the specified values are not sufficient to meet the TVE. [35] [36] [37] [38]

Table 6 shows the achieved performance of GPS Single Frequency (SF) and Galileo Dual Frequency (DF) measurements from quarterly performance reports. Note that a normal error distribution is assumed when converting the 95% error to 1σ. The VPE values are based on actual real-world measurements under standardized conditions. Note that these values may not be fully representative of the en-route aviation domain (e.g. high altitude, moving receiver instead of a ground based stationary one.) Nonetheless, if these values are taken, the current system performance would be sufficient to meet the TLS.

**Table 6: Average VPE (95%) of GPS and Galileo from quarterly performance reports. The values for GPS are the average of the average VPE per day for two quarters. The values of Galileo are said to not have exceeded these values on a per month basis for two months.**

| | **VPE (95%)** | **VPE (1σ)** |
|---|---|---|
| GPS Single Frequency | 3.98 m = 13.1 ft | 2.03 m = 6.7 ft |
| Galileo Dual Frequency | 3.35 m = 11.0 ft | 1.71 m = 5.6 ft |

The matter of liability and responsibility regarding GNSS performance is rather complex however. However, both GPS and Galileo do not assume responsibility if the specified accuracies are not achieved. Even though in the past the systems may have performed such that the requirements are met, this may not be guaranteed in future use. It is up for the aviation authorities to decide what kind of evidence is required to show that the GNSS performance is indeed sufficient.

#### 3.2.3.2.2 Multi GNSS

Using multiple GNSS constellations in conjunctions is a way to improve accuracy and availability. With multi-GNSS navigation, there are more satellites in the field of view, while only one additional satellite (five instead of four satellites) is needed when determining a three-dimensional position estimate, to account for the clock difference between the constellations. The exact increase of the accuracy of multi-GNSS navigation is not yet known. ICAO did however adopt new dual-frequency multi constellation standards in March 2023, so it will likely be implemented in the near future. [39]

#### 3.2.3.2.3 SBAS

Another way of increasing GNSS integrity and accuracy is by using SBAS. SBAS consists of many reference (ground) stations, along with a few master stations. The measurements of the reference stations are sent to the master stations, which determine differential corrections and corresponding confidence bounds. The data is processed and transmitted to an uplink station. These provide information to the end-user with the use of GEO-satellites. [40] The necessity for SBAS in the RVSM 2 concept, and the suitability of SBAS for a high altitude, intercontinental scale domain such as aviation has not been fully determined yet.

#### 3.2.3.2.4 Signal interference

A significant threat to the use of GNSS signals for altitude determination is the potential for jamming and spoofing of the signals. In case of jamming, the GNSS signals are overpowered by other signals in the same radio frequency band, rendering the GNSS locally ineffective. Incidents of intentional, large-scale jamming have among others occurred in Eastern Europe in relation to the conflict in Ukraine, in the USA and in the Middle East [43]. However, also the use of personal privacy devices to prevent tracking has been known to locally jam GNSS signals.

In case of spoofing, counterfeit GNSS signals are broadcast, causing receivers to compute incorrect position estimates. In contrast to jamming, the *production* of signals able to spoof GNSS receivers cannot occur as an unintended side effect because of the complexity of the signal, but incidents of unintentional spoofing are known: e.g. when the replay of recorded GNSS signals for test purposes has unintentionally been received by operational users [44]. It appears that even after an aircraft has flown out of an area with spoofing, its navigation might be disturbed for some time as the navigation filters may have been incorrectly tuned with the counterfeit position and/or velocity input.

In order to minimise the effects of jamming and spoofing on the operations in the RVSM 2 airspace, aircraft should be equipped with DF receivers. These are capable of reducing unintentional jamming effects.

### 3.2.3.3 Surveillance

In the context of aircraft surveillance, there will not be any significant changes with respect to the current operation. Altitude surveillance will be done with secondary radar. Regulation (EU) No 1207/2011 requires that all flights operating as general air traffic in accordance with instrument flight rules within the EU are equipped with mode S transponders. Mode S is a Secondary Surveillance Radar (SSR) process that provides barometric altitude and identification data. Most transponders are equipped with an Automatic Dependent Surveillance in Broadcast Mode (ADS-B). This adds geometric altitude data from the satellite navigation receiver to the signal broadcasted to other aircraft and air traffic controllers.

Aircraft with a maximum certified take-off weight exceeding 5700 kg or having a maximum cruising true airspeed capability greater than 250 knots with an individual certificate of airworthiness first issued on or after 8 January 2015 are equipped with SSR transponders (EASA, 2011). Therefore, the aircraft operating in en-route airspace are likely already compatible with this requirement.

### 3.2.4 Applicable standards and regulations

Section 3.4.1 of ICAO Annex 11 on Air Traffic Services ([28]) states that the separation minima within a given portion of airspace shall be selected by the provisions of the PANS-ATM (Doc 4444) ([26]) and the Regional Supplementary Procedures (Doc 7030) ([45]). It leaves the possibility to apply other separation minima where types of aids are used or circumstances prevail which are not covered by current ICAO provisions. Such other separation minima shall then be established by the appropriate ATS authorities, following consultations with operators, for routes contained within the sovereign airspace of a State or by regional air navigation agreements for routes contained within airspace over the high seas or over areas of undetermined sovereignty.

Considering the scale of establishing 500 ft minimal vertical separation, it seems most beneficial to have these minima contained within the provisions of an updated PANS-ATM, see next paragraph. Assuming then that 500 ft vertical minimal separation would indeed be contained by the PANS-ATM provisions, ICAO Annex 11 3.4.1 b) prescribes that “*the selection of these minimal separation shall be made in consultation between the appropriate ATS authorities responsible for the provision of air traffic services in neighbouring airspace when:*

1. *traffic will pass from one into the other of the neighbouring airspaces;*
2. *routes are closer to the common boundary of the neighbouring airspaces than the separation minima applicable in the circumstances.”*

Chapter 5 of the current PANS-ATM is about Separation methods and minima. Section 5.2, on the provisions for the separation of controlled airspace, states that vertical or horizontal separation shall be provided:

a) between all flights in Class A and B airspaces;
b) between IFR flights in Class C, D and E airspaces;
c) between IFR flights and VFR flights in Class C airspace;
d) between IFR flights and special VFR flights; and
e) between special VFR flights, when so prescribed by the appropriate ATS authority;

This and other provisions do not need to be adapted when it comes to the introduction of 500 ft minimal vertical separation.

Section 5.3 of the current PANS-ATM, on vertical separation, starts by stating that “*Vertical separation is obtained by requiring aircraft using prescribed altimeter setting procedures to operate at different levels expressed in terms of flight levels or altitudes*”, referring to the altimeter setting procedures provided in its Section 4.10, which in turn assumes barometric altimetry, using terms as “*transition altitudes*”, “*flight levels*” and “*forecast pressures*”. The statement needs to be adapted to introduce geometric altimetry. Most relevant in the context of 500 ft vertical separation is the provision 5.3.2 that:

“*The vertical separation minimum (VSM) shall be:*

*a) a nominal 300 m (1 000 ft) below FL290 and a nominal 600 m (2 000 ft) at or above this level, except as provided for in b) below; and*
*b) within designated airspace, subject to a regional air navigation agreement: a nominal 300 m (1 000 ft) below FL410 or a higher level where so prescribed for use under specified conditions, and a nominal 600 m (2 000 ft) at or above this level.*”

It is this provision that might need to be adapted in order to establish 500 ft minimal vertical separation.

The Regional Supplementary Procedures (Doc 7030) complement the PANS-ATM per ICAO region; it contains in particular the European (EUR) regional supplementary procedures. These procedures do not include statements or requirements on separation minima, but for example specify in which FIR/UIRs the RVSM shall be applicable, that some State authorities may establish designated airspace for the purpose of transitioning non-RVSM approved aircraft and that coordination messages shall be supplemented verbally by a description of the cause of the contingency, if a single aircraft is experiencing an in-flight contingency that impacts RVSM operations. These procedures might need to be adapted once the 500 ft vertical separation are introduced within the EUR region.

The EU regulations basically correspond with the ICAO provisions. Within the Standardised European Rules of Air (SERA) [46], the formulation about separation provisioning is slightly different. SERA.8005(b) states that "Clearances issued by air traffic control units shall provide separation…" and then lists the same as in section 5.2 of the current PANS-ATM, with the exception that line e) above is replaced with "between special VFR flights unless otherwise prescribed by the competent authority". The regulation SERA.8005 (c) about the minimal vertical separation is formulated as follows:
*"Except for cases when a reduction in separation minima in the vicinity of aerodromes can be applied, separation by an air traffic control unit shall be obtained by at least one of the following:*
*(1) vertical separation, obtained by assigning different levels selected from the table of cruising levels in Appendix 3 to the Annex to this Regulation, except that the correlation of levels to track as prescribed therein shall not apply whenever otherwise indicated in appropriate aeronautical information publications or air traffic control clearances. The vertical separation minimum shall be a nominal 300 m (1 000 ft) up to and including FL410 and a nominal 600 m (2 000 ft) above this level;*
*…"*
The Appendix 3 provides a table of cruising levels, which is partially given in Table 9 [46]. It is this European regulation that might need to be adapted in order to establish 500 ft minimal vertical separation.

**Table 7: Part of the table of cruising levels as shown in [46]**

| Track | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| From 000 to 179 degrees | | | | | | From 180 to 359 degrees | | | | | |
| IFR Flights | | | VFR Flights | | | IFR Flights | | | VFR Flights | | |
| Level | | | Level | | | Level | | | Level | | |
| FL | Feet | Meters | FL | Feet | Meters | FL | Feet | Meters | FL | Feet | Meters |
| 010 | 1000 | 300 | - | - | - | 020 | 2000 | 600 | - | - | - |
| 030 | 3000 | 900 | 035 | 3500 | 1050 | 040 | 4000 | 1200 | 045 | 4500 | 1350 |
| 050 | 5000 | 1500 | 055 | 5500 | 1700 | 060 | 6000 | 1850 | 065 | 6500 | 2000 |
| 070 | 7000 | 2150 | 075 | 7500 | 2300 | 080 | 8000 | 2450 | 085 | 8500 | 2600 |
| 090 | 9000 | 2750 | 095 | 9500 | 2900 | 100 | 10000 | 3050 | 105 | 10500 | 3200 |
| 110 | 11000 | 3350 | 115 | 11500 | 3500 | 120 | 12000 | 3650 | 125 | 12500 | 3800 |
| etc | etc | etc | etc | etc | etc | etc | etc | etc | etc | etc | etc |

The formulation in SERA about the selection of separation minima also slightly differs from the formulation in ICAO Annex 11. SERA.8010 on Separation Minima states that "(a) *The selection of separation minima for application within a given portion of airspace shall be made by the ANSP* *responsible for the provision of air traffic services and approved by the competent authority concerned" and " (b) For traffic that will pass from one into the other of neighbouring airspaces and for routes that are closer to the common boundary of the neighbouring airspaces than the separation minima applicable in the circumstances, the selection of separation minima shall be made in consultation between the ANSPs responsible for the provision of air traffic services in neighbouring airspace."*

In addition to the separation minima with the purpose of collision avoidance, separation minima to avoid hazardous wake vortex encounters are also defined. The oldest and most commonly used separation scheme is defined by ICAO in PANS-ATM (Doc 4444) [26], which originally used three different wake turbulence categories for the aircraft types depending on their maximum take-off mass (MTOM). An additional category for the Airbus A380 has been defined later. A short summary of this separation scheme is provided in Table 8. In this scheme, the wake turbulence categories are defined as follows:

- Light: MTOM of 7,000 kg or less
- Medium: MTOM of more than 7,000 kg but less than 136,000 kg
- Heavy: MTOM of 136,000 kg or more
- Super: A380

**Table 8: minimal separation norms as a function of wake turbulence category [26].**

| | | Follower | | | |
|---|---|---|---|---|---|
| | | Super | Heavy | Medium | Light |
| Leader | Super | | 6 NM | 7 NM | 8 NM |
| | Heavy | | 4 NM | 5 NM | 6 NM |
| | Medium | | | | 5 NM |
| | Light | | | | |

For the aircraft category pairings for which no wake turbulence separation is defined, only the minimum radar separation has to be applied.

Even though the wake turbulence separation scheme defined by ICAO is the most commonly used scheme, it should be noted that in many countries different schemes are used and there are also additional initiatives in progress for modifying the wake turbulence separation schemes such as e.g. RECAT-EU [47] in order to achieve capacity gains without compromising safety.

As a result of the Wake Turbulence Risk Analysis [24], backed up by results of the R-WAKE project [48], it can be stated that is improbable that these longitudinal / lateral separation minima can be upheld unconditionally, i.e. more complex modes of separation made be necessary. The investigation of those, however, is beyond the scope of the current Solution at TRL2).



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## 3.3 Detailed operating method

### 3.3.1 Previous operating method

In the current operation commercial, military and general aviation mainly rely on barometric measurements for determining altitude. Even though aircraft are equipped with GNSS receivers and broadcast both geometric and barometric altitudes, navigation is done using barometric altimetry. An exception to this is the final approach phase where geometric altimetry is sometimes used in Approach with Vertical Guidance LPV, SBAS or GBAS or RNP APCH using LNAV/VNAV. These systems rely on single constellation GNSS.

Barometric altimetry however leads to a relative measure of height since local pressure will vary as a result of atmospheric conditions. It is therefore important that all airspace users follow the same reference, or pressure settings in order to be able to judge the altitude difference between different aircraft. The operating procedure therefore is that all airspace users switch to the same pressure setting when aircraft cross a transition layer that is located at a given altitude. This is called the standard pressure and has the value of 1013.25 hPa.

In the en-route flight phase, aircraft determine their altitude using barometric altimetry. Due to the decreasing accuracy of barometers with altitude, vertical separation minima traditionally have been set to 1000 ft up to FL290 and 2000 ft at higher flight levels. However, in order to increase capacity above FL290 the RVSM program was introduced resulting in the reduction to 1000 ft minimal vertical separation between FL290 and FL410.

### 3.3.2 New SESAR operating method

In the newly proposed concept, geometric altimetry will be used instead of barometric altimetry. The en-route phase of the flight will be studied in particular. Here the vertical separation minima in RVSM airspace shall be reduced to 500 ft. Because GNSS altimetry does not suffer from the same degradation in accuracy with increasing height as barometric altimetry, the upper limit of the RVSM airspace will be extended to FL600. This new concept is named RVSM 2, where the EUR RVSM region serves as a testing ground. The extremities of the EUR RVSM region will serve as transition airspace. ANSPs in these FIRs will manage the transition of aircraft between RVSM 2 and adjacent RVSM airspace and will ensure sufficient separation is maintained.

#### 3.3.2.1 Use cases

As the current research aims to elevate the concept from TRL 1 to TRL 2 the use-case under study focuses on the viability of the concept under the most basic conditions. That is, can the vertical separation minima be safely reduced to 500 ft above FL290 under nominal conditions, where geometric altimetry measurements are available on a sufficient level of accuracy, availability and integrity. The EUR RVSM area is used as a test case and it is assumed that traffic complexity is comparable to the current situation. Factors such as failure modes, contingency procedures, transition zones and mixed mode operations are important topics that should be elaborated in future projects. Initially, the focus is on nominal conditions.

In view of the results of the R-WAKE project [48], it is perfectly possible that the use case will prove lacking and advanced modes of separation will need to be studied. The approach is, however, to assume as little change as possible to today's equipage and modes of operation, and to introduce changes iteratively and only when performance is shown to be lacking.

### Use case "RVSM 2" description

As explained above, in this initial step of research only a basic use case is considered, in view of the fact that it is not sure whether the nominal target state of operation is feasible.

1. The use case covers the en-route flight phase in upper airspace, specifically flight levels 290 to 600 inclusively, in the EUR RVSM area.
2. All airspace users use geometric altimetry as vertical navigation reference, meaning that the flight management system and flight controller work with geometric data for altitude and altitude rates. ATC assigns all altitudes as geometric altitudes.
3. The source of the geometric altitude is satellite navigation in a multi-GNSS setting, while using DF signals.
4. Vertical separation minima are reduced to 500 ft in the flight levels defined above. Horizontal separation minima are not changed, nor is the general approach to altitude assignment by ATC, i.e. the only change in provision of separation is the magnitude of the minimum vertical separation.
5. Route structures are not changed.
6. The semi-circular flight rule, i.e. the separation of traffic with eastbound vs. westbound (or northbound vs. southbound in the FIRs or UIRs of Italy, France, Portugal and Spain) velocity components are not altered.
7. Traffic mix and density are comparable to today's operation.

## 3.3.3 Differences between new and previous operating methods

| Activities (in the SESAR architecture) that are impacted by the SESAR solution | Current operating method | New operating method |
|---|---|---|
| | In current operations in the EUR RVSM region, aircraft are vertically separated by 1000 ft. | According to SESAR solution 0407 'separation minima', aircraft in the EUR RVSM 2 airspace are vertically separated by 500 ft. |
| | The altitude source is pressure altitude (barometric altimetry). | The altitude source is geometric, specifically GNSS, altitude. |

**Table 9: differences between the new and the previous operating method**



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# 4 Key assumptions

This chapter lists the assumptions that are applicable to the 'Separation Minima' solution.

## 4.1 Operational assumptions

- 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) 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 [26] 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.

## 4.2 Airborne domain assumptions

- 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.

## 4.3 Altitude information domain assumptions

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

# 5 References

## 5.1 Applicable documents

This OSED 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

### 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 00.03.01, 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.

## 5.2 Reference documents

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[22] 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.

[23] Jonk, P.; Boshuizen, I: "SESAR 3 ER 1 Green-GEAR – D4.5 – FRD – Separation Minima", Version 01.00, 30th April 2025.

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

[25] 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.

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

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

[28] ICAO: Annex 11 of the Convention on International Civil Aviation, 2018.

[29] 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.

[30] ICAO: DOC 7030 Regional Supplementary Procedures, 2008.

[31] EUROCONTROL: the EUR RVSM pre-implementation safety case, RVSM 691, 2001.

[32] ICAO: Airborne Collision Avoidance System (ACAS) Manual, 2006.

[33] FAA: Introduction to TCAS II Version 7.1, 2011.

[34] Gerz, T.; Holzapfel, F. and Darracq, D.: Commercial Aircraft Wake Vortices. Progress in Aerospace Sciences, 2002, p181-208.

[35] GSC: European GNSS (Galileo) Services - Open Service - Quarterly Performance report - October - December 2023.

[36] GSC: European GNSS (Galileo) Services - Open Service - Quarterly Performance report - January - March 2024.

[37] GMV: Global Positioning System (GPS) Performance - Quarterly report 1 (January to March), 2024.

[38] GMV: Global Positioning System (GPS) Performance - Quarterly report 2 (April to June), 2024.

[39] ICAO: GNSS milestone achieved as ICAO Council adopts new dual-frequency multi-constellation standards, 2023.

[40] Teunissen, P. and Montenbruck, O.: Springer Handbook of Global Navigation Satellite Systems, 2017.

[41] ESA: New technology version of EGNOS will harness Galileo for aviation, 2018.

[42] ESSP: EGNOS monthly performance report, 2024.

[43] M. Felux, P. Fol and B. Figuet, "Impacts of Global Navigation Satellite System Jamming on Aviation," *Institute of Navigation,* 2024.

[44] K. Alexander and D. Lawrence, "GNSS Intentional Interference and Spoofing," FAA, 2015.

[45] ICAO: Doc 7030, Regional Supplementary Procedures, 2008.

[46] EASA: Standardised European Rules of Air (SERA). December 2024, https://www.easa.europa.eu/en/document-library/easy-access-rules/online-publications/easy-access-rules-standardised-european?page=15.

[47] Rooseleer, F. and Treve, V. : "RECAT-EU" European Wake Turbulence Categorisation and Separation Minima on Approach and Departure, 2018. Published by EUROCONTROL.

[48] Busto J.; Ruiz, S.: Final Project Report. SESAR 2020 R-WAKE Deliverable D2.1, ed.01.00.00, 2018.

# Appendix A Stakeholder identification and benefit impact mechanisms (BIM)

## A.1 Stakeholders identification and expectations

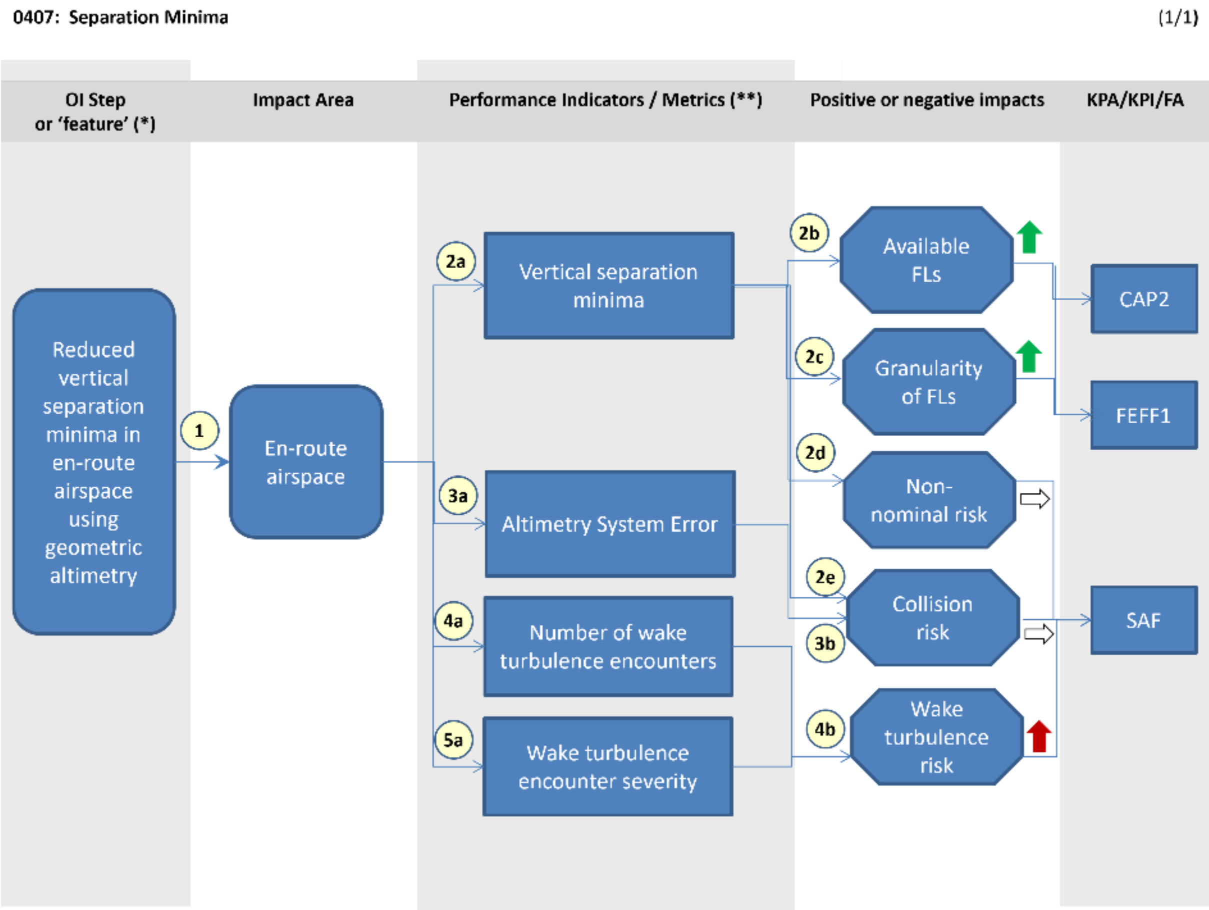
Table 10 shows the stakeholders that are impacted by a reduction of the vertical separation minima to 500 ft. Furthermore, it is outlined why this impacts the stakeholders.

| Stakeholder | Involvement | 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. |
| Airspace Users | | Generally: understanding of the potential of the Solution for more cost efficient and environmentally friendly operations.<br><br>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. |
| 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 of the impact on collision risk and of 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 10: stakeholders' expectations and involvement**

## A.2 Benefits impact mechanisms (BIM)

The figure below shows the Benefit Impact Mechanisms (BIM) for the ‘Separation Minima’ solution.




Feature description:
(1) Reduced vertical separation in en-route airspace.
(2a) Reduced vertical separation to 500 ft.
(2b) With smaller vertical spacing, more flight levels become available.
(2c) With smaller spacing, the granularity of the available flight levels increases, allowing aircraft to fly closer to the preferred altitude.
(2d) The separation minima are of influence on the non-nominal risk. The overall risk may increase but will still be below the allowed threshold (TLS).
(2e) The separation minima are of influence on the collision risk. The overall risk may increase but will still be below the allowed threshold (TLS).
(3a) Using geometric altimetry the Altimetry System Error will improve.
(3b) A reduced Altimetry System Error with the use of geometric altimetry will reduce the collision risk.
(4a) The number of wake turbulence encounters will increase with reduced separation minima.
(4b) The increased number and severity of wake turbulence encounters will negatively affect wake turbulence risk.
(5a) The severity of the wake turbulence encounters will increase when reducing separation minima.

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