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Abstract

The RVSM2 concept studies the reduction of vertical separation minima to 500 ft in RVSM airspace as enabled by geometric altimetry. In addition, the upper limit of RVSM will be extended to FL 600. The EUR RVSM region will serve as a test case. The concept will mostly be studied from a safety perspective and has been written with the subsequent steps of the study in mind, among which are a Collision Risk Assessment, a Wake Turbulence Risk Analysis, a Safety Case and an Eco-Eval.

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Authoring & approval

Author(s) of the document

Author	Organisation	Date
Patrick Jonk	**NLR**	26/04/2024
Ingmar Boshuizen	**NLR**	01/05/2024
André Koloschin	**DLR**	20/06/2024
Bart Klein Obbink	**NLR**	
Job Smeltink	**NLR**	

Reviewed by

Organisation name	Date
DLR	28/06/2024

Approved for submission to the SESAR 3 JU by[1]

Organisation name	Date
DLR	28/06/2024
NATS	
NLR	28/06/2024
Work Package Manager WP4 and Solution Lead, NLR	28/06/2024
Project Manager, DLR	28/06/2024

Rejected by[2]

Organisation name	Date

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[1] Representatives of all the beneficiaries involved in the project

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Green-GEAR

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

Green-GEAR

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1 Executive summary

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, except for a few exceptions, navigation is done using barometric altimetry.

Traditionally vertical separation minima have been set to 1000 ft up to FL 290. Because of the decreasing accuracy of altimeters with increasing height the separation minima from FL 290 to FL 410 were set at 2000 ft. In order to increase capacity above LF 290 the RVSM program was introduced resulting in the reduction to 1000 ft minimal vertical separation between FL 290 and FL 410 .

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 will 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 FL 600. The exact GNSS configuration that could be used for the concept will be explored in future parts of the project. This new concept is named RVSM2, where the EUR RVSM region will serve 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 RVSM2 and adjacent RVSM airspace and will ensure sufficient separation is maintained.

Many emergent airspace users already rely on geometric height measurements and because of that have a difference in altitude reference with the existing airspace users that make use of barometric altimetry.

The most important assumptions regarding this study are that traffic complexity will be comparable to the complexity in the past years. In addition, all airspace users will be assumed to be using geometric altimetry. At least in the initial OSED it is assumed that there is some GNSS configuration (e.g. single- or dual-frequency, single- or multi-constellation, etc.) that provides sufficient accuracy, availability and integrity. The final OSED may give more details regarding this topic.

This research aims to elevate the concept of a further reduction of the vertical separation minima as enabled by geometric altimetry from TRL 1 to TRL 2. Issues such as the transition to the RVSM2 concept and mixed (baro- and geometric altimetry) operations will have to be investigated later in this project, or in subsequent projects.

2 Introduction

2.1 Purpose of the document

This document defines the Operational Service and Environment Description (OSED) for Separation Minima 0470 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, 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. The OSED will serve as the basis for further steps such as a collision risk assessment, a wake vortex risk assessment, a safety case including a Function Hazard Analysis (FHA), a cost benefit analysis and an assessment of the potential increase in capacity. Furthermore, some operational challenges may be identified and discussed. This could for example be topics such as certification, global introduction, deployment of the concept, etc.

2.2 Scope

The initial OSED will focus on a concept for reduced separation minima in RVSM airspace in the EUR RMA region. In this airspace all users will be using the same type of altimetry, i.e. geometric. The needed update in the route network as a result of the changed separation minima will be discussed. The technical background that is necessary for the design of the concept will be introduced and will be complemented in the subsequent steps of the project as appropriate. For the initial concept, it will be assumed that sufficient levels of availability, integrity and accuracy will be met by some (combination of) GNSS system(s) and SBAS.

The final OSED may discuss topics such as mixed (altimetry) mode operations, deployment of the concept but this is dependent on further outcomes of the research. In addition, practical issues regarding availability and integrity of GNSS signals may be discussed in the final OSED. Considering the maturity of the topic it is impossible to cover all details regarding the deployment of the concept. The current study aims to cover the most important ones regarding safety which are decisive for further research into the topic.

2.3 Intended readership

This document was written for everyone that is interested in geometric altimetry and a possible reduction in vertical separation minima enabled by it. This includes consortium partners, fellow researchers in other SESAR projects, Air Navigation Service Providers (ANSPs) or governing authorities that are interested in transitioning to geometric altimetry-based air navigation procedures and the representatives of the SJU program.

2.4 Background

The use of geometric altimetry to reduce the separation minima in RVSM airspace is a novel concept that has not been explored in previous (SESAR) projects. However, the introduction of, and current operational procedures of 1000 ft RVSM airspace will serve as a starting point for this project. The methodologies used in the RVSM post-implementation safety studies and in previous wake turbulence risk analysis will be modified to test the viability of the safe introduction of reduced separation minima based on geometric altimetry.

In 1980, it was concluded that a reduction of the vertical separation minimum of aeroplanes above FL290 from 2000ft to 1000ft would have major benefits for the division of the airspace. Therefore, major studies were undertaken to investigate the feasibility of RVSM. The mid-air collision risk because of navigation errors was an important factor in meeting the Target Level of Safety (TLS). For this, the height-keeping performance above FL290 was studied in detail to determine the Total Vertical Error (TVE). To implement RVSM in the operation, airworthiness performance requirements for aircraft, new operational procedures, and a comprehensive means of monitoring the safe operation of the system were established (ICAO European and North Atlantic Office, 2001).

EUROCONTROL and NLR are responsible for pre-implementation and post-implementation safety studies of RVSM in ICAO's European and Africa Indian Oceans Regions respectively These studies analyse data on the height keeping performance of aircraft and traffic flow 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 (Smeltink & Moek, 2005).

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.

2.5 Structure of the document

Chapter 3 gives an overview of the RVSM2 concept where the minimal vertical separation norms in RVSM airspace are reduced to 500 ft as enabled by a transition from barometric to geometric altimetry. Section 3.1 first gives a short summary of the concept. In section 3.2 the concept is elaborated from a perspective of the airspace, the proposed route structure, transition zones, aircraft characteristics, CNS/ATS and applicable related rules and regulations. Section 3.3 will subsequently give a comparison of the current operation and the new suggested concept. Finally, in chapter 4 the most important assumptions regarding the concept are listed.

2.6 List of acronyms

Term	Definition
ADS-B	Automatic Dependent Surveillance in Broadcast Mode
ANSP	Air Navigation Service Provider
ASE	Altimetry System Error
ATC	Air Traffic Control

ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
ATS	Air Traffic Services
CNS	Communication Navigation Surveillance
CPDLC	Controller Pilot Data Link Communications
DES	Digital European Sky
EGNOS	European Geostationary Navigation Overlay Service
ERP	Exploratory Research Plan
FHA	Functional Hazard Analysis
FIR	Flight Information Region
FL	Flight Level
FLOS	Flight Level Orientation Scheme
FTE	Flight Technical Error
GA	Grant Agreement
GDPR	General Data Protection Regulation
GNSS	Global Navigation Satellite System
HE	Horizon Europe
ID	Identifier
ISA	International Standard Atmosphere
MSL	Mean Sea Level
OSED	Operational Service and Environment Description
RAIM	Receiver Autonomous Integrity Monitoring
RMA	Regional Monitoring Agency
RVSM	Reduced Vertical Separation Minima
SBAS	Satellite-Based Augmentation System
SESAR	Single European Sky ATM Research

SESAR 3 JU	SESAR 3 Joint Undertaking
SRIA	Strategic Research and Innovation Agenda
SSR	Secondary Surveillance Radar
TCAS	Traffic Collision Avoidance System
TLS	Target Level of Safety
TRL	Technology Readiness Level
TVE	Total Vertical Error
WGS 84	World Geodetic System 84

Table 1: list of acronyms

3 Operational service and environment definition (OSED)

3.1 Green-Gear reduced vertical separation: a summary

Position determination of aircraft has been done using barometric altimetry for decades. The altitude of the aircraft is derived by associating the measured pressure with altitude, using the International Standard Atmosphere (ISA). However, local changes in pressure, caused by weather for example, result in limited accuracy which is characterized by the Altimetry System Error (ASE) Figure 1. Due to this error in true altitude, aircraft were separated vertically by 2000ft since the early days of aviation. Between 1997 and 2005, the RVSM program was implemented globally, which allowed for 1000ft vertical separation. This was a major milestone in aviation as it significantly increased the available capacity in the airspace.

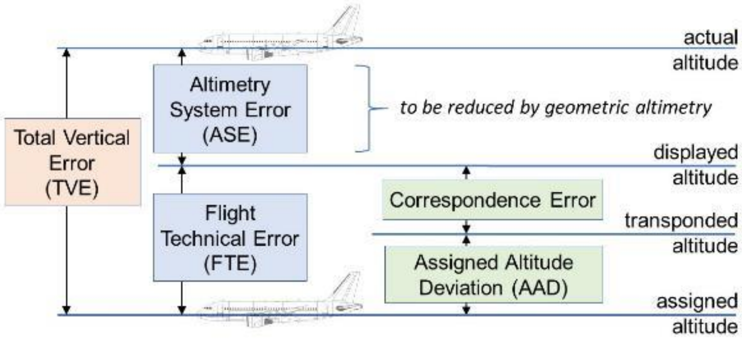

Figure 1: ASE and its role in the deviation from the assigned altitude.

The introduction of geometric altimetry, i.e. the determination of altitude by GNSS measurements, may reduce the ASE to such a degree that a reduction of the vertical separation minima to 500 ft in RVSM airspace is possible. This concept of reduced separation minima in RVSM airspace will be named RVSM2. An artist impression of the transition to RVSM2 is shown in Figure 2.

The reduction of the vertical separation minima has several advantages. Route optimization is an important factor in reducing aviation's climate impact. Reduction of the vertical separation minima to 500 ft will introduce additional flight levels, allowing a single aircraft to fly at an altitude closer to the optimal route. In addition, the additional flight levels increase the capacity around the optimal flight levels and thereby preventing congestion. It might also act as an enabler to limit the length of detours that are flown to avoid regions of high climate impact. Finally, geometric altimetry does not suffer from the same degradation in accuracy with increasing height as barometric altimetry. Therefore, geometric altimetry will allow the extension of the upper limit of RVSM airspace from flight level 410 to 600.

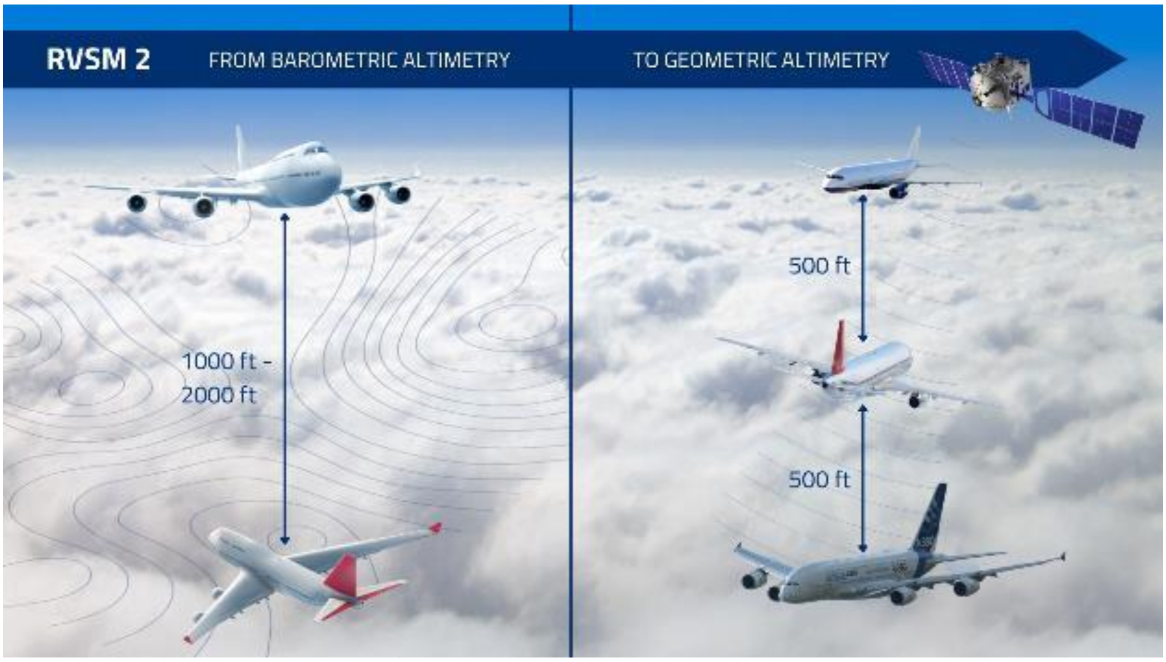

Figure 2: Artists impression of the transition to the RVSM2 concept.

3.1.1 Deviations with respect to the SESAR solution definition

This section will be updated in the final OSED.

3.2 Detailed operational environment

3.2.1 Operational characteristics

3.2.1.1 Airspace

The concept of RVSM2 will entail the reduction of vertical separation to 500 ft in the EUR RVSM airspace, where RVSM airspace will be extended to span between the flight level 290 to 600 inclusive. 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. Like 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 RVSM2 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 (RMAs) is shown in Figure 3.

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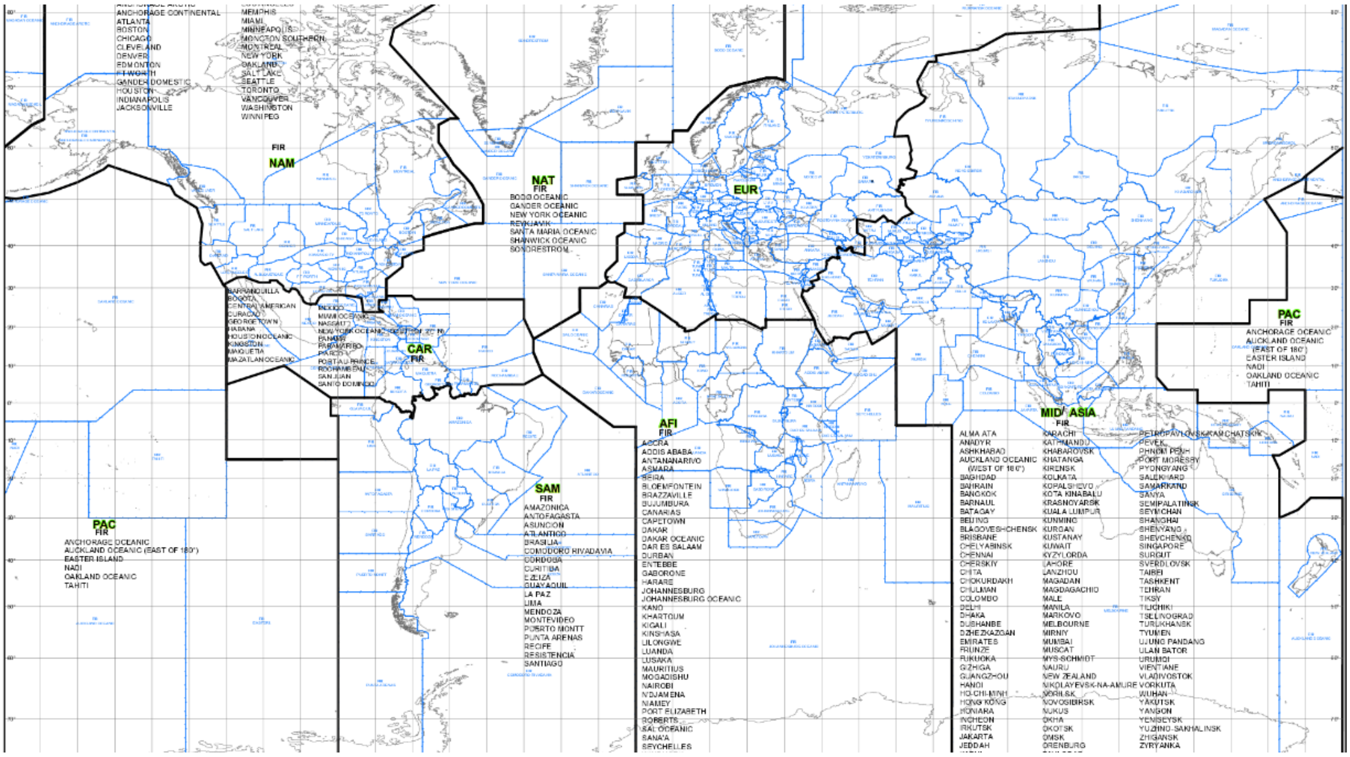

Figure 3: Chart of the RMAs and the member FIRs (ICAO, DOC 7030 Regional Supplementary Procedures, 2008).

When reducing the vertical separation between aircraft to 500ft, requirements must be established concerning the airspace. To do this, the RVSM airspace is used as a reference. This means that aircraft should be RVSM approved, including pilot training and the aircraft should possibly be equipped with an SBAS receiver.

A 500ft vertical separation airspace should be a demarcated, controlled (class A, B, C, D, E; including VFR) airspace, where Air Traffic Control (ATC) has the authority to grant or deny access. Initially the airspace will be from FL 280 to FL 600, and it should be fully covered by a GNSS configuration, with or without SBAS, that meets a sufficient level of performance.

3.2.1.2 Route structure

When comparing to the old Flight Level Orientation Scheme (FLOS) (EUROCONTROL, 2001), transitioning from 1000 ft to 500 ft separation in RVSM airspace will result in 12 additional flight levels within the FL 290 to FL 410 altitude limits of current RVSM airspace. In addition, 6 flight levels will be reversed. When the upper limit of RVSM airspace is extended from 410 to 600 this will result in 38 additional flight levels above FL 410. The new FLOS is shown in Table 2. What flight levels can be used is determined by the heading, 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 2: Orientation of flight levels with 500 ft separation.

Westbound flights (180-359°M)	Eastbound Flights (000-179°M)	Remarks
	FL600	
…	…	Similarly, 38 extra flight levels above FL 410.
	FL 410	
FL 405		
	FL 400	
FL 395		
	FL 390	
FL 385		
	FL 380	
FL 375		
	FL 370	
FL 365		
	FL 360	
FL 355		
	FL 350	
FL 345		
	FL 340	
FL 335		
	FL 330	
FL 325		
	FL 320	
FL 315		
	FL 310	
FL 305		

	FL 300	
FL 295		
	FL 290	
		FL 285 not used
FL 280		Non-RVSM level

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. (EUROCONTROL, 2001) In the meantime however free routing airspace has become more common and therefore RVSM2 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 500 ft RVSM is introduced (EUROCONTROL, 2001). For aircraft entering a separation minimum of 500 ft can be applied if the aircraft are both RVSM2 approved. Aircraft leaving the EUR region will have to be separated by a minimum of 1000 ft or 2000 ft depending on the rules of the adjacent airspace.

The introduction of RVSM2 may introduce several new challenges. Two possible transitions to an adjacent airspace are: (I) with geometric altimetry and 1000 ft separation, and (II) with barometric altimetry and 1000 or 2000 ft vertical separation.

I. When entering the airspace with geometric altimetry 1000ft vertical separation, the number of available flight levels decreases compared to the airspace with 500ft vertical separation. This means that aircraft that fly on a discontinuous flight level must either ascent or descent 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 ascent/descent to the same flight level, causing collision risks.

II. When entering the airspace that uses barometric altimetry, similar issues will arise compared to case (I). When barometric altimetry is used, 1000ft vertical separation will be required in an RVSM approved airspace. If the adjacent airspace is a non-RVSM airspace, a 2000ft vertical separation is required, meaning that there will be even less available flight levels. This might increase the required lateral size of the transition zone.

Only RVSM2 approved aircraft and state aircraft will be cleared into the EUR RVSM2 airspace. A vertical separation minimum of 500 ft will be given between RVSM2 approved aircraft. All other aircraft will be separated 1000 ft (RVSM approved aircraft) or 2000 ft (non-RVSM approved aircraft).

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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 should have the capability to operate with geometric altimetry. Furthermore, they should possibly be SBAS equipped for increased accuracy. Besides technological requirements, adjustments of the current technology must be made.

Nowadays, aircraft are usually equipped with a Traffic Collision Avoidance System (TCAS) 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 (ICAO, 2006). The altitude threshold of TCAS v7.1 is higher than 500 ft at all altitudes (FAA, 2011), which imposes a problem when vertical separation minima are reduced to 500 ft. Therefore, TCAS may have to be adjusted to not give warnings when aircraft are separated by 500 ft.

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

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 (Gerz, Holzapfel, & Darracq, 2002) The two main influencing factors of the wake generating aircraft (typically referred to as the "leader aircraft") 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 stronger when the vortices are stronger. Thus, using the maximum take-off weight of the aircraft type as a conservative assumption is in fact not a conservative assumption because it also influences the motion of the wake vortices and thus a possible wake encounter might remain unnoticed 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 a precise calculation of the vortex motion. The wingspan of the wake generating 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 very important as well. However, in contrast to the aircraft mass, the wingspan remains constant in most cases and is precisely known for a given aircraft type, thus for the wake vortex risk analysis, the estimation of the aircraft mass is more problematic than the determination of the wingspan.

When not only analysing the number and the position of the wake vortex encounters but also performing a hazard assessment, in addition to the mentioned characteristics of the wake generating 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

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encounter the wake vortex in crossing or opposite direction. Generally, the mass and wingspan of the follower aircraft are very important as well because these parameters influence the susceptibility of the aircraft to external disturbances such as wake vortices. In addition to that, the control effectiveness of the different 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.

Depending on the encounter geometry, the relevance of the different control surfaces varies. For example, when encountering a wake vortex in longitudinal direction as it is typically the case during approach or departure behind another aircraft, then 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 the general case, when encountering a wake vortex in an arbitrary direction, the effectiveness of several control surfaces needs to be considered.

3.2.1.5 Traffic

In the initial OSED, no specific restrictions will be imposed on traffic complexity. As a starting point it will be assumed that traffic complexity and related parameters such as passing frequencies are similar to the current operations. Later exercises in the project may reveal that certain limitations are necessary, and they will be discussed when these issues arise.

3.2.1.6 Contingency procedures

In the initial OSED, no changes to the current contingency procedures are foreseen except possibly for the case that all GNSS systems fail and a transition has to be made to barometric altimetry. This scenario will be further described in the final OSED.

3.2.2 Roles and responsibilities

Within the roles and responsibilities, a distinction is made between ATC and the aircrew. First, ATC should grant or deny access to the airspace. This should be based on geometric altimetry capabilities of the aircraft. If an aircraft does not fulfil the requirements to enter the airspace, access shall be denied by ATC. 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 will give the aircrew a revised clearance, after which the aircrew can deviate from the earlier route. Whenever RVSM2 is suspended for whatever reason, ATC will apply 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 that have to be fulfilled in the 500 ft vertical separated airspace by comparing the new situation with the current operation.

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3.2.3.1 Communication

In terms of communication, there are no significant changes in the RVSM2 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.

3.2.3.2 Navigation

Regarding navigation, there will be significant changes. In the RVSM2 airspace a high position accuracy has to be achieved to minimise the risk of mid-air or near mid-air collisions. Therefore, the European GNSS Galileo could be a good candidate to use as the main navigation system because of its higher accuracy. Aircraft in the airspace should all use Galileo as their GNSS since it is more accurate than GPS, which is currently used. (European Union, 2023) (Banfield, 2023)

There are several ways to further increase the accuracy of GNSS. First of all by using SBAS. SBAS uses several ground stations of which the location is precisely known. Therefore, a (atmospheric) correction can be determined by comparing the measured location with the known location. This correction is then sent to the user (e.g. aircraft) using geostationary satellites. Europe has its own SBAS service: the European Geostationary Navigation Overlay Service (EGNOS) which could potentially be used in the RVSM2 concept.

Other ways of increasing the accuracy is through the use of dual frequency measurements or multi GNSS. By combining GPS and Galileo for example, a higher accuracy can be achieved (Li, 2015). The collision risk assessment that will be performed in a later stage of the project will indicate the required accuracy in the new airspace and thus which GNSS configuration is needed.

For vertical navigation it could be necessary that aircraft use barometric altimetry in case of contingencies. For example in circumstances where there are not enough GNSS satellites in the field of view, or the position error exceeds the alert limit. The use of multi GNSS however would allow for more satellites in the field of view, allows for better global GNSS coverage and a higher accuracy (Li, 2015), and may possibly negate the necessity of barometric altimetry for contingency procedures.

Currently, commercial aircraft are usually SBAS equipped. The performance of EGNOS is published on a monthly basis (ESSP, 2024) and can be used as the baseline for the RVSM2 research. The vertical error is especially important when vertical separation is reduced. When combining GPS with EGNOS, the 95% vertical error is in the range of 1.3 – 4.2 meter. However, it varies with the location of the SBAS ground stations as can be seen from Figure 4: Histogram of the accuracy of GPS with different EGNOS ground stations in March 2024. The mean accuracy is about 2 meters, but there are a few outliers. These are ground stations located in Southern Europe and Northern Africa (Agadir, La Palma and the Canary Islands), near the boundary of the EGNOS service area.

Besides accuracy, integrity is an important parameter when using geometric altimetry. Integrity is defined as a measure of trust that can be placed in the correctness of the information supplied by the GNSS. This is directly related to the ability of the system to provide timely warnings to users when the system should not be used.

In aviation, integrity can be improved using Receiver Autonomous Integrity Monitoring (RAIM). RAIM is a technology that can assess the integrity of individual signals. If there is one satellite providing a bad signal, it can be filtered out by the algorithm. Similar to accuracy, integrity can also be improved using multi GNSS.

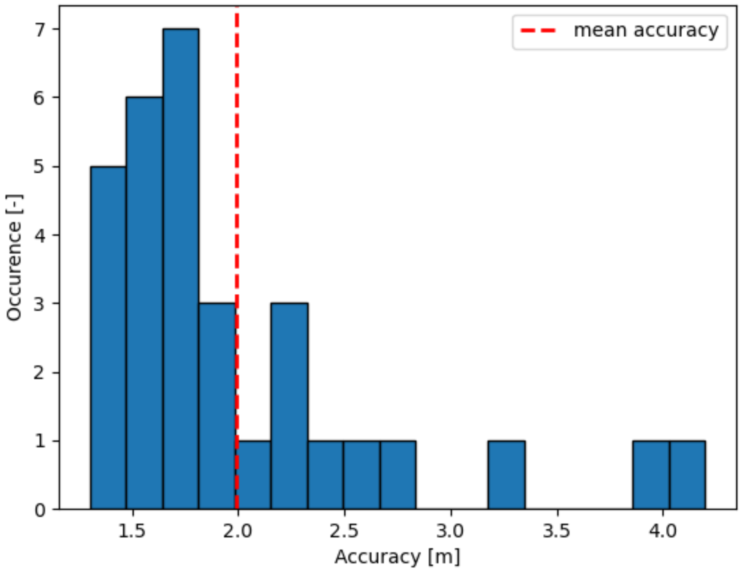

Figure 4: Histogram of the accuracy of GPS with different EGNOS ground stations in March 2024. (ESSP, 2024)

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 global navigation data 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).

3.2.4 Applicable standards and regulations

Section 3.4.1 of ICAO Annex 11 on Air Traffic Services states that the separation minima within a given portion of airspace shall be selected by the provisions of the PANS-ATM (Doc 4444) and the Regional Supplementary Procedures (Doc 7030) (ICAO, Annex 11 ot the Convention on International Civil Aviation, 2018), (ICAO, Doc 4444, Procedures for Air Navigation Services , 2007), (ICAO, Doc 7030, Regional Supplementary Procedures, 2008). 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 500ft 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 500ft 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 500ft 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 500ft 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 FL 290 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 FL 410 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 500ft 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 if a single aircraft is experiencing an in-flight contingency that impacts on RVSM operations, the associated coordination messages shall be supplemented verbally by a description of the cause of the contingency. These procedures might need to be adapted once the 500ft vertical separation are introduced within the EUR region.

The EU regulations basically correspond with the ICAO provisions. Within SERA (EASA, n.d.), 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 FL 410 and a nominal 600 m (2 000 ft) above this level;
…"

The Appendix 3 provides a table of cruising levels, which is partially given Table 3 below (EASA, n.d.). It is this European regulation that might need to be adapted in order to establish 500ft minimal vertical separation.

Table 3: Part of the table of cruising levels as shown in (EASA, n.d.)

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 until today most commonly used separation scheme is defined by ICAO in PANS-ATM (Doc 4444) (ICAO, Doc 4444, Procedures for

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Air Navigation Services , 2007), 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 the table below. 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 4: minimal separation norms as a function of wake turbulence category (ICAO, Doc 4444, Procedures for Air Navigation Services , 2007).

		Follower			
		Super	Heavy	Medium	Light
Leader	Super		6 NM	7NM	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 (Rooseleer & Treve, 2018) in order to achieve capacity gains without compromising safety.

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. 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.

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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 pressure setting that is used at low altitudes is QNH. QNH indicates the height above sea level and variations in the pressure due to atmospheric conditions are corrected at the airfield. As such, the altimeter will read runway elevation when the aircraft is on the runway.

At different airports the local atmospheric conditions will tend to differ. As a result aircraft from different airfields are likely to use different QNH values. Therefore, without knowing the QNH settings of all aircraft, it would not be possible to judge the altitude difference between them. The operating procedure therefore is that when aircraft cross a transition layer that is located at a given altitude all airspace users switch to the same pressure setting, which is called the standard pressure. This standard pressure has the value of 101.325 kPa.

Many emergent airspace users already rely on geometric height measurements and because of that have a difference in altitude reference with the existing airspace users that make use of barometric altimetry.

Traditionally vertical separation minima have been set to 1000 ft up to FL 290. Because of the decreasing accuracy of altimeters with increasing height the separation minima from FL 290 to FL 410 were set at 2000 ft. In order to increase capacity above LF 290 the RVSM program was introduced resulting in the reduction to 1000 ft minimal vertical separation between FL 290 and FL 410.

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 will 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 FL 600. The exact GNSS configuration that could be used for the concept will be explored in future parts of the project. This new concept is named RVSM2, where the EUR RVSM region will serve 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 RVSM2 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 will focus 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 FL 290 under nominal conditions, where barometric altimetry measurements are available of a sufficient level of accuracy, availability and integrity. The EUR RVSM area is used as a test case and traffic complexity comparable to the current situation is assumed. Factors such as failure modes, contingency procedures, transition zones and mixed mode operations are important topics that will be touched upon in future parts of the projects, but the focus will initially be on nominal and basic conditions.

3.3.3 Differences between new and previous operating methods

All sections related to the SESAR architecture such as the table in this section are out of scope for the initial OSED and will be included in the final OSED.

4 Key assumptions

Since the end state of the study is aimed to be at TRL 2 the focus is on a simplified case where a number of important assumptions are made. A limited list of assumptions is shown below and will be further developed in the final OSED.

Operational assumptions:

- Traffic complexity will be comparable to the complexity in the past years.
- In the initial OSED all airspace users are assumed to be using geometric altimetry. A mixed mode of users with barometric and geometric altimetry users is out of scope.
- In the initial OSED the transition in time, to the RVSM2 concept, is not considered. The concept is studied from a perspective in which it is fully operational.

Safety assumptions:

- It is assumed that the RVSM Collision Risk Assessment methodology is suitable for assessing the concept of geometric altimetry.

Performance assumptions:

- In the initial OSED it is assumed that there is some GNSS configuration (e.g. single- or dual-frequency, single- or multi-constellation, etc.) that provides sufficient accuracy, availability and integrity.

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