# SESAR 3 ER 1 Green-GEAR – D3.5 – Final OSED – Geometric Altimetry

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## Abstract

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

This document describes the Operational Service and Environment Definition (OSED), for Solution 0406 "Vertical guidance using Geometric Altimetry" at TRL2 level, seeking to enable optimised airspace design with continuous climb and descent through the Transition Layer, as well as route separation based on vertical path performance limits. It represents the final version of the OSED.



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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

This document defines the operational service and environment (OSED) for Geometric Altitude. The operational concept is considered for both the idealised end state (fully geometric operations) as well as the transitory state (mix of geometric and barometric operations). The concept is limited to a number of key focus areas.

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

- 1 – Waypoint/fix altitude constraints are defined relative to geometric altitude instead of barometric.
- 2 – Procedural vertical paths are defined as geometric paths with Instrument Flight Procedures (IFPs) defined in 3 dimensions; one sub-option with a vertical tolerance established in certification; the second sub-option as a Vertical-RNP type solution with onboard performance monitoring and alerting.

The benefits were assessed for method 2 in the Exploratory Research Report (ERR) but a composite solution of the two methods is considered to be the optimal final end state of the concept. Therefore, the assumptions are considered relative to both methods.

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

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

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

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

1. Step 1 – Geo Final Approach & Initial Approach
2. Step 2 – All altitude constraints within a defined airspace volume, e.g. TMA, switched from Baro to Geo Alt, with no airspace redesign.
3. Step 3 – Composite geometric solution applied within a defined airspace volume, e.g. TMA, Geo Path applied to Descents where necessary for procedural deconfliction.
4. Step 4 - Composite geometric solution applied within a larger airspace block, e.g. FIR.

The solution partners represent: Academic/Industrial research groups, Aircraft manufacturers and ANSPs.

Other stakeholders interested in the outcome of the validation include: Airlines, Avionics Suppliers and Communities neighbouring airports.



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# 2 Introduction

## 2.1 Purpose of the document

This document defines the operational service and environment (OSED) for Geometric Altitude, at TRL2, which covers the following project objectives:

- **OBJ 1.1**: Determination of whether Geo Alt can safely deliver a net fuel efficiency benefit for an ATM network in the TMA
- **OBJ 1.2**: Determination of whether Geo Alt can enable safe removal of Transition Layer
- **OBJ 1.3**: Use of Geometric Altimetry instead of barometric altimetry for required navigation performance (RNP) arrivals down to the intersection with the Final Approach segment**.**

This document represents the geometric altimetry solution requirement definition through development of the concept of operations.

## 2.2 Scope

This is the initial OSED for the geometric altimetry solution, providing an initial description of the new operating method. These concepts will be developed and assessed through the project's research as laid out in the Exploratory Research Plan (ERP).

Relevant topics of the operational concept consider both the idealised end state (fully geometric operations) as well as possible transition steps. The focus areas are as follows:

- New vertical capability requirements
- Capacity due improved vertical containment and new vertical containment requirements
- Cruise impact (aircraft cruise level not impacted by pressure variation)
- Fuel efficiency assessment, including greater CDO and CCO ignoring atmospheric variations (pressure and temperature) and the Transition Layer.
- Fuel efficiency through improved airspace design due to improved vertical containment balanced against the impact of constraining individual flight efficiency.
- Impact of improved accuracy/consistency of altitude on performance (predictability, safety, workload, fuel efficiency and noise impact)
- Capacity – do not lose Flight Levels at the Transition Layer due to pressure variation
- Safety and Human Performance aspects, such as avoiding risk due to mis-entry of QNH
- Fallback for GNSS
- Consideration of mixed Geo/Baro scenarios.
- Baro and Geo altitude are both available in the cockpit and are both downlinked from the aircraft to the ATC ground system

- The system capability needed to take both Geo and Baro inputs and present the relevant altitude to the Controller Working Position (CWP).

## 2.3 Intended readership

This document is aimed at the following stakeholders:

- All Green GEAR consortium members who are contributing directly to the solution research or contributing to related solutions or work packages in the project (Airbus, DLR, EUROCONTROL, NATS, NLR, UNITS, UoW)
- Relevant SESAR projects
- Members from PEARL
- SJU Program representatives, as the owner and final approver of this document.

## 2.4 Background

This section presents the background on which the Green-GEAR project is building.

**PJ.02 EARTH Solution 02-11 (2016-2020)**

In SESAR 1, PJ.02-11 - Enhanced Terminal Area for efficient curved operations explored future CONOPS, including the use of geometric altitude during approach phase and the use of curved procedures.

PJ.02-11 reached V1 maturity by the end of SESAR 1 and gave recommendations on future Research and Innovation (R&I) activities linked to Advanced curved TMA operation. The Real Time Simulations that took place in PJ.02-11 addressed primarily airborne aspects and ground aspects were discussed during Expert Group meetings. The potential in using GNSS based Advanced curved TMA operation was recognised for both arriving and departing aircraft. However, it was identified that future Research and Innovation work needed to cater for ATC aspects as well, for both the new arrival and departure concepts to mature.

**PJ.02-W2 AART Solution 04.3 (2020-2023)**

PJ.02-W2-04.1/2/3 was the continuation of PJ.02-11.

The Airport Airside and Runway Throughput project worked on the concept of Advanced Curved Operation in the TMA, which was linked to three SESAR Solutions, one of which was Advanced Curved Approach Operation in the TMA with the use of geometric altitude.

**SESAR 2020 VLD2 ALBATROSS (2020-2023)** [24][27]

ALBATROSS had the aim to demonstrate how the technical and operational R&D achievements of the past years translate into fuel efficiency improvements in real operations. The Demonstration activity covered all flight phases and addressed both operational and technological aspects of aviation and Air Traffic Management (ATM).

Among the concepts demonstrated in real conditions was exercise EXE-03 where a demonstration and study were conducted to evaluate the benefits of closed-path PBN-to-ILS procedures with and without a pilot support system for energy management, compared to radar vectoring procedures to the same runway. The specific feature of EXE-03 was that the closed-path trajectory was already assigned by ATC to the pilots at the beginning of the descent when passing the IAF (Initial Approach Fix) of the STAR (Standard Instrument Arrival (Route)), avoiding tactical lateral instructions during the approach. Lateral tactical ATC instructions prevent optimised CDAs, as the distance-to-go (DTG) is crucial information to estimate the aircraft's energy state and hence decide on the energy dissipation strategy. The conclusions stressed the necessity to deploy PBN-to-xLS procedures (including RNP or LPV approaches) to as many flights as possible. Green-GEAR works especially on the vertical component of PBN-to-xLS, whose increased predictability is expected to contribute significantly to reducing the need for ATCO intervention.

**SESAR 2020 PJ37-W3 ITARO (2021-2023)**

ITARO project demonstrated on a larger scale several solutions in the airport environment, including procedures to enable more efficient and integrated runway throughput and terminal operations; a collaborative framework for managing delay constraints on arrivals; and improved arrival and departure operations.

Among those, a flight trial EXE-003 was conducted to increase the maturity level of Interval Management (IM) operations on RNP routes/procedures and continuous descent operations (i.e. fixed profile descents) in high density TMA environments by performing flight trials with an aircraft equipped with the RNP, VNAV and Flight-deck Interval Management (FIM) capability.

EXE-003 conducted arrival operations with frequent speed adjustments on business jet flights following closed PBN STARs with fixed descent angle of 2° or 2.5°.

The consolidated pilot feedback on the IM speed guidance aspect of the concept was that sometimes speed brakes were necessary to create sufficient deceleration, suggesting that the use of speed brakes for low-drag airliners may be needed to decelerate on RNAV routes with a fixed vertical angle.

It showed that a balance is to be found between by the procedure designer: a shallower vertical profile will require less speed brakes, but also gives less fuel/noise benefits.

That said, the use of speed brakes did not raise pilot acceptance issues, therefore the corresponding HP validation objective was assessed as OK.

## 2.5 Structure of the document

The Initial OSED describes the concept of using geometric altimetry for vertical navigation and constitutes project deliverable D3.1.

Section 2 (this section) provides the context for the project concept.

Section 3 is the main section of this document and defines the concept, which is split into a target end state and a transition state. The concept summary explores different options:

- (a) Fully geometric TMA (all aircraft, all flight phases), divided into two methods:
    1) Procedural altitude constraints defined in geometric
    2) Procedural vertical path defined in geometric
- (b) Consideration of GeoAlt operations per flight phase, including cruise
- (c) Mixed capability environment




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The detailed concept focuses on:

(a) A composite solution of the two methods for a fully geometric TMA
(b) Transition steps from barometric to geometric operations

Section 4 states the assumptions for the concept, as described in Section 3, to be realised.

Appendix A defines the Benefit Impact Mechanism (BIM) for the concept, showing how the SESAR solution contributes to the delivery of the expected performance benefits.

## 2.6 Glossary of terms

| Term | Definition | Source of the definition |
|---|---|---|
| **AIR-REPORT** | A report from an aircraft in flight prepared in conformity with requirements for position, and operational and/or meteorological reporting. | ICAO Annex 3 |
| **Final Approach** | That segment of an instrument approach procedure in which alignment and descent for landing are accomplished<br><br>*Below the Transition Layer* | ICAO PANS OPS [32] |
| **Geometric Altitude/ Geo Alt** | Defining routes and procedures using geometric altitude. Aircraft navigation systems constructing vertical paths based on geometric altitude and navigating to geometric altitude. | Project Definition |
| **Geometric Constraints (at waypoints)** | Flight procedures continue to constrain vertical flight profiles through the use of altitude constraints, but the constraints become geometric altitudes instead of barometric. Defined as Concept Method 1. | Project Definition |

| Term | Definition | Source of the definition |
|---|---|---|
| **Geometric Path / Geo Path** | Paradigm change in flight procedures, now being vertically defined by published geometric paths with vertical containment assumptions. Defined as Concept Method 2, with two sub-options:<br>• Sub-option 2.1 - without V-RNP: navigation and guidance capability with vertical containment performance demonstrated at aircraft certification / ops approval level but without RNP-like onboard monitoring and alerting.<br>• Sub-option 2.2 - with V-RNP: navigation and guidance capability with vertical containment performance supported by RNP-like onboard monitoring and alerting. | Project Definition |
| **Initial Approach** | That segment of an instrument approach procedure between the initial approach fix and the intermediate fix or, where applicable, the Final Approach fix or point.<br>*Typically, below the Transition Layer* | ICAO PANS OPS [32] |
| **Instrument Approach Procedure / IAP** | A series of predetermined manoeuvres by reference to flight instruments with specified protection from obstacles from the initial approach fix, or where applicable, from the beginning of a defined arrival route to a point from which a landing can be completed and thereafter, if a landing is not completed, to a position at which holding or en-route obstacle clearance criteria apply. | ICAO PANS OPS [32] |
| **Instrument Flight Procedures** | Instrument flight procedures (IFP) are used by aircraft flying in accordance with instrument flight rules and are designed to facilitate safe and efficient aircraft operations.<br>It is a published procedure used by aircraft flying in accordance with the instrument flight rules which is designed to achieve and maintain an acceptable level of safety in operations and includes one or more of the following: an instrument approach procedure, a standard instrument departure (SID), a planned departure route and a standard instrument arrival (STAR) | ICAO [33] and IFATCA [34] |

| Term | Definition | Source of the definition |
|---|---|---|
| **Standard Instrument Departure / SID** | A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated A TS route, at which the en-route phase of a flight commences.<br><br>*Typically, below or crossing the Transition Layer* | ICAO PANS OPS [32] |
| **Standard instrument arrival / STAR** | A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced.<br><br>*Typically, above or crossing the Transition Layer* | ICAO PANS OPS [32] |
| **Transition Layer** | The airspace between the transition altitude and the transition level, where the Transition Altitude is the altitude at or below which the vertical position of an aircraft is controlled by reference to altitudes and the Transition Level is the lowest flight level available for use above the transition altitude. | ICAO PANS OPS [32] |
| **Vertical RNP / V-RNP** | There is currently no RTCA/EUROCAE definition or standard for vertical RNP. However, for the purposes of this concept, Vertical RNP is considered to be the equivalent in the vertical plane to RNP in the lateral plane. | PBN Manual [9] |

**Table 1: glossary of terms**

## 2.7 List of acronyms

| Term | Definition |
|---|---|
| **ADS-C** | Automatic Dependent Surveillance - Contract |
| **AIREP** | Air-Report |
| **ALT** | altitude |
| **AMSL** | Average Mean Sea Level |
| **ANS** | Air Navigation Services |
| **ANSP** | Air Navigation Service Provider |

| Term | Definition |
|---|---|
| **APCH** | Approach |
| **AR** | Authorisation Required |
| **ATC** | Air Traffic Control |
| **ATCO** | Air Traffic Controller / ATC Officer |
| **ATM** | Air Traffic Management |
| **ATS** | Air Traffic Services |
| **AU** | airspace user |
| **BAT** | Barometric Alerting Tool |
| **BIM** | Benefit and Impact Mechanism |
| **CAA** | Civil Aviation Authority |
| **CCO** | Continuous Climb Operations |
| **CDA** | Continuous Descent Approach |
| **CDO** | Continuous Descent Operations |
| **CFL** | Cleared Flight Level |
| **CNS** | Communication, Navigation and Surveillance |
| **CRS** | Coordinate Reference System |
| **CWP** | Controller Working Position |
| **D***<no.>* | Deliverable *<no.>* |
| **DES** | Digital European Sky |
| **D-FIS** | Digital Flight Information Service |
| **DFMC** | Dual Frequency, Multi Constellation [GNSS] |
| **DISA** | Delta ISA |
| **DME** | Distance Measuring Equipment |
| **DTG** | Distance to Go |
| **EASA** | European Union Aviation Safety Agency |
| **ECAC** | European Civil Aviation Conference |



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| Term | Definition |
|---|---|
| **EGNOS** | European Geostationary Navigation Overlay Service |
| **EPP** | Extended Projected Profile |
| **EPU** | Estimated Position Uncertainty |
| **ER** | Exploratory Research |
| **ERP** | Exploratory Research Plan |
| **ERR** | Exploratory Research Report |
| **EU** | European Union |
| **EUROCAE** | European Organisation for Civil Aviation Equipment |
| **eVTOL** | electrical Vertical Take-off and Landing |
| **FAS** | Final Approach Segment |
| **FDM** | Flight Data Monitoring |
| **FIM** | Flight Deck Interval Management |
| **FIR** | Flight Information Region |
| **FL** | Flight Level |
| **FMS** | Flight Management System |
| **FOC** | Flight Operations Control |
| **FRD** | Functional Requirements Document |
| **GA** | General Aviation |
| **GALILEO** | (European Satellite Positioning Constellation) |
| **GBAS** | Ground-Based Augmentation System |
| **GDPR** | General Data Protection Regulation |
| **Geo Alt** | Vertical Guidance using geometric altimetry |
| **GLONASS** | Global Navigation Satellite System |
| **GLS** | GNSS Landing System |
| **GNSS** | Global Navigation Satellite System |
| **GPS** | Global Positioning System |

| Term | Definition |
|---|---|
| **Green-GEAR** | Green operations with geometric altitude, Advanced separation & Route charging Solutions |
| **HAO** | High-Altitude Operations |
| **HE** | Horizon Europe |
| **HMI** | Human-Machine Interface |
| **HP** | Human Performance |
| **IAF** | Initial Approach Fix |
| **IAP** | Instrument Approach Procedure |
| **ICAO** | International Civil Aviation Organization |
| **IFATCA** | International Federation of Air Traffic Controllers' Associations |
| **IFP** | Instrument Flight Procedure |
| **IFR** | Instrument Flight Rules |
| **ILS** | Instrument Landing System |
| **IR** | Implementing Regulation |
| **IRS** | Inertial Reference System |
| **ISA** | International Standard Atmosphere |
| **JU** | Joint Undertaking |
| **LNAS** | Low-Noise Augmentation System |
| **LNAV** | Lateral Navigation |
| **LP** | Localiser Performance |
| **LPV** | Localiser Performance with Vertical guidance |
| **MASPS** | Minimum Aviation/Aircraft System Performance Specification |
| **MAX** | maximum |
| **MLS** | Microwave Landing System |
| **MMR** | Multi-Mode Receiver |
| **MSL** | Mean Sea Level |




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| Term | Definition |
|---|---|
| **MTOW** | Maximum Take-Off Weight |
| **NMA** | Navigation Message Authentication |
| **NOTAM** | Notice to Airmen |
| **OBJ**<*no.*> | objective <*no.*> |
| **OCD** | Operation Concept Document |
| **OFP** | Operational Flight Plan |
| **OPS** | operations |
| **OS** | [Galileo] Open Service |
| **OSED** | Operational Service and Environment Description |
| **OPS** | Operations |
| **OPT** | optimum |
| **PA** | Precision Approach |
| **PANS** | Procedures for Air Navigation Services |
| **PBN** | Performance Based Navigation |
| **PNT** | Position, Navigation and Timing |
| **PU** | public [dissemination level] |
| **PZ** | Parameters of Earth 1990 |
| **QFE** | [Q-code designation for] atmospheric pressure at aerodrome elevation or at runway threshold |
| **QNH** | [Q-code designation for] atmospheric pressure at Mean Sea Level |
| **R&D** | Research and Development |
| **REC** | recommended |
| **RF** | Radius to Fix |
| **RFI** | Radio Frequency Interference |
| **RNAV** | Area Navigation |
| **RNP** | Required Navigation Performance |

| Term | Definition |
|---|---|
| **RT** | Radio Telephony |
| **RTCA** | Radio Technical Commission for Aeronautics |
| **RVSM** | reduced vertical separation minima |
| **RWY** | runway |
| **SARPS** | Standards and Recommended Practices |
| **SBAS** | Satellite-Based Augmentation System |
| **SESAR** | Single European Sky ATM Research |
| **SIB** | Safety Information Bulletin |
| **SID** | Standard Instrument Departure |
| **SFL** | Selected Flight Level |
| **SJU** | SESAR Joint Undertaking |
| **S3JU** | SESAR 3 Joint Undertaking |
| **SID** | Standard Instrument Departure |
| **SFL** | Selected Flight Level |
| **SJU** | SESAR Joint Undertaking |
| **SOP** | Standard Operating Procedure |
| **SPR** | Safety and Performance Requirements |
| **SPS** | Standard Pressure Setting |
| **SRM** | Safety Reference Material |
| **STAR** | Standard Instrument Arrival |
| **STD** | Standard atmospheric pressure (1013 hPa) |
| **TA** | Transition Altitude |
| **TAWS** | Terrain Awareness and Warning System |
| **TBD** | to be determined |
| **TMA** | Terminal Manoeuvring Area |
| **ToC** | Top of Climb |

| Term | Definition |
|---|---|
| **ToD** | Top of Descent |
| **TRL** | Technology Readiness Level |
| **UAS** | Unmanned Aircraft Systems |
| **UAV** | Unmanned Aerial Vehicle; *also:* Uninhabited Airborne Vehicle |
| **UK** | United Kingdom [of Great Britain and Northern Ireland] |
| **UKRI** | UK Research and Innovation |
| **USA** | United States of America |
| **VNAV** | Vertical Navigation |
| **VOR** | Very High Frequency Omnidirectional Radio Range |
| **VPPL** | Vertical Path Performance Limits |
| **V-RNP** | Vertical Required Navigation Performance |
| **VSF** | Vertical Scale Factor |
| **WA** | Working Area |
| **WGS-84** | World Geodetic System 1984 |
| **xLS** | [generic abbreviation for different precision approach and landing systems, e.g. ILS, MLS, GLS] |

**Table 2: list of acronyms**

# 3 Operational service and environment definition (OSED)

## 3.1 Geometric Altitude: a summary

| SESAR solution ID | SESAR solution title | SESAR solution definition | Justification (why the solution matters?) |
|---|---|---|---|
| 406 | Vertical Guidance using Geometric Altimetry | Airspace design based on geometric constraints and geometric vertical paths, increasing predictability and enabling continuous climb or descent ignoring atmospheric variation and the Transition Layer. | Variation in localised pressure creates fuel, environmental and workload inefficiencies due to current reliance on barometric altimetry |

**Table 3: Geometric Altitude scope**

This section explores a number of conceptual aspects and options. First is the target end state, where there is a fully geometric environment that encompasses all aircraft in all flight phases reporting geometric altitude and using geometric altimetry for vertical navigation. Two methods could be employed for this end state: Method 1 is where waypoint/fix altitude constraints are defined relative to geometric altitude rather than barometric altitude. This would be a comparatively simple change in method of operation but still introduces significant benefit, as outlined below. Method 2 is where procedural vertical paths are defined as geometric point-to-point paths with a vertical tolerance. This would enable a Vertical-RNP type solution and so offers the greatest potential benefit from an airspace design perspective; however, it would be a more significant and complex change in method of operation, and the flight efficiency benefit will be reduced because there is a large diversity of aircraft climb performance and aircraft deceleration performance meaning that any fixed vertical path cannot be optimised for all aircraft in all weather conditions.

Second, is the transition state, where there is a mixed capability environment and/or a mixed application of Geo Alt and barometric procedures or airspace. It is highly unlikely that a barometric to geometric switch could happen in one go, so the concept considers the environment where some aircraft operate geometric altimetry for vertical guidance, but others do not. Again, two options for this transitory state could be considered. Option 1 is where all Baro and Geo flights are integrated in the same airspace. Option 2 is where Baro and Geo operations are segregated. Option 2 is seen as the most practical.

### 3.1.1 Fully Geometric Environment

The idealised end state is where all airspace users operate geometric altimetry for vertical navigation in all flight phases, i.e. there is a single common datum for aircraft altitude in use under nominal operations. This would include emerging airspace users such as drones/UAS, eVTOL / air taxis and High-Altitude Operations (HAO) and general aviation.

An environment where geometric altimetry is used by all airspace users would enable better integration of emerging with incumbent airspace users as the airspace framework would be constant (would not vary according to atmospheric conditions).

There are two potential high-level methods to apply geometric altimetry for vertical navigation, as follows

Method 1 - Defined lateral path + altitude constraints

Conceptually, geometric altimetry could be used for vertical path construction and navigation, with vertical separation provided by altitude constraints at waypoints as per today's operation. This concept is referred to as 'Geometric Constraints'. This could potentially allow geometric altimetry to be used without changing today's airspace or Instrument Flight Procedures (IFPs). However, any existing altitude constraints would need to be converted from barometric altitudes and Flight Levels to geometric altitude, which uses a different source of reference. Barometric altitudes are based on local QNH setting referenced to Mean Sea Level, but geometric altitude would be reference to a WGS-84 geoid [10]. There would be significant potential benefit in redesigning airspace and IFPs without the limitation of the Transition Layer, which would no longer need to be applied in a geometric operation.

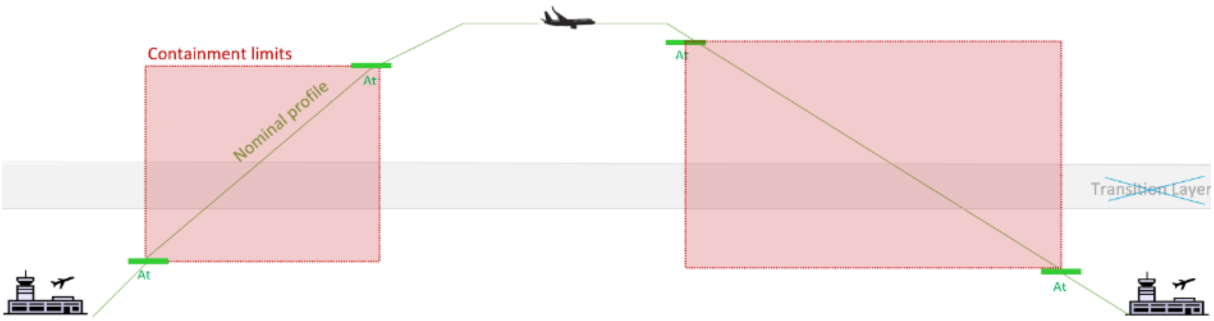


**Figure 1 – Geometric vertical navigation using defined lateral path + altitude constraints**

The benefits of airspace and procedure design could not be maximised because there would remain vertical position uncertainty in-between waypoints, but there are a number of benefits, including:

- Avoiding the need for manual pressure datum change when crossing the Transition Layer
- Consistency of altitude, which at low level, could offer performance and noise benefits
- Would not lose Flight Levels due to the Transition Layer
- Reduction in ATCO training in altimetry; however, increased training in contingency procedures

The limitation with this approach is that there could still be significant vertical position uncertainty between waypoints for ATC, meaning that airspace design efficiency could not be maximised under this conceptual option.

Reporting geometric altitude (in parallel in barometric altitude) is current aircraft capability. However, constructing and navigating to a geometric vertical path would require new aircraft capabilities.

Research into technical resilience to loss of GNSS through GNSS Jamming and Spoofing continues outside of the project. There is also research into possible options to maintain geometric operations using barometric measurements, albeit with increased vertical uncertainty and, therefore, greater buffers [36]. Regardless, it is envisaged that the ultimate fallback will be to revert to barometric altimetry. Therefore, regular training in contingency procedures will be necessary for both controller and pilot. The switch from geometric to barometric continency would be more complex under Method 2 than Method 1, due to the increased reliance on Geo Alt in 3-dimensional airspace systemisation.

<u>Method 2 - Defined lateral & vertical path</u>

Conceptually, geometric altimetry could be used for vertical path construction and navigation, optionally with vertical separation assured against the geometrically-constructed path as a form of Vertical RNP (V-RNP). This concept is referred to as 'Geometric Path'. This would enable Instrument Flight Procedures (IFPs) to be constructed and separated much more efficiently in 3 dimensions than today, so that the benefits of airspace and procedure design could be maximised.

The benefits of this method include all of those from method (1) plus the ability to optimise the efficiency of route/procedure design due to the significant improvement in containment. Today, procedures often incorporate level segments to ensure vertical separation against other, e.g. crossing, routes. If geometrically-constructed 3D routes could be defined, with specified route tolerance/accuracy applied in the vertical plane as well as the horizontal plane, then routes would be able to cross without requiring level-offs or longer track distance to ensure separation.

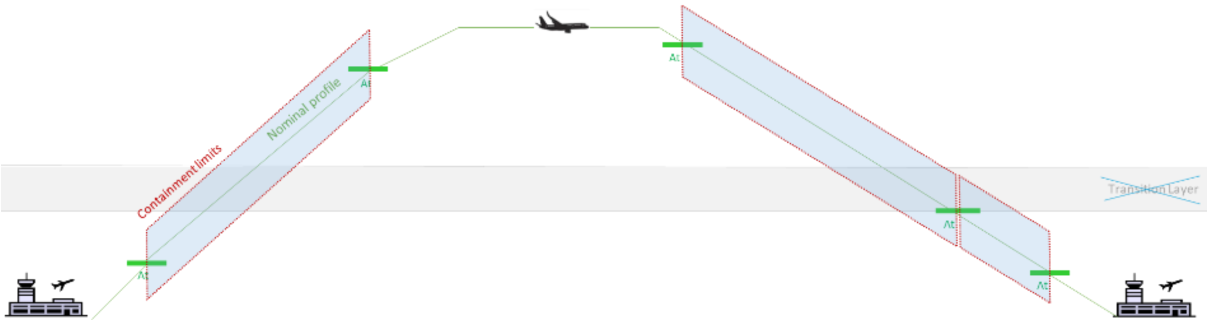


**Figure 2 – Geometric vertical navigation using defined lateral & vertical path**

However, the flight efficiency benefit may be reduced because there is a large diversity of aircraft climb performance and aircraft deceleration performance meaning that any fixed vertical paths cannot be optimised for all aircraft in all weather conditions. This diversity is also likely to grow larger with new entrants. For Example, at the extremes, HAO platforms can take several days to cross FL100 to FL400. Either the procedural vertical profiles would have to be designed following conservative assumptions regarding aircraft climb and descent performance in order to be flyable by all aircraft types in all expected flight and weather conditions, or multiple IFPs covering a range of vertical performance options would have to be provided.

### 3.1.2 Geometric Environment per flight phase

Geometric altimetry for vertical navigation is already being used only in a specific flight phase, final Approach. It is likely that it would be applied in further stages, dictated by the technological capabilities of the aircraft and current methods of operation. Working backwards from Final Approach, each flight phase has its own unique challenges.

**Initial Approach Procedures** – Flight-tested a proof-of-concept capability for geometric Approaches into Frankfurt [30] and Zurich [31] airports found that an accurate start altitude for the IAP (a fixed point for the Flight Management System (FMS) to aim at every time), provided the following benefits:

- Noise reduction of 1.8 dB for an A320, equivalent to an air traffic reduction of c.30%
- Fuel reduction of 6.8% for an Approach into ZRH and 25% into FRA (>20kg per flight)
- Predictability of arrival time for capacity-constrained airport

The DLR studies point to greater benefit in the Initial Approach.

**Descent –** If this were using Geometric Path, aircraft would need to be able to demonstrate vertical capability and containment that does not currently exist. The use of Geometric Constraints in descent still offers fuel and safety benefits:

- Safety benefit due to avoided need for manual change in pressure datum (STD to QNH/QFE)
- Fuel benefit due to improved procedure design ignoring atmospheric variations (pressure and temperature) and the Transition Layer. The full fuel benefits are only obtained if aircraft are allowed to fly their predicted profile, i.e. without ATC intervention.
- Capacity through additional FLs (no Transition Layer); improved vertical containment used with Geo Path could improve this further.

If Geo Alt is used for descent only, a Geo to QNH switch would be required for the start of the Initial Approach meaning the uncertainty in pressure variations would remain (as per the current STD to QNH switch). It could be possible that a manual switch by the pilot is done at a defined point instead of having the SOP variation of today, but it is unclear whether this could be enforced or, indeed, practical.

If a switch between Baro and Geo is needed, it would need to be determined whether the aircraft's navigation system could do this automatically or whether it would need to be a pilot action.

The basic principle for vertical navigation in descent is that the FMS first constructs the vertical path backwards from the end constraint and then, second, must navigate to the vertical path. Today, some FMS can compute a bridge through the Transition Layer; however, the pilot is still relying on Baro altitude reporting.

**Cruise** – Flying at constant geometric altitude instead of equivalent constant barometric altitude does not provide a fuel burn benefit but rather a small disbenefit due to aircraft performance being naturally based on barometric conditions, which evolve along a geometric cruise level due to isobar variations. This prevents the aircraft from consistently flying at the optimum barometric conditions (i.e. those associated to the optimum barometric cruise level).

In addition, if isobar variations along the flight are significant enough, the geometric cruise level may even locally exit the (barometric) maximum recommended altitude "REC MAX" for the given aircraft, flight and weather conditions, which brings additional operational complexity. Indeed, to avoid exceeding the REC MAX, the flight crew would need to monitor the evolution of the barometric altitude along the geometric cruise, and request a step-down level change if it gets too close to REC MAX. Alternatively, the flight could be planned at a lower-than-optimal altitude to increase margin with respect to REC MAX in order to minimise the operational complexity at the cost of decreasing flight efficiency, which is not desirable either.

Therefore, the solution envisages that cruise will remain managed to standard barometric levels (1013 hPa) unless there is a compelling need to move to geometric as part of a broader geometric airspace block, which would provide a network-level benefit, or other Solutions relying on geometric cruise (e.g. RVSM2). For instance, there could be potential for application of geometric cruise in the North Atlantic, but the fallback scenario becomes more complex.

**Climb** – Using Geometric Path in the climb phase would be more complex than using it for the descent phase because, in descent, the vertical path is the primary goal whereas, in climb, the speed schedule is the primary goal, so this logic would need to be changed.

Using Geometric Constraints in the climb phase could offer significant benefits for the network as a whole:

- Safety benefit due to avoided need for manual change in pressure datum (QNH/QFE to STD)
- Greater use of CCOs because SID design ignores atmospheric variations (pressure and temperature) and the Transition Layer. The climb efficiency is likely to be sub-optimal because any fixed gradient would have to cater for a large diversity of aircraft climb performance, so the benefit comes from procedural design eliminating the need for vertical level segments where there are crossing procedures.
- Planned constraints to higher levels – Requires use of Climb Via instructions to enable the full benefit
- Capacity through 3D SID definition
- More efficient design of Controller Airspace borders through reduced profile uncertainty

Geo Alt in climb would yield the greatest benefit if used in combination with Geo Alt on departure and cruise. If applied in isolation, the pilot would need to switch from QNH to Geo after the initial departure phase and then Geo to STD upon reaching the Top of Climb.

**Departure** – There are several factors during the initial departure phase through Thrust Reduction Altitude and Acceleration Altitude, where obstacle clearance is the primary concern. This makes it unlikely that a geometric vertical path could be constructed and navigated to during this phase. However, geometric altitude reporting and vertical navigation to adhere with procedural constraints and obstacle avoidance could be possible if the topography could be mapped to the geoid reference used for geometric altitude under WGS-84 [10]. This would offer benefits:

- Safety – avoids the risk of mis-entry of QNH when using Baro

New integrity systems would be required to support GNSS altitude – there is already some aircraft capability to filter but this would need to be further developed.

Geo Alt in departure would be most efficient if also used in Approach and climb (to support SIDs to FL / CCO). If departure on Geo and Approach (/go-around) on Baro, it could create a safety risk with vertical separation potentially being very small. Complexity would also be added if FIS/GA traffic were on Baro.

### 3.1.3 Mixed Capability Environment

There already is a mixed capability environment with geometric altimetry being used for some Final Approach operations, but everywhere else being reliant of barometric altimetry. If there is a demonstrable cost-benefit to incorporating geometric altimetry in other flight phases, then it is likely that use of Geo Alt will increase. However, airspace and aircraft changes tend to happen over extended periods of time. Therefore, due consideration needs to be given a mixed capability environment.

The introduction of a transition from barometric altimetry to geometric altimetry within aviation, particularly for air traffic controllers, necessitates a thorough examination of the pertinent human



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factors and safety considerations. The initial phase of this transition represents the apex of risk, mandating the implementation of standardised phraseology, rigorous training regimens, initiatives to foster user acceptance, and the seamless assimilation of emergent technological platforms. In a scenario characterised by the coexistence of both barometric and geometric altimetry systems, there will be a shift of where the safety risks are present. There are two potential methods to apply geometric altimetry for vertical navigation for only a proportion of airspace users, whilst others continue to navigate to barometric altimetry, as follows.

(a) Universal barometric altitude reporting with some aircraft using Geo Alt;
(b) Some aircraft using Geo Alt and reporting geometric altitude.

There are already cases of mixed Baro/Geo aircraft capability on the Final Approach. Garmin users already use GPS/SBAS for every type of approach (their fallback solution is Baro Alt), complying with the flight procedure as defined, so will be flying Geo on Baro procedures. However, outside of this, it is paramount among the safety and human factors advantages inherent in the transition that a standardised datum be established across all airspace users within a volume of airspace, thereby facilitating streamlined communication and navigation protocols.

Transitioning to a mixed-mode operation, where both geometric and barometric altimetry are used simultaneously, presents unique challenges. Controllers would need to switch between altimetry modes depending on the aircraft’s equipment, which could increase the likelihood of mode-switching errors, such as issuing incorrect altitude clearances. Additionally, communicating altitude commands in mixed-mode operations may lead to misunderstandings, as controllers must convey commands using both geometric and barometric terminology. This dual terminology increases the risk of communication errors, particularly in high-pressure situations. As a result, mixed-mode operations may temporarily strain situational awareness and elevate workload, particularly until controllers gain proficiency with both altimetry systems. To mitigate these risks, controllers recommended clear visual indicators on displays to highlight an aircraft's altimetry mode and emphasised the importance of standardised training to address potential mode-switching scenarios.

The controller primarily needs to be able to separate and, to do this, they need to know where each aircraft is in relation to each other; therefore, all flights reporting a common altitude datum, even if some are navigating in Geo, would be easier to manage for the controller.

In the PJ.02-W2-04.3 assessment, the FMS navigated to Geo but reported in Baro on Primary Flight Display (PFD) so that both pilot and ATCO could manage it against other traffic. Outside of the Approach, this may be more difficult as the Geo/Baro difference increases.

PJ.02-W2-04.3 proposed a conversion between barometric and geometric, “*The reference for Barometric altitude is Mean Sea Level, whilst the reference for Geometric (GNSS based) altitude is the WGS-84 ellipsoid. To obtain a Geometric altitude with reference to MSL, a conversion needs to take place.*

*The use of the GNSS altitude in the TMA (outside the LPV and GLS FAS) requires the conversion of the GNSS altitude from WGS-84 coordinate system to the ICAO Vertical Reference System (i.e., MSL altitude). This altitude conversion, together with the transition from a Barometric source to a GNSS source, can be managed onboard with different avionic solutions*.” [35]

Electronic Conspicuity with Digital Flight Information Services (D-FIS) will help solve the airspace integration aspects, whilst the base of airspace may need to be defined in both Baro and Geo Alt.

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

There is currently no deviation from the solution definition.

## 3.2 Detailed operational environment

### 3.2.1 Operational characteristics

**Airport / Airspace environment**

Section 3.1 explores application of the concept per individual flight phase (Departure, Climb, Cruise, Descent, Initial Approach). What is notable is that the benefit of geometric altimetry for vertical navigation can only be fully realised by universal application; when applied to only some flight phases or procedures, it can still provide benefits but also provides new complications. For example, if Geo were applied to descent but not to Initial Approach, then arrival procedures may be able to efficiently cross the Transition Layer, but a Geo to QNH switch would be required for the start of the Initial Approach meaning the uncertainty in pressure variations has simply been moved.

Therefore, the end state of this concept is considered applicable to all airspace and all airports. It is also considered applicable to all commercial airline, business aviation, military and general aviation traffic, with geometric reference as the common datum that enables full airspace integration with emerging users, such as UAVs and air taxis.

However, it is highly likely that, before this end state could be reached, there will be a number of transitional stages. The following are envisaged.

1. Geometric Final Approach and Initial Approach. Implementation would be on a case-by-case basis, applicable to airports that currently utilise geometric Final Approach procedures and early adopter airlines and business aviation.
2. Switch from Baro to Geo Altitude constraints within a defined airspace volume. Implementation would be on a case-by-case basis, applicable to airports or TMAs that already utilise geometric Final and Initial procedures by this point and where there are significant procedural inefficiencies that cannot be resolved through design based on barometric altitude. At this stage, all airspace users would operate Geo Alt within this defined airspace volume, including UTM and general aviation; mandates may be applied. Non-capable aircraft may need to be either be managed by exception or segregated.
3. Composite geometric solution applied within a defined airspace volume. Implementation would be on a case-by-case basis, building on applicable airports and TMAs that have already implemented stage 2. All airspace users would operate Geo Alt within this defined airspace volume, including UTM and general aviation; mandates may be applied. Non-capable aircraft may need to be either be managed by exception or segregated.
4. Composite geometric solution applied within an airspace block. Expansion from airports and TMAs that have already applied stage 3, expending to encompass enroute airspace, e.g. at FIR or Functional Airspace Block level. All airspace users would operate Geo Alt within this airspace block, including UTM and general aviation; mandates may be applied. Non-capable aircraft



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may need to be either be managed by exception or segregated. There are likely to be border inefficiencies where Geo and baro cruise operations abut. Therefore, a change to Geo Alt in cruise would need to be a cross-border coordinated implementation, at least at a regional level, e.g. Borealis, FABEC, etc, if not at a global level.

**GNSS operational environment**

GNSS is currently used as the primary navigation source for lateral navigation using Performance Based Navigation (PBN) in the departure, climb, cruise, descent and Initial Approach phases of flight It is also used with SBAS on Final Approach. Coverage is extensive at all altitudes across European airspace. GNSS receivers on commercial airlines, business aviation and military aircraft are commonplace. GNSS is also being used widely by emerging users such as UAVs for navigation, both in the lateral and vertical planes.

In Europe, an implementing regulation for Performance-Based Navigation (Regulation (EU) 2018/1048, also known as PBN IR), was published in 2018. It stipulates that providers of air traffic management/air navigation services (ATM/ANS) and operators of aerodromes must implement PBN routes and approach procedures according to specific implementation deadlines, as follows:

- Implementation by 3 December 2020
- RNP APCH or RNP AR to all Instrument Runway Ends without PA (except some exceptions) and, where required, RF legs
- RNAV 5 for all ATS routes at or above FL150
- Implementation by 25 January 2024
- RNP APCH or RNP AR to all Instrument Runway Ends, and, where required, RF legs
- For all Instrument Runway Ends, RNAV 1 or RNP 1 (including, where required, RNP 1 RF leg and/or vertical paths defined by constraints) for at least one established SID/STAR
- For all Instrument Runway Ends, RNP 0.3 or RNP 1 or RNAV 1 for at least one established SID/STAR for rotorcraft operations
- RNAV 5 for ATS routes established below FL150
- RNP 0.3 or RNP 1 or RNAV 1 for ATS routes established below FL150 for rotorcraft operations
- Implementation by 6 June 2030
- RNAV 1 or RNP 1 (including, where required, RNP 1 RF leg and/or vertical paths defined by constraints) applicable to all SIDs/STARs when established
- RNP 0.3 or RNP 1 or RNAV 1 applicable to all SIDs/STARs for rotorcraft operations when established

As for 2024, the PBN IR implementation is ongoing across Europe despite some observed delays with respect to the initial deadlines.

In very recent years, there has been an increase in GNSS jamming and spoofing occurrences. As per EASA's investigation, this issue particularly affects the geographical areas surrounding conflict zones but is also encountered in the south and eastern Mediterranean and Black Sea, and present in Baltic Sea and Arctic area.

Jamming is a radio frequency interference (RFI) with GNSS signals. This interference prevents receivers from locking onto satellites signals and has the main effect of rendering the GNSS system ineffective or degraded for users in the jammed area. Spoofing involves broadcasting counterfeit satellite signals to deceive GNSS receivers, causing them to compute incorrect position, navigation, and timing data (PNT).



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The effects of GNSS jamming and/or spoofing have been observed by crews in various phases of flight, in some cases leading to re-routing or diversions, to ensure safe continuation of flight, and also triggering false Terrain Awareness and Warning System (TAWS) Alerts.

Detection of jamming or spoofing as well as distinguishing which type of interference is being experienced is difficult, as there are generally no specific flight crew alerts for interference. Depending on aircraft integration, various side effects of jamming have been observed which could be attributed to spoofing and vice-versa.

The magnitude of the issues generated by these interferences depends upon the extent of the area concerned, on the duration, on the phase of flight, and how dependant the aircraft systems on GNSS signals are.

In this context, EASA has published a Safety Information Bulletin (SIB) [29] recommending the implementation of the following mitigating measures for the different aviation stakeholders:

Civil Aviation Authorities:

- Ensure that contingency procedures are established in coordination with ATM/ANS providers and airspace users, and that essential conventional navigation infrastructure, particularly Instrument Landing Systems, are retained and fully operational;
- Implement appropriate and proactive mitigating measures as a matter of high priority, including the issuance of NOTAMs, e.g. describing affected areas and related limitations (as appropriate and determined at State level);
- Facilitate the establishment by ATM/ANS service providers of a process to collect information on GNSS degradations, in coordination with the relevant National Telecommunications Authorities, and promptly notify the related outcomes to air operators and to other airspace users;
- Initiate discussion at a national level to restrict the usage of GNSS jammers;
- Confirm that contents of this SIB are duly considered by air operators, including helicopter operators, ATM/ANS providers, and aircraft and equipment manufacturers.

ATM/ANS providers:

- Establish a process to collect information on GNSS degradations, in coordination with the relevant CAAs, National Telecommunications Authorities, and promptly notify the related outcomes to air operators and to other airspace users;
- Assess the impact of loss or anomalies of GNSS-based timing on CNS systems;
- Issue NOTAMs to provide relevant information to airspace users (as appropriate and determined at State level);
- Provide reliable surveillance coverage that is resilient to GNSS interference, as well as maintain essential conventional navigation infrastructure operational (Instrument Landing Systems, Distance Measuring Equipment (DME), Very High Frequency omnidirectional range (VOR)) in support of conventional navigation procedures;
- Ensure that their contingency plans include procedures to be followed in case of large-scale GNSS jamming and/or spoofing events;
- Monitor the traffic closely to prevent any deviation from the flight track/route;

Air operators, including helicopter operators, should:

- Ensure that flight crews are aware of and trained on the importance of prompt reporting by means of a special air-report (AIREP) to air traffic services of any observed interruption, degradation or anomalous performance of GNSS equipment or related avionics (e.g. map shifts, suspected GNSS spoofing, position and duration of the GNSS interference);

- Evaluate different possible scenarios based on the type of operations in order to provide the flight crew with timely information to increase awareness of jamming and spoofing;
- Ensure that GNSS outage or spoofing topic is included in the flight crew ground recurrent training, highlighting the identified operational scenarios to recognise, react in a timely manner to different jamming and spoofing cases;
- Assess operational risks and limitations linked to the loss of on-board GNSS capability, including any on-board systems requiring inputs from a reliable GNSS signal;
- Ensure that operational limitations introduced by the dispatch of aircraft with inoperative radio navigation systems in accordance with the Minimum Equipment List, are considered before operating an aircraft in the affected areas;
- Ensure, in the flight planning and execution phase, the availability of alternative conventional arrival and approach procedures (e.g. an aerodrome in the affected area with only GNSS, including augmentation, approach procedures should not be considered as destination or alternate);
- If subject to Flight Data Monitoring (FDM) requirements and necessary data are available, use FDM programme to identify and assess GNSS spoofing events;
- Concerning spoofing: contact aircraft or equipment manufacturers for instructions on how to deal with spoofing cases of their products and implement the recommendations in the Standard Operating Procedures.
- Ensure that flight crews follow specific recommendations for jamming mitigation:
  - be aware of possible GNSS jamming;
  - verify the aircraft position by means of conventional navigation aids when flights are operated in proximity to the affected areas;
  - check that the navigation aids critical to the operation for the intended route and approach are available;
  - remain prepared to revert to a non-GNSS arrival procedure where appropriate and inform air traffic services in such a case; and
  - report (AIREP) to air traffic services any observed irregularities.
- Ensure that flight crews follow specific recommendations for spoofing mitigation:
  - be aware of possible GNSS spoofing;
  - continuously monitor aircraft position using non-GNSS navaids and all available automatic navigation accuracy calculations, including the Estimated Position Uncertainty (EPU) figures;
  - Monitor the GNSS time versus non-GNSS time sources;
  - Closely monitor the ATC Frequencies in the vicinity of spoofing area;
  - Apply the manufacturer's instructions for the aircraft type on dealing with suspected spoofing.

Aircraft and equipment manufacturers:

- Support Air operators, by providing instructions to follow on how to deal with suspected GNSS spoofing events, when using their products.



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### 3.2.2 Roles and responsibilities

Regarding ATCOs, when qualitatively assessing roles and responsibilities, it was indicated that switching from barometric to geometric altimetry within the current airspace structure would likely have minimal impact on controllers' daily tasks, workload, and situational awareness.

However, transitioning to a geometric altimetry system in a more systemised airspace with defined lateral and vertical paths would shift the controller's role from active control to a primarily monitoring role. This change could introduce complexities and potentially decrease situational awareness, as controllers may need to continuously monitor rather than actively control aircraft trajectories, increasing the risk of missed deviations.

Additionally, in emergencies or system deviations, controllers in a primarily monitoring role might face sudden demands for active decision-making, which could be overwhelming, especially for those less experienced in handling barometric operations. In such cases, if the fallback requires reverting to barometric altimetry, controllers may experience a significant decrease in situational awareness and an increase in workload, which could be particularly challenging for newer controllers who lack barometric experience.

Regarding Flight Crews, no dedicated Human Performance assessment has been conducted at this maturity level, but some results of the aircraft impact assessment are related to flight crew operation.

In Solution 0406, the flight crew, supported by the aircraft systems and the EFB, would be able to:

- Deal with Departure, Arrival and Approach procedures published with geometric altitude constraints (regarding AIM data, flight plan management, vertical navigation, ATC communications, etc).
- Deal with Arrival and Initial/Intermediate Approach procedure segments published with fixed geometric vertical angle, and ensure compliance with vertical containment assumptions on such segments.
- Monitor automatic transition or perform manual transition between geometric and barometric flight phases (and vice versa) in nominal conditions.
- Manage non-nominal operation requiring fallback to barometric altimetry, including automatic or manual geo-baro reversion and related ATC communications.

Operating arrival and initial/intermediate approach procedures with fixed vertical angle segments may bring operational challenges related to speed management considering the diversity of aircraft performance. Indeed, aircraft deceleration along a fixed vertical angle is not the most operationally efficient, since in some cases aircraft may need to start deceleration very soon and with a low deceleration rate, both of which may be operationally unpractical for flight crew and ATC. That said, Solution 0406 can be deployed with or without this airspace design feature depending on the local needs, and the use of such fixed vertical angle segments can be limited to the smallest extent possible.

An operational challenge common to whatever airspace structure implementing geometric altimetry is related to the fact that aircraft performance remains intrinsically linked to barometric conditions, meaning that aircraft flight envelope, climb & descent performance, fuel consumption, etc., are still depending on barometric altimetry. The phase of flight most impacted by this would be Cruise, but it has not been retained as part of the core Solution scope (see 4.2). For the use of geometric altimetry limited to Climb, Descent and Approach, systems-based solutions for airborne predictions could be enough to prevent impact on flight crew operation.

Last but not least, it may be expected that the management of loss of GNSS by operational actors in TMAs implementing geometric altimetry could lead to a higher increase of workload than in barometric-based TMAs. That's why mitigation means for the increasing GNSS jamming & spoofing threats have been identified as a pre-requisite for the deployment of the Solution (see 4.3).

| Node | Responsibilities |
|---|---|
| Aerodrome ATS | Performs all the aerodrome ATS operations.<br><br>[RELATED ACTORS/ROLES]<br>Runway controller, ground controller, etc. |
| En-Route/Approach ATS | Performs all the enroute and approach ATS operations.<br><br>[RELATED ACTORS/ROLES]<br>Executive controller, planning controller, etc. |
| Flight Deck | Performs all the on-board AU operations including flight execution/monitoring according to agreed trajectory, compliance with ATC clearances/instructions, etc.<br><br>[RELATED ACTORS/ROLES]<br>Flight Crew |

**Table 4: roles and responsibilities**

### 3.2.3 CNS/ATS description

**GNSS systems**

The ECAC region is covered by several GNSS core constellations: GPS (United States), Galileo (European Union), GLONASS (Russian Federation), and BeiDou (China), as well as by one SBAS augmentation system: EGNOS (European Union).

Very few GBAS augmentation systems are deployed.

Global aviation GNSS capabilities have traditionally relied mainly on just one core constellation and one frequency via GPS L1, but new standards have been developed for Dual Frequency Multi-constellation capabilities, which is expected to improve the performance and robustness of GNSS-based navigation.

However, the use of GNSS core constellations may be subject to national restrictions due to liability and/or sovereignty policies, which may constraint the usability of the multi-constellation capability.

SESAR Geo Alt solution addressed by Green-GEAR is not initially assuming Dual-Frequency Multi-Constellation (DFMC) capability as a pre-requisite for the operational concept.

Also, it is to be noted that the use of SBAS augmentation by large commercial aircraft for navigation and guidance is currently limited to LPV and LP approaches only. This is due to the navigation architecture of such aircraft outside such operations being based on tightly coupled GPS+IRS positioning.

SESAR Geo Alt solution addressed by Green-GEAR is not initially assuming as a pre-requisite for the operational concept the use of SBAS augmentation for navigation and guidance outside Final Approach, at least not for aircraft currently equipped with GPS+IRS navigation capabilities.

SESAR Geo Alt solution will rather follow a performance-based approach, where an equivalent to ICAO Annex 10 detail of ICAO SARPS [10] for non-augmented GNSS in Final Approach could be applied all Geometric altimetry in other flight phases and an equivalent for vertical as well as horizontal.

For obstacle clearance under barometric/orthometric procedure design, obstacles are based on contour height plus building/obstruction height. Using a geometric ellipsoid would require a measurement in 3D space. Therefore, a possible reference source could be to define (x,y,z) 3D coordinates in space relative to the centre of the earth, which is a technique used in space dynamics. WGS-84 [10] supports Galileo and is the globally recognised standard for GNSS. Other solutions exist, such as PZ-90 for GLONASS, but WGS-84 is considered the most likely global solution.

The Coordinate Reference Systems (CRS) used will be WGS-84 for worldwide Geographic location points. WGS-84 uses an ellipsoid as a 'best fit' for the world, which works better if some regions than others. In some regions, a static geometric altitude may take aircraft further away from, or closer to, the earth. Curvature of the earth effects are seen from 10nm so procedure designers may have to take this into account. Obstacle clearance already uses the geoid referenced to Average Mean Sea Level (AMSL), where the obstacle elevation is a surveyed distance from AMSL and the local datums for an airport (Aerodrome, Threshold Departure End of Runway) are also measured from AMSL. Applicable standards and regulations

The following Standards and Regulations apply to this concept

EUROCAE ED-323 / RTCA DO-229, Minimum Operational Performance Standards (MOPS) for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment".

EUROCAE ED-75 / RTCA DO-236, Minimum Aviation System Performance Standards (MASPS), Required Navigation Performance for Area Navigation

ICAO Annex 2 (Rules of the Air) – Additional code in fields 10 and 18 of the ICAO flight plan. Enables assignment of capability to routes.

ICAO Annex 15 (as publication standards in the AIP for Geo Alt will be required)

ICAO Doc 8168 PANS-OPS.

ICAO Doc 9613, PBN Manual.

ICAO Doc 9674, World Geodetic System – 1984 (WGS-84) Manual

ICAO Doc 9854, FF-ICE.

EASA Safety Information Bulletin (SIB) No. 2022-02R2

## 3.3 Detailed operating method

### 3.3.1 Previous operating method

This sub-section describes the situation without the SESAR solution.

Geometric altimetry for vertical navigation is used for specific operations on Final Approach, including Approach with Vertical Guidance LPV, SBAS or GBAS or RNP APCH using LNAV/VNAV. These procedures are reliant on single constellation GNSS. Technically, the ILS or MLS also provides a geometric path. The transition from a barometric Initial Approach to a geometric Final Approach creates an unpredictable transition.

Outside of the Final Approach, commercial aircraft, military aircraft and general aviation rely on a barometric pressure model to determine altitude. Both geometric and barometric altitude is broadcast by the aircraft, but only barometric altitude is reported and used for navigation. This commonality of pressure datum ensures traffic can be safely separated. However, at lower altitudes, the datum is based on the pressure local to the proximate airfield (QNH), which is typically the origin or destination airfield. At higher altitudes, the datum is based on standard pressure (STD), which is 1013 hPa, providing commonality across all airspace globally through the use of Flight Levels. This model requires that there be a Transition Layer between where local and standard pressure datums are used. The altitude of the Transition Layer varies from state-to-state and sometimes within an FIR. Setting and changing the pressure datum is reliant on manual action by the pilot and airline Standard Operating Procedures (SOPs) vary in terms of when the change is actioned. Typically, SOPS dictate either:

(a) The pressure datum is changed at the altitude the aircraft reaches the Transition Layer, or
(b) The pressure datum is changed at the time the flight is cleared to an altitude on the other side of the Transition Layer.

There is a safety risk that incorrect entry of QNH will lead to an incorrect indication of onboard altitude, which could lead to insufficient terrain clearance or a level bust.

There is a capacity limitation due to pressure variations compared to STD pressure leading to loss of highest useable Altitude and lowest usable Flight Level.

There is a fuel burn inefficiency because flight profiles are constrained by procedural constraint that are necessary to account for the Transition Layer.

An additional complexity is that the altitude of the Transition Layer can vary between 3,000 ft and 18,000 ft depending on the country, and even from region to region within a country. For example, in the UK the Transition Altitude is 3,000 ft outside of controlled airspace and generally 6,000 ft within controlled airspace, except for Manchester TMA which is at 5,000 ft. By contrast, the USA and Canada use a common 18,000 ft Transition Layer.

There was a big push for a common European Transition Altitude but, after detailed project work, the idea was abandoned due to cost and practicality issues

Outside of the Final Approach, vertical containment is only assured at waypoints that have altitude constraints associated with them. This enables aircraft to determine their own the profile in-between the waypoints so long as they comply with the waypoint constraints. From an ATC perspective, this leads to large uncertainties about where the aircraft could be in the vertical plane in-between waypoints. With experience, the controller will know what to expect, which reduces tactical uncertainty considerably; however, this uncertainty significantly impacts procedure design, meaning large volumes of airspace need to be allowed for.

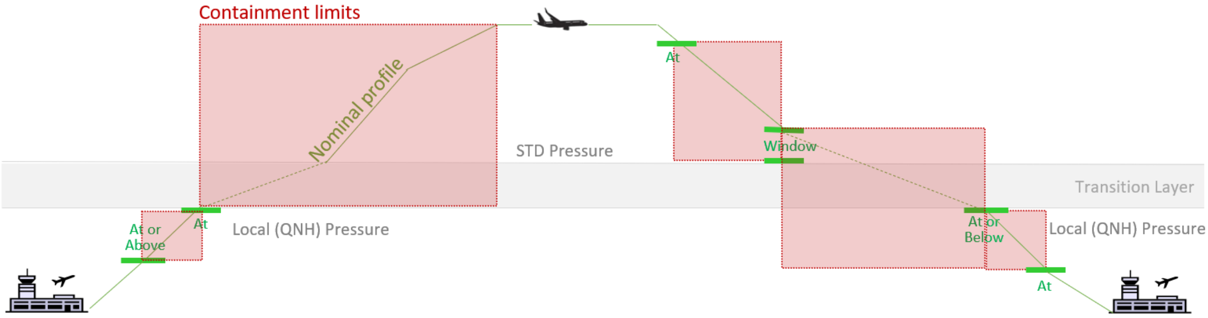


**Figure 3 – Previous Operating Method using Barometric Altimetry**

The Minimum Aviation System Performance Standards (MASPS) Required Navigation Performance for Area Navigation [8] set out that RNP RNAV systems can navigate to a constructed geometric vertical path in Approach, within the VPPL. Further, that RNP RNAV systems are able to construct a geometric point to point path on Descent as well as Approach. However, current FMS systems only build geometric point to point segments during Descent and Approach (outside Final Approach Segment) when the use of an optimal flight profile would not comply with the altitude constraints.
In addition, it is to be noted that, unlike Final Approach Segment, such geometric segments are not based on a published vertical angle but on the bounding altitude constraints. Therefore, no operational credit is given for navigating to the geometric path outside of the Final Approach segment.

The MASPS do not include the geometric point to point segment capability for the climb phase. The whole concept of flying to a speed schedule would need to change to enable the aircraft to follow a geometric path in climb.

In cruise, aircraft fly along the isobars meaning that the geometrical cruise level fluctuates according to pressure variations. This results in small climbs and descents during cruise flight when the atmospheric pressure is changing and thus it results in small changes of the required engine thrust. However, flying along the isobars ensures that the flight state with respect to the surrounding atmosphere is not changing due to pressure variations and thus the aerodynamic drag of the aircraft remains constant. This reduces thrust fluctuations that would occur when using geometric altimetry. It needs to be assessed which of these counteracting effects would outweigh the other when using geometric altimetry instead of barometric altimetry and thus if the thrust fluctuations and the fuel burn would be increasing or decreasing.

Emerging airspace users, such as delivery/inspection/survey drones and air taxis use geometric altimetry for vertical reporting and navigation in all phases of their flight. This puts them on a different altitude datum to crewed commercial aircraft, military aircraft and general aviation.

## 3.3.2 New SESAR operating method

This sub-section describes the situation with the SESAR solution; however, the scope of geometric altimetry is broad, so the project concept focuses on key focus areas rather than providing an exhaustive account.



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#### 3.3.2.1 End State

This section describes the target concept end state in a universal geometric environment, following method 2 identified in Section 3.1.1. A number of developments are assumed, these are specifically identified in Section 4. The key elements of this concept cover the following focus areas:

- New vertical capability requirements
- Cruise impact (aircraft cruise level not impacted by pressure variation)
- Fuel efficiency assessment, including greater CDO and CCO ignoring atmospheric variations (pressure and temperature) and the Transition Layer.
- Fuel efficiency through improved airspace design due to improved vertical containment balanced against the impact of constraining individual flight efficiency.
- Impact of improved accuracy/consistency of altitude on performance (predictability, safety, workload, fuel efficiency and noise impact)
- Capacity – do not lose Flight Levels at the Transition Layer due to pressure variation
- Safety and Human Performance aspects, for example avoiding risk due to mis-entry of QNH
- Fallback for GNSS
- Baro and Geo altitude are both available in the cockpit and are both downlinked from the aircraft to the ATC ground system
- The system capability needed to take both Geo and Baro inputs and present the relevant altitude to the Controller Working Position (CWP).

All aircraft are now required to use geometric altimetry at the primary reference for altitude reporting and navigation, with GNSS being the primary navigation source, supplemented with SBAS, or equivalent, capability. This applies both inside and outside of controlled airspace, meaning there is a common altitude datum used by both long-standing (commercial aircraft, military aircraft and general aviation) and emerging (delivery/inspection/survey drones, air taxis and High-Altitude Operations) airspace users.

On Final Approach, there remains a mix of methods using geometric altimetry, such as LPV, SBAS, GBAS and RNP APCH using LNAV/VNAV. There is an efficient and predictable transition from initial to Final Approach phase; the pilot knows the flight path and configuration in advance and there is no need to switch height datums when transitioning. The accuracy and consistency of altitude gives improved performance in terms of predictability, safety, workload, fuel efficiency and noise impact.

Outside of Final Approach, new vertical capability requirements are based on a ‘composite solution’ for a fully geometric TMA, which utilises a mix of Geometric Constraints and Geometric Path:

1) **Geometric Constraints** - Instrument Flight Procedures define a set of geometric altitude constraints at waypoints and the vertical path between constraints is defined by the aircraft navigation system
2) **Geometric Path** - Instrument Flight Procedures define the geometric path that the aircraft FMS has to follow.

With method 1, vertical containment is only assured at waypoints that have altitude constraints associated with them. This means ATC still have large uncertainties about where the aircraft could be in the vertical plane in-between waypoints and this uncertainty still adversely impacts procedure design. However, a Transition Layer is no longer required, which greatly improves the efficiency of airspace and procedure design, notably:

- Greater CCO and CDO design is possible without concern for atmospheric variation and the Transition Layer, and there is an improved transition efficiency onto Approach.
- Local pressure (QNH) is still entered into the FMS but is only required for fallback procedures (as above), greatly reducing the risk of incident in the event of QNH mis-entry.
- There is greater airspace capacity around where the Transition Layer would be, with no loss of level bands.

With method 2, geometric altimetry enables Vertical RNP through new vertical containment requirements, which provides additional airspace capacity and the opportunity to optimise route network design. Vertical containment is assured all along the flight profile as the flight meets the procedurally defined path within acceptable tolerance. This procedural constraint all along the path inhibits fuel efficiency for the individual flight. However, the greatly reduced uncertainty of both lateral (PBN) and vertical (V-RNP) profile enables maximised use of the available airspace to optimise the efficiency of airspace design. Therefore, an overall fuel efficiency and environmental benefit might potentially be seen at the network level.

In the composite solution, Geometric Path is used for Initial Approach, deriving the safety and efficiency benefits in the interface between Initial and Final Approach. By default, Geometric Constraints are used in Climb and Descent, enabling airspace design efficiencies ignoring atmospheric variations (pressure and temperature) and the Transition Layer.

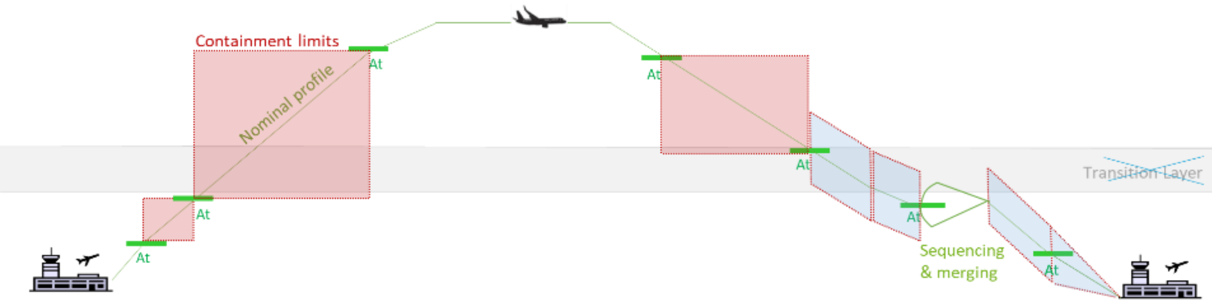


**Figure 4 – Illustration of the Composite Geometric TMA Solution, combining Geo Constraints and Geo Path**

For contingency, the pilot still sets local pressure (QNH/QFE) and has both geometric and barometric altitude references available to them in the cockpit. Barometric altitude is still downlinked to the ATC ground systems and is available at the controller working positions.

In the Navigation Database, geometric procedures are tagged as such, to differentiate them from barometric.

Geometric Path is used for sections of the Descent where containment is required for procedural deconfliction with other STARS or SIDs. From an airspace design perspective, Geo Path in descent is the most efficient – particularly if used in combination with Geo Path on the Initial and Final Approaches, allowing a fully designed 3D profile. Initial Approaches are designed to interface with Final Approach Segments / glideslope without a level deceleration segment but one or more shallower descent phases may still be required to enable deceleration and minimise the risk of energy management issues.

In high complexity traffic environments, an interruption to the descent path may be necessary to design in sequencing and merging capability for multiple arrival streams, such as Trombone or Point Merge procedures. However, descent interruptions can be minimised through design – for example, using Point Merge sequencing legs without level segments; such concepts have been developed by EUROCONTROL.

From an aircraft flight efficiency perspective, the less the vertical profile is constrained, the more efficient the calculated descent profile will be. Therefore, limiting the duration of Geometric Path segments reduces the inefficiencies to the individual flight of having to adhere to a fixed gradient and so minimises the risk of energy management issues.

The use of Geo Path for Climb has been demonstrated to be practical and potentially beneficial from an airspace design perspective. However, achieving a beneficial design is difficult and the level of change to the aircraft systems is significant. Climb performance varies significantly due to aircraft type, weight, wind and temperature so any airspace design may require different SIDs for different aircraft categories to be effective or be limited to the lowest common denominator. From an airspace design perspective, Geo Path in climb offers the most predictable design in 3D. However, from an aircraft flight efficiency perspective, the more the vertical profile is constrained, the more challenging it would be for the individual flight to comply with the profile. Significant navigation system changes would be required; they would need to predict the whole climb profile instead of just the next waypoint and would need to prioritise vertical path compliance over speed schedule.

Therefore, Geo Path in Climb should only be considered for highly congested airspace, and as part of a composite solution together with Geo Path in Descent and Approach. If this option were to be progressed, the following limitations would have to apply:

- Geo Path in Climb only where necessary for deconfliction; limit fixed vertical angle paths to the smallest extent possible. Where possible, avoid using fixed vertical angle paths at low altitudes where aircraft would normally be accelerating from take-off speed to climb speed.
- Where fixed angle paths are required, consider the diversity of aircraft climb performance under all reasonable meteorological conditions, for example by publishing two alternative departure procedures with different vertical profile, one for high climb performance traffic and other for low climb performance traffic.
- Geo Path in Climb to allow for tapering climb profile where necessary: progressively decrease the required vertical angle along subsequent segments of the departure procedure.
- Where possible in the airspace design (i.e. without significant detriment to the overall design efficiency), still rely on Geo constraints at waypoints (Option 1), allowing the use of optimised FMS profile in descent and allowing free climb profile.



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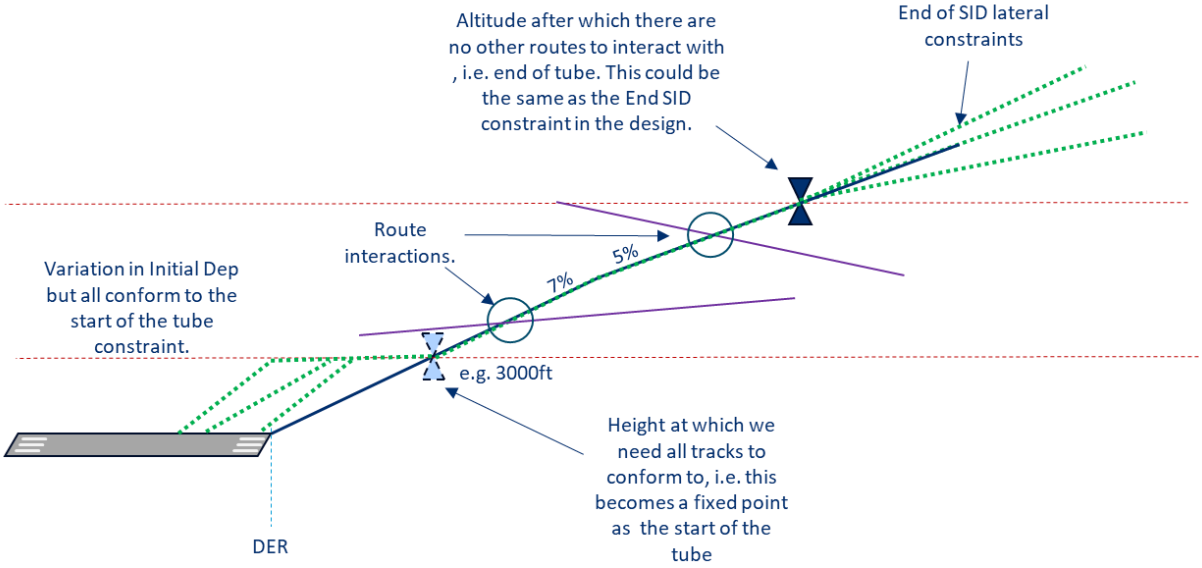


**Figure 5 – Potential application of Geo Path in Climb (not part of recommended composite solution)**

ATC use ground-based conformance monitoring tools to continuously monitor flights against the procedural Geometric Path, as well as adherence to Geometric Constraints at procedural waypoints.

Using these conformance monitoring tools, pilots and controllers are able to recognise GNSS degradation, or loss, and safely manage with suitable contingency and fallback measures.

Dual-Frequency Multi-Constellation (DFMC) receivers allow for redundancy in the GNSS signal. Onboard inertial systems and ground system navigation aids provide short-term contingency for safety. In the event of a sustained widespread loss of GNSS, there is a procedural fallback to barometric altitude enabling ATC to clear the skies and provide a continued service.

Where Geo Path is implemented, aircraft navigation systems provide onboard alerting capability in the vertical plane equivalent to that in the lateral plane. An RNP system requires on-board performance monitoring and alerting, as defined in the ICAO PBN Manual [9] and this has now been extended the vertical plane so that a caution is provided to the pilot when the navigation system does not comply with the containment integrity requirement of the current Vertical-RNP.

What constitutes an acceptable tolerance would need to be calculated and assessed at a higher maturity level of the concept. However, For the purposes of this project, a credible figure needs to be chosen to support the basis for route separation in the test case airspace design to be assessed. To determine this figure, the concept follows the logic for lateral accuracy and applies to the vertical plane.

The Minimum Aviation System Performance Standards (MASPS) Required Navigation Performance for Area Navigation [8] specify that the total system error components in the cross-track and along track directions that are less than the RNP 95% of the flying time. The ICAO PBN Manual, section 5.3.3.1.2, [9] specifies, "*The installed RNP system is required to provide an alert if the accuracy requirement is not met, or if the probability that the lateral TSE exceed 2xRNP NM is greater than 1x10-5per flight hour. The alert must be consistent with RTCA DO-236(), DO-283(), DO-229() and EUROCAE ED-75().*" The MASPS, section 1.3.2, states, "*Following consideration of typical performance of existing navigation systems and evaluating what was necessary to obtain operational benefit, a lateral containment limit of two times the RNP (2xRNP) has been chosen*". If this is the track containment, Minimum Radar Separation has to be added to ensure no losses of separation. The MASPS specify that



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vertical performance shall have total system error components in the vertical direction that are less than the specified performance limit 99.7% of the flying time, which is better than the lateral case. In this case, Vertical Path Performance Limits (VPPL) are defined for the navigation system. The VPPL is specified for level flight and descent, relative to altitude; the largest limit is 260 ft.

For the end concept, we are assuming that Geo Alt can be used equally in climb and descent, therefore, the VPPL values are assumed to hold true for the climb as well.

Therefore, the vertical route separation rules for the geometric test case airspace design will be based on:

- **Routes crossing or overlapping whilst in level flight**= 1,000 ft
- **Route crossing or overlapping whilst one or both are not in level flight**= 1,520 ft

Where,
1,000 ft is the minimum separation, and
2 x VPPL + minimum separation = 1,520 ft

Instrument Flight Procedures are defined with a vertical tolerance as per the VPPL and these are codified using Vertical Scale Factors, which are defined in ARINC 424 as follows.

"*Section 5.293 Vertical Scale Factor (VSF) is used to set the vertical deviation scale. Source/Content: VSF values derived from official source will be used when available. They are entered into the field in feet (three digits). The content can be: When used on Enroute Airway segments, VSF shall apply inbound to the fix when viewed in decreasing sequence number order. The VSF applies only to the airway leg on which it is specified. If no VSF value is coded on a segment, there is not a database specified VSF for that segment. When used on a SID, STAR, Approach Transition or Missed Approach record, the VSF shall apply to the balance of the procedure route unless superseded by another value of VSF on a subsequent record. Procedure route must be determined by the Route Type field (see Section 5.7). When used on Final Approach records, VSF must apply to the waypoint referenced by the Final Approach record. Used On: Enroute Airways, SID, STAR and Approach Route and Controlled Airspace Records, Holding Pattern Records Length: 3 characters Character Type: Numeric Examples: 250, 100, 050*"

Airspace design carefully balances the efficiencies of design afforded by Geometric Constraints and Geo Path against the constraints on the individual flight. For example, fixing a descent profile in an instrument flight procedure would have to allow for the lowest common denominator considering all weather conditions. If the path is too steep or if there are strong wind conditions, some flights may end up in overspeed (even though it may be manageable for other aircraft types), but if the path is shallow enough to deal with all situations, it will be environmentally inefficient. Therefore, it is prudent to limit the length and application of the Geo Path segments.

The improved containment afforded by Vertical RNP allows for greater scope in definition of STARs and IAPs, i.e. descent profiles can be more targeted to traffic requirements with the potential to offer multiple profile options to suit different vertical performance of different aircraft under different meteorological conditions.

With the increased spatial predictability offered by Climbs using Geometric Constraints and the 3D containment of descent procedures using Geo Path, traffic density in TMA airspace is increased. Therefore, in situations such as convective weather there will be a greater amount of traffic for the controller to deal with; however, there is an increased number of routes options for the controller to use.



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In systemised airspace, adopting geometric altimetry may increase RT demands and potentially create operational challenges, whereas in non-systemised (todays airspace), geometric altimetry offers the potential to reduce RT load and improve communication clarity by minimising QNH readbacks. Removing the Transition Layer and fully implementing geometric altimetry could enhance safety by reducing altitude-related errors, particularly QNH discrepancies that contribute to loss-of-separation risks.

### 3.3.2.2 Transition Stages

The transition stages see a mixed capability environment, following scenario 2 identified in Section 3.1.2.

While geometric altimetry could significantly enhance efficiency and safety in a fully systemised airspace, the transition from barometric to geometric altimetry requires careful planning and robust support systems.

A successful shift to geometric altimetry, particularly in a fully systemised airspace, relies on integrating technological, procedural, and training adjustments to maintain situational awareness, minimise workload, and enhance safety.

Transitionary factors, particularly in mixed mode operations, require significant attention as the controllers emphasised the importance of effective tools, such as conformance monitoring, clear visual indicators and consistent phraseology to distinguish between barometric and geometric operations, especially when in failure scenarios. Training will play a critical role in ensuring controllers and pilots are equipped to manage new procedures effectively. The dual terminology required for transitionary mixed-mode operations significantly raises the risk of miscommunication, particularly under high pressure conditions or emergencies. In such scenarios, inadequate communication could result in pilots and controllers misinterpreting altitude instructions, leading to separation breaches or conflicting trajectories.

A switch from barometric to geometric constraints without changing the airspace was considered to be relatively simple and may results in managing less complex and easier interactions. However, with the development of an airspace change to a more optimised airspace, this in turn impacts the severity of the effect on roles, technology, communication and training for the controller.
With the progression to a more systemised airspace, every step of this transitionary period would require an in-depth human performance and safety assessment, to further investigate the impact. Such a transition would, in the end, involve significant changes in controller roles and responsibilities, require advancements in technology, updates to communication and teamwork, as well as extensive training requirements, as such influencing the impact on human performance.

To safely separate traffic, the controller needs to know where each aircraft is in relation to one another. Therefore, all aircraft will report a common datum altitude, even in a mixed capability environment, where some aircraft use geometric altimetry and others still rely on barometric altimetry. This enables geometric and barometric traffic to be managed in the same environment.

Both Baro and Geo aircraft altitude is available in the cockpit, and both are downlinked from the aircraft to the ATC ground system. The ATC system capability takes both Geo and Baro inputs and presents the relevant altitude to the Controller Working Position.

Given the points raised in section 3.1.2, it is likely that geometric altimetry for vertical navigation will be implementable from cruise to approach before departure to cruise. Therefore, transitory stages



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must be considered. The following are considered logical steps based on a balance of practicality and operational need.

**Step 1 – Final Approach & Initial Approach**
Extending geometric operations from Final Approach back into the Initial Approach would be the first logical step because this is where the aircraft's Geo Alt capability is most mature and would yield safety and efficiency performance benefits with the least complexity added to ATC procedures.

With barometric, the actual altitude that an aircraft intercepts the Final Approach glideslope will vary depending on weather conditions. These altitude variations necessitate a shallow segment to ensure glideslope capture, which is inefficient.

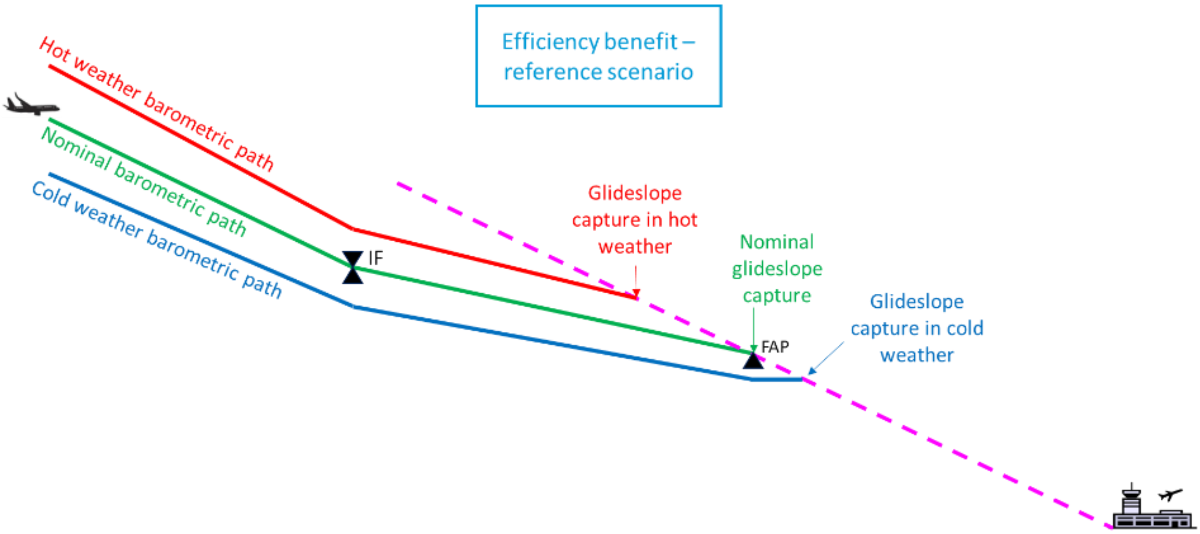


**Figure 6 – Transition State, Step 1: Efficiency Benefit, Reference Scenario**

ICAO Doc 8168 and related IFP design criteria account for altitude variation at the FAP by adding an extra margin (stabilisation segment) between the RWY threshold and the FAP to permit the aircraft to capture and being stabilised on the ILS Glide Slope [35].

With geometric, flight paths are not dependent on weather conditions so there is no need for a shallow segment, which reduces fuel and $CO_2$ emissions as well as noise impact to local communities.




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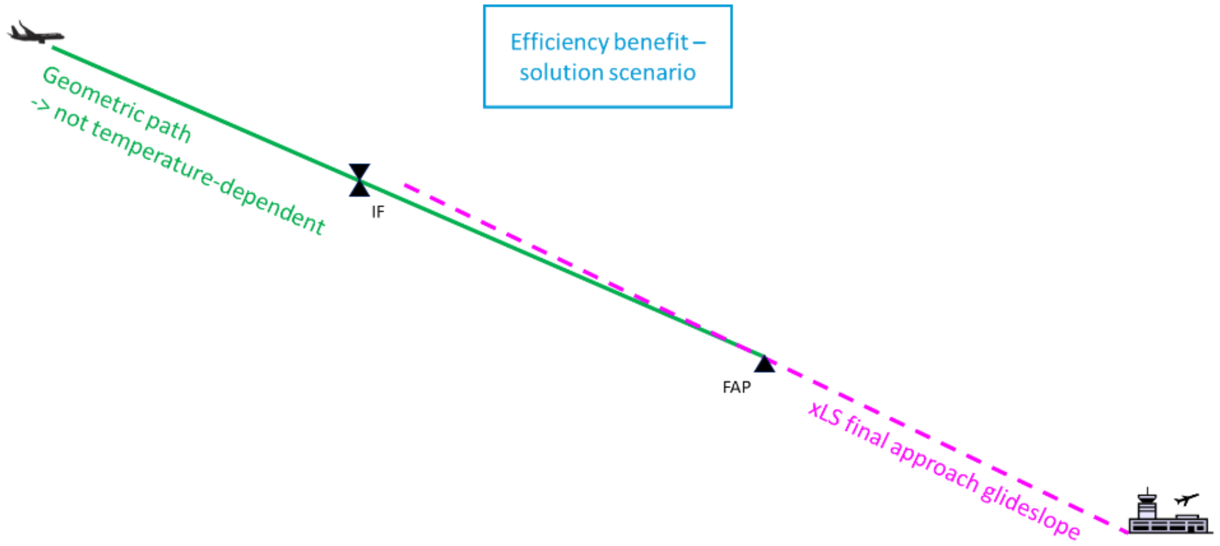


**Figure 7 – Transition State, Step 1: Efficiency Benefit, Solution Scenario**

Also, the risk of glidepath overshoot and go-arounds is reduced. Late ATC clearance combined with hot weather conditions can lead to situations where the aircraft has already crossed the glideslope meaning the flight crew has to take over and dive to capture the glideslope from above. This may be feasible, but undesired for approach stabilisation purposes

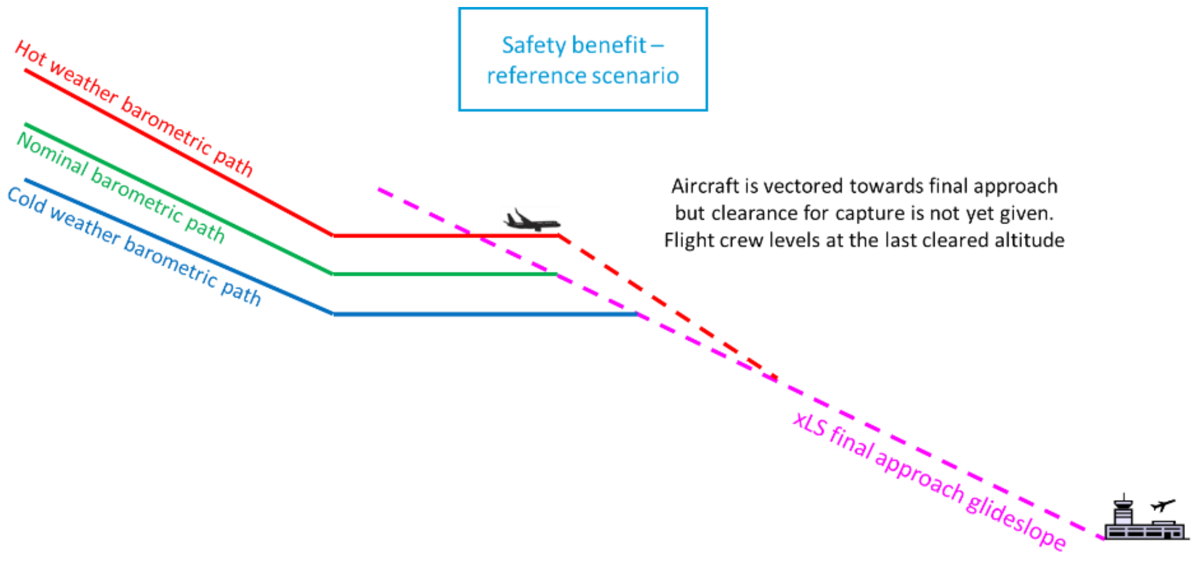


**Figure 8 – Transition State, Step 1: Safety Benefit, Reference Scenario**

With geometric, flight paths are not dependent on weather conditions so there will be consistency in altitude and lateral position, even if level segments are retained for glideslope capture. If a late ATC clearance is given, the aircraft is still in a position to capture the glideslope normally or with minimal flight crew intervention.

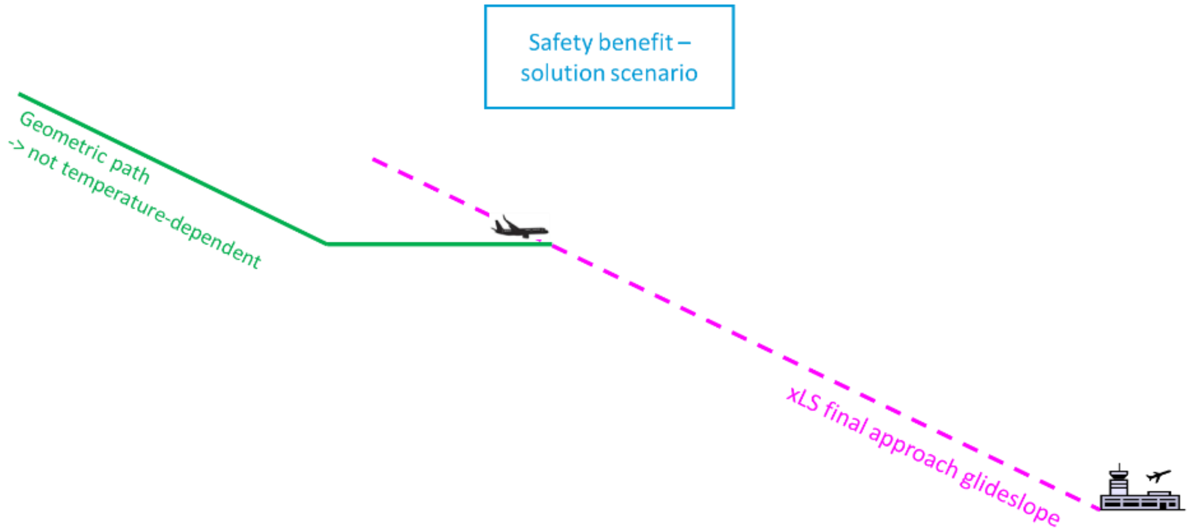


**Figure 9 – Transition State, Step 1: Safety Benefit, Solution Scenario**

There would be an interface between barometric and geometric as the aircraft transits from the STAR to the Initial Approach Procedure. This may require an extended IAP to enable Baro to Geo capture under all meteorological conditions. Curved tracks (like a point merge sequencing leg but where you can hit any part) could be implemented for this purpose; potentially, using extended GBAS curved Approaches.

**Step 2 –Switch from Baro to Geo Altitude constraints within a defined airspace volume**

All altitude constraints within a defined airspace volume, e.g. TMA, switched from Baro to Geo Alt, with no airspace redesign.

Geometric altimetry is introduced alongside current lateral path operations. Airspace structures remain unchanged, and the focus is on enhancing accuracy without redesigning instrument flight, procedures, sectors or separation standards. This approach involves moderate updates to training and procedures to incorporate geometric data to cover the removals of the Transition Layer.

This would move the volume of airspace onto a single geometric datum, providing a platform for airspace change. However, the straight switch would offer benefits without airspace change:

- Under normal operations, the need to use local pressure, manually set by the pilot, is not required, which reduces the risk of manual error leading to a loss of separation
- Vertical profiles are more predictable, making vertical interactions less complex and easier for the controller to manage, which reduces the risk of a loss of separation
- Controller workload reduction, supporting both of the previous points
- Small fuel benefits because the weather dependency of the altitude constraints is removed as shown in Figure 6 and Figure 7

All airspace users would operate Geo Alt within this defined airspace volume, including UTM and general aviation; mandates may be applied. Non-capable aircraft may need to be either be managed by exception or segregated.

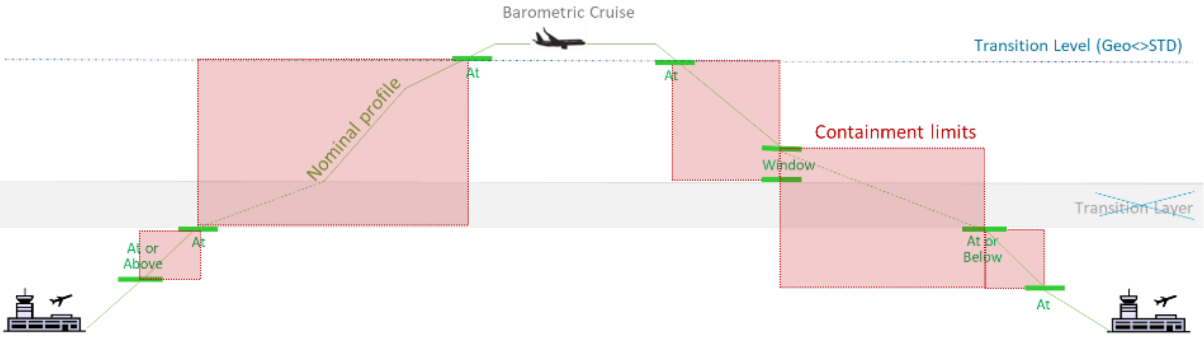


**Figure 10 – Transition state, Step 2: Geo Constraints with no airspace change**

A transition between Geo and Baro exists at the boundaries of the airspace volume. Cruise remains based on barometric levels meaning that there needs to either be a switch at high level Transition Layer or some form of 'transition gates' – for example at calculated points such as ToC and ToD or at specific waypoints that define the entry/exit points of the geometric airspace volume.

Effectively, this sets the Transition Layer to high level. The number of datum changes through the Transition Layer would be the same but it would remove the need base navigation on local pressure settings (QNH/QFE) under normal conditions. The transition would be between Geo and Standard pressure (1013 hPa) instead of between local and Standard pressure. This would provide consistency of Geo Alt application below the Transition Layer (within a TMA or specified block of airspace), for climbs, descents and Initial, Final and Missed Approaches, which would be beneficial for route design as well as controller situational awareness. The risk of QNH mis-entry would no longer apply under normal conditions. The full benefits of removing the Transition Layer would not be realised but it would place the transition well above the lower airspace where there are complex traffic interactions and high controller workload.

By way of contrast, if the Transition Layer was simply raised (with no Geo Alt implementation), complexity is added because the higher the Transition Layer the more likely aircraft with significantly different local pressure settings will be intermixing.

**Step 3 – Composite geometric solution applied within a defined airspace volume**

From an operational and practicality perspective, it would be logical to develop Geo Alt operations across the whole of a defined airspace volume, such as a TMA, because it would yield the most significant benefits. Airspace change could be applied in a single big step or as a series of incremental changes, e.g. airport per airport. Either would be possible because the airspace has been moved entirely to geometric in Step 2.

A composite geometric solution is envisaged, reflecting the concept end state (Section 3.3.2.1) through improved airspace design with vertical path containment, where necessary in Descent and Approach, and removal of the Transition Layer under nominal operating conditions. The outcomes are increased CCO, CDO, reduced workload, and improved safety and capacity.

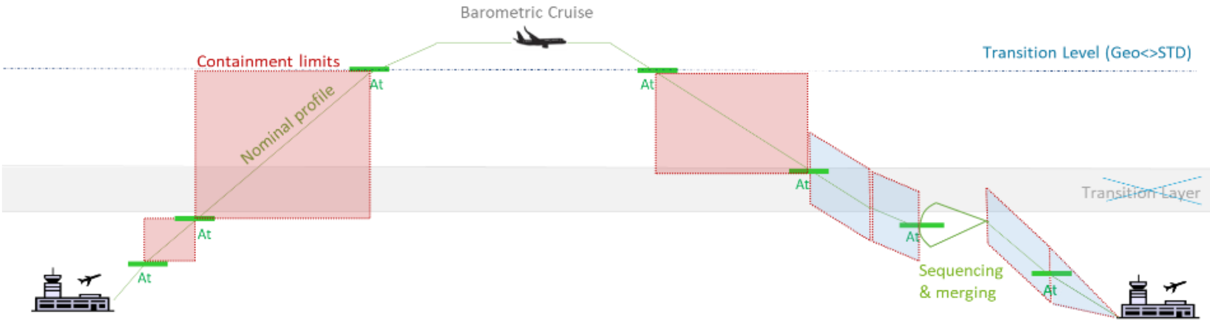


**Figure 11 - Transition state, Step 3: Geo Constraints with no airspace change**

All airspace users would operate Geo Alt within this defined airspace volume, including UTM and general aviation; mandates may be applied. Non-capable aircraft may need to be either be managed by exception or segregated.

As with Step 2, a transition between Geo and Baro exists at the boundaries of the airspace volume. Cruise remains based on barometric levels meaning that there needs to either be a switch at high level Transition Layer or some form of 'transition gates' – for example at calculated points such as ToC and ToD or at specific waypoints that define the entry/exit points of the geometric airspace volume.

**Step 4 – Composite geometric solution applied within an airspace block**

Composite geometric solution applied within a larger airspace block, for example, encompassing a whole Flight Information Region or Functional Airspace Block. This would be a challenging step; as with Steps 2 and 3, All airspace users within this geometric airspace would need to operate Geo Alt. At the 'Airspace block' level, this would capture a much broader set of general aviation and diverse airspace users, so there is a likelihood that some segregated zones for barometric altimetry would persist, at least initially. If this were the case, suitable buffer zones would need to be applied.

Where there are boundaries between barometric and geometric operations, vertical buffers are designed to allow for the switch between baro and Geo levels, which could be different by multiple Flight Levels. Flights would transit to the nearest equivalent level geometrically rather than the equivalent level numerically, e.g. a flight may transit from FL330 to 31,000 ft Geo because it's the least physical vertical deviation, rather than transiting from FL330 to 33,000 ft Geo. Pilots would need to adjust level to capture the nearest Flight Level or nearest 1,000 ft geometric altitude upon instruction from ATC. Controllers will have a system support to indicate how to manage the flights to adjust for the revised level.

Localised implementation of Geo Alt at cruise could be used to avoid the need for vertical transitions between baro and geo operations. However, this could lead to a patchwork of airspace blocks where flight crews would frequently have to switch from Baro to Geo along their cruise path increasing risk of error, so a broad, coordinated regional change would be a better solution. Once implemented it would connect up the individual cases to optimised end-to-end flight efficiency and avoid the need to switch between baro and Geo datums.
In cruise, the aircraft flies at more stable geometric cruise level, on one hand potentially with less thrust variation because the aircraft cruise level is not impacted by pressure variation, but on the other hand the atmospheric conditions along cruise will evolve since the aircraft is not maintaining a barometric flight level, thus potentially making the aircraft flight at a less optimal altitude (impact in flight efficiency), and in extreme cases, even bringing the aircraft to its operating ceiling and thus



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requiring a step descent (operational constraints). This effect is small over short distances but greater over longer distances where pressure and temperature variations increase.

**Other considerations**
An alternative transitory step could be by airspace rather than by procedure, i.e. where some airspace is converted to Geo and other airspace remains in Baro. In this case, pilots and controllers would need to be able to transition between the two. If Geo Alt was applied to some ATC sectors but not others, controllers would need increased mode switching when operating the different sectors

One of the above could potentially be an end-state but, for purposes of completeness, this document will assume an end state of geometrical altimetry being used for vertical navigation universally.

Transitioning all airspace users to geometric altimetry holds significant human factors and safety benefits, primarily stemming from the establishment of a common datum. This uniform reference point streamlines communication and navigation processes, reducing the likelihood of errors and enhancing overall safety. With everyone operating on geometric altimetry, there's greater consistency and clarity in altitude measurements, fostering a more cohesive and predictable airspace environment. However, despite these advantages, implementing such a transition is not without its risks. The introduction of new technology, procedures, and training requirements carries inherent challenges, requiring careful planning and management to mitigate potential disruptions and ensure a smooth transition process. Therefore, while geometric altimetry offers promising safety enhancements, its implementation necessitates prudent consideration of associated risks and diligent oversight to safeguard aviation operations.

#### 3.3.2.3 Use cases

**Use Case 1: Geometric Initial Approach and Final Approach**

Based on TMA airspace design and related ATC operations described in Use Case 5, the onboard operation from the end of cruise down to the runway can be described as follows:

1. The aircraft reaches the Top of Descent of its barometric cruise phase and, provided ATC clearance is provided, conducts a barometric descent along the published STAR towards the Initial Approach fix as usual.
2. When reaching transition altitude, flight crew sets QNH in order to have appropriate barometric altitude during the QNH part of the arrival procedure (nominal operation) as well as during the approach phase in case of fallback following GNSS loss.
3. When cleared by ATC, the flight crew pursues own navigation towards Final Approach following the cleared Initial Approach transition using geometric vertical navigation. A transitory phase may be observed when switching altitude sources, during which the aircraft may find itself above or below the geometric vertical path, potentially requiring a capture manoeuvre (increase or decrease vertical speed until rejoined).
4. Flight crew uses autoflight system managed lateral and vertical navigation modes whenever possible.
5. Flight crew monitors compliance of FMS predicted flight path with altitude and speed constraints in the published procedure, which are expressed in geometric instead of barometric altitude reference.




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6. In case of V-RNP solution option, flight crew also uses onboard monitoring and alerting features to ensure conformance to the required vertical containment of current procedure segment.
7. Primary aircraft altitude indication to the flight crew and altitude parameter used by systems for navigation and guidance is geometric instead of barometric altitude.
8. Barometric altitude indication is still available to the flight crew while in geometric altitude mode (HMI TBD) for management of non-nominal conditions (e.g. troubleshooting requiring check of geometric altitude consistency against barometric altitude).
9. Report of both geometric and barometric altitude to ATC is automatically done by systems.
10. Primary altitude source switching capability is provided to the flight crew to enable use of barometric altitude in case of GNSS loss.
11. When cleared for approach by ATC, flight crew arms approach guidance modes and monitors Final Approach capture as in current operations. When operating geometric Final Approaches (LPV, GLS or ILS), the use of geometric altitude source both in Initial and Final Approach reduces the potential vertical offset between these two phases, but the geometric source may not be the same (e.g. GNSS+IRS hybridisation in initial approach and SBAS, GBAS or ILS in Final Approach). Current philosophy of having distinct TMA navigation guidance modes and Final Approach guidance modes is not changed.
12. The flight crew reports established on Final Approach and lands provided Tower ATC clearance is granted, as in current operations.

**Use Case 2: Geometric Descent**

Based on TMA airspace design and related ATC operations described in Use Case 5, the onboard operation from the end of cruise down to the runway can be described as follows:

1. The aircraft reaches the Top of Descent of its barometric cruise phase and, provided ATC clearance, conducts a geometric descent along the published STAR towards the initial approach fix. The computed ToD already takes into account that geometric vertical navigation is used all along descent, so the aircraft exits the cruise level already established on its geometric vertical path (no vertical discontinuity requiring capture manoeuvre during descent).
2. Flight crew uses autoflight system managed lateral and vertical navigation modes whenever possible.
3. Flight crew monitors compliance of FMS predicted flight path with altitude and speed constraints in the published procedure, which are expressed in geometric instead of barometric altitude reference.
4. In case of V-RNP solution option, flight crew also uses onboard monitoring and alerting features to ensure conformance to the required vertical containment of current procedure segment.
5. Primary aircraft altitude indication to the flight crew and altitude parameter used by systems for navigation and guidance is geometric instead of barometric altitude.
6. Barometric altitude indication is still available to the flight crew while in geometric altitude mode (HMI TBD) for management of non-nominal conditions (e.g. troubleshooting requiring check of geometric altitude consistency against barometric altitude).
7. Report of both geometric and barometric altitude to ATC is automatically done by systems.

8. Primary altitude source switching capability is provided to the flight crew to enable use of barometric altitude in case of GNSS loss.
9. When reaching transition altitude, flight crew sets QNH in order to have appropriate barometric altitude reading in case of fallback following GNSS loss.
10. When cleared by ATC, the flight crew pursues own navigation towards Final Approach following the cleared Initial Approach transition using geometric vertical navigation. No transitory phase is observed since the aircraft is already established on its geometrical vertical path.
11. When cleared for approach by ATC, flight crew arms approach guidance modes and monitors Final Approach capture as in current operations. When operating geometric Final Approaches (LPV, GLS or ILS), the use of geometric altitude source both in Initial and Final Approach reduces the potential vertical offset between these two phases, but the geometric source may not be the same (e.g. GNSS+IRS hybridisation in descent and initial approach, and SBAS, GBAS or ILS in Final Approach). Current philosophy of having distinct TMA navigation guidance modes and Final Approach guidance modes is not changed.
12. The flight crew reports established on Final Approach and lands provided Tower ATC clearance is granted, as in current operations.

**Use Case 3: Geometric Cruise**

Assessment of the cruise flight based on geometric altimetry in the en-route airspace is included in the ERR [25]-; however, it is not included as part of the core solution scope as part of this OSED because it was found to introduce a small detrimental disbenefit when considered in isolation.

**Use Case 4: Fully Geometric TMA, including Departure, Climb, Descent, Initial Approach and Final Approach, using a composite solution of Geo Constraints and Geo Path**

A fully geometric TMA based on geometric constraints plus geometric paths, with vertical path tolerances assigned to Instrument Flight Procedures (IFPs), where necessary for procedural route deconfliction, enables airspace design in 3 dimensions, eliminating inefficiencies around the Transition Layer, to demonstrate maximum benefits of the conceptual target end state. SIDs and STARs extend into enroute airspace.

1. All IFPs in and out of the TMA are designed using geometric constraints.
2. Where necessary for procedural route deconfliction, Initial Approaches are defined with geometric paths using a standardised vertical tolerance commensurate with a Vertical RNP type operation. Aircraft navigation system accuracy would be commensurate with VPPL relative to the altitude, as defined in ED-75 [8].
   a. Minimum vertical route separation is 1,000 ft for routes crossing in level flight until minimum lateral separation is attained.
   b. Minimum vertical route separation is 1,520 ft in all other circumstances, i.e. one or both routes are not in level flight.
3. Where necessary for procedural route deconfliction, Descent paths on STARs are defined with geometric paths using a standardised vertical tolerance commensurate with a Vertical RNP type operation. Aircraft navigation system accuracy would be commensurate with VPPL relative to the altitude, as defined in ED-75 [8].
   a. Minimum vertical route separation is 1,000 ft for routes crossing in level flight until minimum lateral separation is attained.




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   b. Minimum vertical route separation is 1,520 ft in all other circumstances, i.e. one or both routes are not in level flight.

4. Each IFP provides at least minimum separation between all other IFPs in either, or both, lateral and vertical planes.
5. SIDs extend from runway to enroute airspace.
6. STARs extend from cruise level to the IAF (hold fix), i.e. to enroute airspace.
7. Stack holding is used in the same manner as today, where required.
8. Initial Approaches are designed to interface with Final Approach Segments / glideslope without a level deceleration segment (a shallow descent phase may still be required to enable deceleration).
9. Arrivals are cleared on a STAR to the IAF.
10. Approaches are cleared from the IAF to Final Approach via Initial Approach Transitions.
11. Controllers manage spacing on any individual IFP using speed control, when necessary.
12. Approach controllers aim to deliver the required spacing dictated by the airport/tower.

**Use Case 5: Single aircraft loss of GNSS**

Technical solutions are deployed to reduce the risk that geometric operation cannot be complied with; however, in the in the case of a sustained loss of GNSS as the primary navigation source, reversion to barometric operations will be employed as the fallback procedure.
A single GNSS loss could be due to one of several causes, such as system failures (local, regional or onboard), space weather, and reliance on backup systems. The response to such a cause would depend on the fall-back systems for lateral navigation. Fallback procedures would be reliant on multi-DME or IRS for lateral navigation, similar to the current day. For operations relying fully on geometric altimetry, response to GNSS loss would hinge on the accuracy of backup systems. Controllers would likely need to increase lateral or vertical separation for affected aircraft, particularly if they revert to barometric altimetry while others remain on geometric. If one aircraft loses GNSS in the operational environment as per today's operation, this could lead to short term workload spikes for controllers as they would need to adhere to separation standards. They would need tools to calculate separation adjustments quickly, with clear visual displays and established procedures to guide their responses. Within a more systemised airspace, this would exacerbate the situation so the controllers would need to ensure the aircraft stays as close as possible to their 3D trajectory. Controllers may need to revert to traditional techniques of barometric altimetry to ensure separation.

Mode switching between barometric and geometric could create further risks, such as incorrect phraseology. Radar and display interfaces would need to flag affected aircraft to avoid manual conversions between geometric and barometric measurements as well as dedicated SQUAWK codes to indicate GNSS disruption. Although situational awareness during this emergency might not be substantially different from barometric operations today, controllers would benefit from clear HMI to retain operational clarity. ATC systems would also require a unified common datum source to ensure consistent altitude comparisons across aircraft.

Steps

1. Flight cleared on a geometric STAR using Descend Via.
2. Failure of primary GNSS source. Aircraft navigation system switches to alternative GNSS source. Flight continues on STAR using alternative GNSS source

3. Failure of all GNSS sources. Aircraft continues on STAR using Inertial Reference System. Pilot reports loss of GNSS to ATC.
4. The pilot is able to access and see barometric altitude for the aircraft in the cockpit.
5. The controller brings up the barometric altitude of the flight on the Track Data Block (TDB) at the Controller Working Position (CWP). Both barometric and geometric altitude are reported at the CWP.
6. The controller reports the flight's current barometric altitude (FL above TA, Alt below) and confirms SPS (1013.2) or arrival airport QNH and asks for confirmation from the pilot.
7. The pilot confirms their barometric altitude and reads back relevant pressure datum setting.
8. The controller instructs the pilot to follow barometric fallback procedures.
9. The controller notifies their supervisor of the GNSS loss.
10. The ATC supervisor ensures appropriate actions are taken within the ATC sector group adjoining areas, as necessary.
11. Ground support tools calculate separation adjustments quickly, with clear visual displays provided to the controller who uses established procedures to guide their response.
12. The controller manages the flight by exception, providing descent instructions related to barometric altitude to follow as closely as possible the geometric path of the STAR, but within increased lateral or vertical separation between the affected aircraft operating in barometric and other aircraft operating in geometric.
13. Controllers in the ATC sector group use speed controls to manage flights on crossing routes to ensure lateral separation is maintained with the flight with the GNSS failure if necessary.
14. At the Transition Level, the pilot switches from Standard to local QNH.
15. The controller provides descent instructions related to barometric altitude to follow as closely as possible the geometric path of the Initial Approach Procedure, until the flight is established on Final Approach.

**Use Case 6: Single aircraft subject to GNSS Spoofing**

When a single aircraft is subject to GNSS spoofing, the impacts would mirror those of a single aircraft GNSS loss. However, these is a need for a dedicated alert system, and enhanced conformance monitoring to alert controllers and pilots to potential discrepancies, supported by a cross-checking capability to compare between geometric and barometric values.

Similar to GNSS loss, impacts on situation awareness and workload would be exacerbated through the controller having to monitor both geometric and barometric altimetry positions. Without careful planning of processes and procedures, controllers may face increased stress due to uncertainty about the integrity of altitude data, which could hinder their ability to manage the airspace effectively. Likewise, controllers would need enhanced technological support tools to manage these challenges.

<u>Steps</u>

1. Flight cleared on a geometric STAR using Descend Via.
2. GNSS spoofing affects the flight making the aircraft think it is higher than it actually is.
3. Based on comparison of downlink altitude based on SPS alongside geometric altitude, the ATC ground system conformance monitor alerts the controller at the CWP that the flight is not conforming to the vertical path because it is lower than it is expected to be.
4. The controller asks the pilot to confirm (geometric) altitude.



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5. The pilot reports their altitude, which does not match the altitude reported at the CWP.
6. The controller brings up the barometric altitude of the flight on the Track Data Block (TDB) at the Controller Working Position (CWP). Both barometric and geometric altitude are reported at the CWP.
7. The pilot is still able to access and see both barometric and geometric altitude for the aircraft in the cockpit.
8. The controller reports the flight's current barometric altitude (FL above TA, Alt below) asks for confirmation from the pilot.
9. The pilot confirms their barometric altitude.
10. The controller alerts the pilot to the anomaly and provides the CWP stated figure.
11. The pilot investigates, comparing primary and secondary systems to confirm the discrepancy. If a problem is confirmed, the pilot reports suspected GNSS spoofing and requests barometric fallback procedures
12. The controller confirms barometric fallback procedures and confirms SPS (1013.2) or arrival airport QNH and asks for confirmation from the pilot.
13. The pilot confirms fallback to barometric procedures and reads back relevant pressure datum setting.
14. The controller notifies their supervisor of suspected GNSS spoofing.
15. The ATC supervisor ensures appropriate actions are taken within the ATC sector group /adjoining areas as necessary.
16. The controller manages the flight by exception, providing descent instructions related to barometric altitude to follow as closely as possible the geometric path of the STAR.
17. Controllers in the ATC sector group use speed controls to manage flights on crossing routes to ensure lateral separation is maintained with the flight on barometric fallback procedures if necessary.
18. At the Transition Level, the pilot switches from Standard to local QNH.
19. The controller provides descent instructions related to barometric altitude to follow as closely as possible the geometric path of the Initial Approach Procedure, until the flight is established on Final Approach.

**Use Case 7: Complete loss of GNSS**

Technical solutions are deployed to reduce the risk that geometric operation cannot be complied with; however, in the in the case of a sustained loss of GNSS as the primary navigation source, reversion to barometric operations will be employed as the fallback procedure.

A complete loss of GNSS across multiple aircraft presents many of the same workload and situation awareness challenges, whilst also necessitating fallback procedures similar to the current reliance on DME or IRS navigation. Be that as it may, in this use case of a complete loss a controller would be required to adopt a different method of operation, as the fallback for complete loss could result in substantial workload increases due to having to apply traditional separation methods and having to use 'old school' barometric techniques. Controllers may face heightened situation awareness loss and



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potential loss of separation as discrepancies between altimetry modes (barometric and geometric) emerge.

Nonetheless, for a single or a complete loss of GNSS, radar and display systems would need to indicate the affected aircraft and have the ability to convert between barometric and geometric altimetry. A common and known altitude datum for all aircraft as a backup would be necessary to maintain operational clarity. In terms of communication, a significant challenge would involve managing both geometric and barometric altimetry during emergencies and failure scenarios, which might slightly increase the risk of mode-switching errors for controllers.

In scenarios involving complete GNSS loss a key consideration would be the timing of the controller's awareness of the issue across all aircraft. A proposal was suggested for pilots to issue a SQUAWK code indicating GNSS loss; if controllers notice multiple such codes, they could infer a system wide loss and revert to barometric procedures. Across both single and complete GNSS loss situations, there would likely be a notable increase in controller workload and a decrease in situational awareness, with some mode-switching errors as controllers navigate mixed altimetry modes.

Steps

1. A large-scale loss of GNSS source for all aircraft within a TMA operating fully geometric operations.
2. Pilots selects GNSS failure SQUAWK.
3. Any aircraft on procedures or ATS route continue on Multi DME for lateral route. (check whether space weather could also impact DME – they are not)
4. Pilot is able to access and see barometric altitude/level for the aircraft in the cockpit.
5. The controller brings up the barometric altitude/level of the flights on the Track Data Block (TDB) at the Controller Working Position (CWP). Both barometric altitude/level and geometric height are reported at the CWP.
6. Controller broadcast QNH & awareness of GNSS issue (standard broadcast message?) barometric reversion for all airspace users.
7. The controller reports the flight's current barometric altitude/level (FL above TA, Alt below) and confirms SPS (1013.2) or appropriate QNH, positive affirmation could be received from each aircraft on next clearance.
8. The pilot confirms their barometric altitude/level and reads back relevant pressure datum setting.
9. The controller notifies their supervisor of the GNSS loss.
10. The ATC supervisor ensures appropriate actions are taken within the ATC sector group adjoining areas, as necessary.
11. The controller manages all flights based on barometric procedures.
12. At the Transition Level, the pilot switches from Standard to local QNH. (Needs to be explored how flight crew would be aware of transition altitude/level).
13. Traffic is stopped/restricted as necessary, departures and traffic at boundaries stopped.

**Use Case 8: Fully Geometric TMA, including Departure, Climb, Descent, Initial Approach and Final Approach, using Geo Constraints only**



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All altitude constraints within a defined airspace volume, e.g. TMA, switched from Baro to Geo Alt, with no airspace redesign.

1. All IFPs in and out of the TMA are designed using geometric constraints.
2. The procedures are unchanged so clearances, instructions and actions by both pilot and controller are largely unchanged.
3. Local pressure (QNH/QFE) is still set by the pilot prior to departure and prior to descent in case fallback procedures are initiated.
4. Controllers instruct pilots to change datum from standard barometric pressure (1013 hPa) to geometric upon entering the TMA. The pilot manually switches datum when instructed.
5. Controllers instruct pilots to change datum from geometric to standard barometric pressure (1013 hPa) upon exiting the TMA. The pilot manually switches datum when instructed.

### 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 |
|---|---|---|
| Altitude/Level reporting | Outside of the Final Approach, aircraft rely on a barometric pressure model to determine altitude/level. | All aircraft are now required to use geometric altimetry at the primary reference for height reporting and vertical navigation. |
| Vertical Navigation in Climb | Barometric height is used for vertical navigation.<br><br>PBN SIDs define a lateral path with a defined tolerance and include altitude constraints at waypoints where necessary for traffic deconfliction, airspace boundaries and obstacle clearance.<br><br>Vertical containment is only assured at waypoints that have altitude constraints associated with them.<br><br>Aircraft prioritise their speed schedule. In managed mode, they will only comply with altitude constraints where the speed schedule allows. | Geometric altimetry is used for vertical navigation, with GNSS as the primary navigation source.<br><br>Geometric SIDs define a path in 3 dimensions allowing for traffic deconfliction, airspace boundaries and obstacle clearance.<br><br>Vertical containment is assured all along the flight profile as the flight meets the procedurally defined path within acceptable tolerance<br><br>Aircraft prioritise vertical path compliance over speed schedule. |

| Activities (in the SESAR architecture) that are impacted by the SESAR solution | Current operating method | New operating method |
|---|---|---|
| Vertical Navigation in Cruise | Barometric level is used for vertical navigation.<br><br>Actual cruise level varies according to the pressure gradients. | Geometric altimetry is used for vertical navigation, with GNSS as the primary navigation source.<br><br>Actual cruise level remains consistent, irrespective of pressure. |
| Vertical Navigation in Descent | Barometric altitude is used for vertical navigation.<br><br>PBN STARs define a lateral path with a defined tolerance and include altitude constraints at waypoints where necessary for traffic deconfliction, airspace boundaries and obstacle clearance.<br><br>Vertical containment is only assured at waypoints that have altitude constraints associated with them. | Geometric altimetry is used for vertical navigation, with GNSS as the primary navigation source.<br><br>Geometric STARs define a path in 3 dimensions allowing for traffic deconfliction, airspace boundaries and obstacle clearance.<br><br>Vertical containment is assured all along the flight profile as the flight meets the procedurally defined path within acceptable tolerance |
| Vertical Navigation in Initial Approach | Barometric altitude is used for vertical navigation.<br><br>PBN IAPs define a lateral path with a defined tolerance and include altitude constraints at waypoints where necessary for traffic deconfliction, airspace boundaries and obstacle clearance.<br><br>Vertical containment is only assured at waypoints that have altitude constraints associated with them.<br><br>Shallow, or level, segments are used to intercept the Final Approach Segment / glideslope. | Geometric altimetry is used for vertical navigation, with GNSS as the primary navigation source.<br><br>Geometric IAPs define a path in 3 dimensions allowing for traffic deconfliction, airspace boundaries and obstacle clearance.<br><br>Vertical containment is assured all along the flight profile as the flight meets the procedurally defined path within acceptable tolerance.<br><br>The Final Approach Segment / glideslope can be intercepted at a steeper descent path. |

**Table 5: differences between the new and the previous operating method**



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# 4 Key assumptions

## 4.1 TMA

Assumptions for the application of geometric altimetry for vertical navigation for all flight phases within the TMA.

### 4.1.1 Ground System and Procedure Design

Assumptions for the future concept relating to the ground systems and procedure design.

ATC ground-based conformance monitoring tools can be developed to continuously monitor flights against the procedural geometric path. Related, local ATC tools have also evolved. For example, NATS currently use Mode-S CFL/SFL checking and a Barometric Alerting Tool (BAT) as safety nets.

Vertical Scale Factors (VSF) can be used in ARINC 424 to define vertical path tolerances equivalent to Vertical Path Performance Limits (VPPL), as part of codified IFPs, which aircraft will comply with.

GBAS curved approaches are defined in the standards, and the capability has been implemented in Multi-Mode Receivers (MMR) on aircraft. The capability for MMR GPS combined with GBAS or SBAS and managed mode for Geo in IAP has been developed.

Agreement can be reached between multiple states to coordinate a transition from barometric to geometric operations.

Where there are boundaries between baro and Geo operations, vertical buffers are designed to allow for the switch between baro and Geo altitudes, which could be different by multiple Flight Levels. Flights may need to adjust altitude to capture the nearest Flight Level or nearest 1,000 ft geometric altitude. Controllers will have a system support to indicate how to manage the flights to adjust for the revised level.

ATC ground tools have been developed to indicate the difference between barometric and geometric altitude where a boundary switch of datum is required. This is provided to the Controller Working Position.

A complementary PNT system can deliver sufficient navigation performance as contingency for any TMA-wide disruption of GNSS.

Queue management ground tools have been developed support the 3-dimensional systemisation of the TMA by streaming arrivals into and through the systemised routes, e.g. arrival management from cruise into descent, Time-Based Separation tools delivering a robust landing rate into congested airports and departure management delivering a robust take-off rate.

### 4.1.2 Airborne System

Assumptions for the future concept relating to the airborne systems.

All aircraft operating within a Geo Alt environment are capable of navigating to vertical geometric constraints. Non-capable aircraft are segregated with sufficient vertical and/or lateral buffers applied to maintain minimum separate under all reasonable atmospheric conditions.



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Reversion from geometric to barometric altitude would reduce capacity due to loss of usable Flight Levels, loss of higher capacity procedure design and an increase in ATCO and pilot workload. Therefore, resilience of GNSS and the ability to remain in geometric altitude operations as far as possible is preferable.

In the event of a sustained loss of GNSS, whether for a single aircraft or widespread, there is a procedural fallback to barometric for the affected aircraft and ATC operation.

It is assumed that from the flight performance perspective, aircraft are capable of being operated with geometric altimetry. All additional requirements imposed by the usage of geometric altimetry are operational requirements or sensor/system requirements but not flight performance requirements.

Aircraft navigation systems have been developed to comply with vertical accuracy requirements associated with Instrument Flight Procedures (IFPs), similar in principle to PBN in the horizontal plane.

Aircraft navigation systems can be developed to provide onboard alerting capability in the vertical plane equivalent to that in the lateral plane.

SBAS, or equivalent capability, have been developed to support geometric operations in flight phases outside of Final Approach.

Aircraft tools and/or common procedures have been developed to minimise variation when transiting between Baro and Geo airspace.

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To get from the current situation to the future concept, the following would apply.

The FMS is responsible for providing predictions to the flight crew from preflight to landing, among which fuel & time are the most operationally critical since these predictions are used by the crew to conduct the flight follow-up to ensure that the safety and mission needs are satisfied. Most of the FMS predicted parameters (e.g. time, altitude, speed) can be downlinked to ATC through ADS-C EPP and might also be used for ATC operations.

Note: Air-Ground exchange of ADS-C EPP data, as well as ground display and alerting of trajectory information, are mandated in Europe by CP1 from end 2027. However, such mandate is only applicable for forward fit. Few aircraft exchange ADS-C EPP data with ATC today.

The FMS predictions computation would be impacted by the switch to geometric reference as the performance of the aircraft is always tied to barometric conditions, and the FMS does not currently have the capability to anticipate the pressure altitudes associated to the expected geometric altitudes.

A simple solution could use conservative assumptions to meet safety objectives regarding fuel, such as considering a worst-case geo-baro offset based on statistical data. A worst-case offset from fuel consumption perspective would bring a lower bound of the baro altitude at a given geo altitude, which would also impact other performance computations such as speed, time, vertical profile, etc.

However, such conservative approach would degrade the accuracy of FMS predictions, leading to a negative impact on predictability, which may also degrade fuel efficiency if the airline FOC requires loading of additional fuel. Flight crew tasks and ATC operations relying on FMS predictions may potentially be also impacted.

It seems necessary to also update FOC flight planning tools, as inconsistencies between the OFP predictions and the FMS predictions are unlikely to be operationally acceptable considering that flight crew is expected to perform fuel monitoring based on FMS predictions compared to the OFP.

The impact of the simple, conservative solution mentioned above would be too high if geometric reference is used all along the flight, especially due to the cumulated error on fuel and time predictions, but it could be interesting for future R&D work to assess if the impact might remain within acceptable limits when the use of geometric reference is limited to Climb, Descent and Approach.

A more advanced solution to tackle this challenge could rely on upgrading FMS and FOC flight planning tools to use meteorological data with pressure forecast grids at different geometric altitudes, as currently done with wind and temperature at different barometric altitudes/FLs.

For the use of geometric altimetry limited to Climb, Descent and Approach, an alternative solution could be based on making the FMS and the FOC flight planning tools able to compute the pressure altitude at an expected geometric altitude by themselves, using the necessary static geographical information for conversion between geo and baro altitudes in ISA conditions, together with the dynamic local atmospheric conditions (e.g. QNH and temperature at departure and destination airports).

In addition to impacts on FMS and FOC flight planning tools, depending on the chosen way forward for airborne predictions, Solution 0406 may require further updates in the SESAR functional architecture:

a) Potential impact on MET services in case of need for providing MET aloft gridded forecast data referenced to geometric altitudes, and possibly including pressure altitude in addition to wind, temperature, etc.

b) Potential impact on AIM services in case of need for publishing static data supporting the conversion between geo and baro altitudes in ISA conditions, possibly with a similar approach as for current data supporting conversion between magnetic and true headings.

## 4.2 Cruise

While the Solution definition is focused on Climb, Descent & Approach phases, the project has had the opportunity to conclude that the use of geometric altimetry is not operationally suitable for Cruise phase, due to significant challenges inherent to the dependency of aircraft performance on barometric conditions, particularly regarding flight envelope (e.g. maximum operating altitude) and cruise altitude optimisation.

Indeed, aircraft performance is intrinsically based on barometric conditions, including the aircraft operating ceiling which is defined in pressure altitude.

In today's operations, pilots can contribute to flight optimisation by requesting, when possible, a cruise flight level as close as possible to the optimum flight level computed by the FMS. The optimum altitude ("OPT ALT") is generally a few thousand feet below the maximum recommended altitude ("REC MAX"), which is considered as the upper limit for safe operation.

The REC MAX is computed by the FMS, not only based on the aircraft maximum certified altitude, but also on performance considerations that depend on flight and weather conditions. It is defined as the lowest of:

- Maximum altitude at maximum cruise thrust in level flight
- Maximum altitude at maximum climb thrust with 300 ft/min vertical speed
- Maximum certified altitude
- 1.3 g buffet limited altitude.



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It must be highlighted that the REC MAX can be several thousand feet below the aircraft maximum certified altitude for a flight operating close to its Maximum Take-off Weight (MTOW) or in hot weather conditions (DISA >> 0).

In this context, a new paradigm defining in FMS a geometric cruise altitude and guiding accordingly may lead to locally exiting the aircraft flight envelope. Indeed, if the atmosphere's isobar is descending along the flight with regard to the geo altitude, this would be perceived by the aircraft as climbing in barometric conditions, potentially above the REC MAX.

In such event, the pilot would need to request to descent to a geo cruise altitude compliant with the maximum pressure altitude. Note that this occurrence would not be predictable as avionics systems cannot currently anticipate the isobar variations.

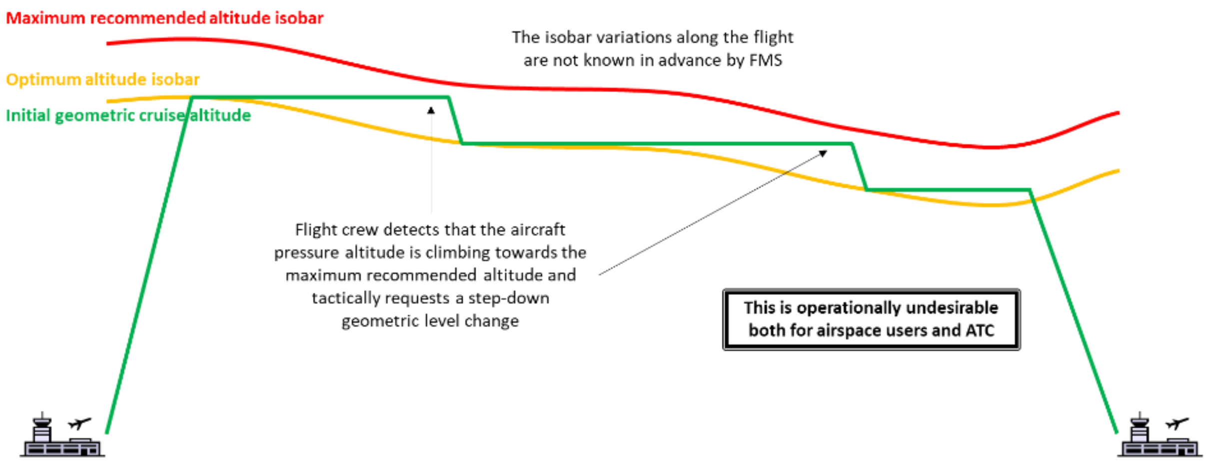


**Figure 12: Geometric navigation in cruise – flight envelope and cruise altitude optimisation challenge (a)**

The operational impact could be reduced by upgrading FMS and FOC flight planning tools to use meteorological data with pressure forecast grids at different geometric cruise levels (as currently done with wind and temperature at different barometric FLs) enabling anticipation and automation of the appropriate geometric level changes along the flight. However, the remaining operational complexity would still be undesirable.

An alternative mitigation would be to plan the flight geometric cruise at lower altitudes to create a buffer with respect to the maximum operating pressure altitude in order to minimise the need for safety-related step-down level changes, and briefing flight crews and briefing flight crews to limit optimisation-related level changes. However, this would bring a negative impact on environment, operational efficiency and potentially also capacity due to reduced use of the upper flight levels.

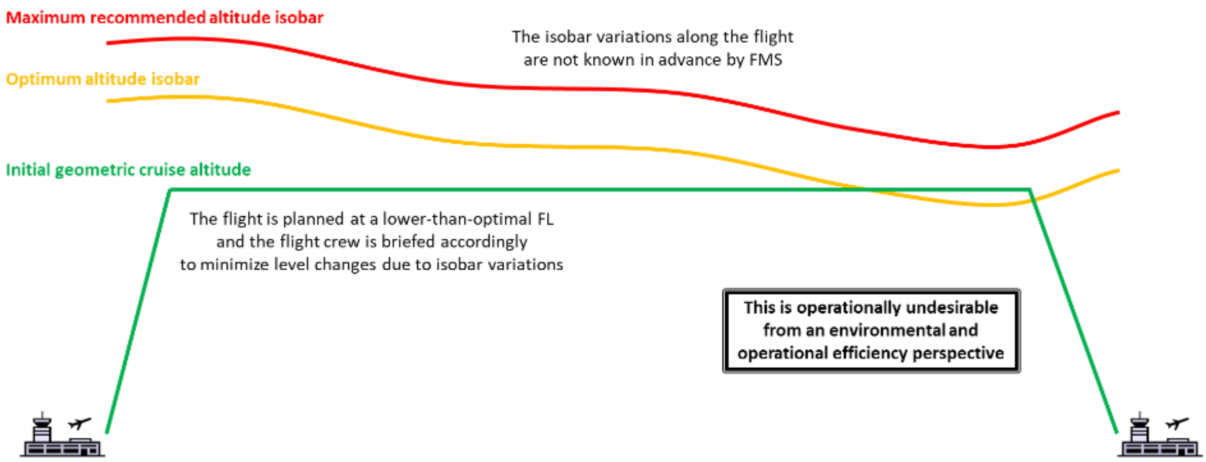


**Figure 13: Geometric navigation in cruise – flight envelope and cruise altitude optimisation challenge (b)**

Due to these operational challenges and the quantitative results identified during validation activities, it has been concluded that the implementation of geometric Cruise is detrimental when considered in isolation.

Geometric Cruise could be worth considering in the future as part of a holistic geometric navigation solution, removing altitude datum transitions and potentially enabling other ATM Solutions relying on geometric altimetry in Cruise (e.g. RVSM 2), if the associated benefits were demonstrated to outweigh the drawbacks identified so far.

This OSED is built under the Solution-level assumption that, for the time being, the most suitable way forward is to keep Cruise phase in barometric STD reference as today.

## 4.3 Management of Jamming and Spoofing Threats

<u>Assumptions for the future concept that specifically relate to the management of GNSS jamming and spoofing threats.</u>

Dual-Frequency Multi-Constellation (DFMC) receivers are widely implemented and aircraft Inertial Reference Systems are able to manage temporary instances in the vertical dimension, i.e. maintaining a gradient on climb or descent.

There are adequate technical and procedural fallback solutions to safely manage loss of GNSS in the vertical plane as well as the lateral plane, even though the operational impact for ATC and Airspace Users is not negligible.[2]

A reversion to barometric altitude will be required on-board the aircraft (automatic or manual) upon detection but more likely preferable before entering the interference area.

[2] Options to maintain geometric operations may include using barometric measurements, albeit with increased vertical uncertainty and, therefore, greater buffers [36].

A reversion to barometric based airspace and management of all aircraft affected in the area by air traffic controllers such as clearance and RVSM constraints must be performed.

A robust jamming and spoofing detection tool (on the ground and/or on-board) must be operational in order to ensure aircraft can timely and concurrently revert to barometric altitude approximately at the same locations.

The management of the transition between an airspace managed in barometric altitude and a geometric altitude: This is already needed under normal conditions but this situation might occur very often in some regions near conflict zones, which could lead to decide to not switch to geometric altitude at all in some airspaces.

Standardised and agreed upon phraseology and SQUAWK notices.

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<u>To get from the current situation to the future concept, the following would apply.</u>

In order to mitigate the increasingly present jamming and spoofing threats and become more resilient, the industry is planning to implement in industry airborne standards from RTCA and EUROCAE, several anti-jamming and anti-spoofing features that will provide more robust navigation capability under interference such as detection capability, return to normal after exiting the interference areas, authentication of GNSS signal (e.g. Galileo OS NMA and SBAS authentication are planned in 2030+).
Beside ongoing airborne standards evolutions, Solution validation outcomes suggest that a number of mitigations to deal with the unavailability of GNSS-based altitude sources due to jamming & spoofing threats should be considered (as captured above).

That said, management of jamming & spoofing threats is a transversal challenge affecting whatever ATM Solution relying on GNSS for lateral and/or vertical positioning, so for the purpose of this FRD, it is considered as a prerequisite for the GeoAlt Solution rather than part of its scope.

Solution features related to monitoring of the GeoAlt capability and fallback to barometric navigation described in this OSED are kept generic, not specifically focused on jamming & spoofing.

# 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] SESAR, Content Integration Executive Overview, 16/02/2023, Edition 00.01

[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] EUROCAE ED-75 / RTCA DO-236, Minimum Aviation System Performance Standards (MASPS), Required Navigation Performance for Area Navigation

[9] ICAO Doc 9613, PBN Manual.

[10] ICAO Doc 9674, World Geodetic System – 1984 (WGS-84) Manual

[11] ICAO Annex 10 detail of ICAO SARPS

### System and service development

### Performance management

[12] SESAR PJ19.04: Performance Framework (2019), 30/11/2019, Edition 01.00.01.

[13] SESAR Guidelines for Producing Benefit and Impact Mechanisms, 23/06/2016, Edition 03.00.01

### Validation

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




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

### Safety

[16] SESAR, DES expanded safety reference material (E-SRM), 17/11/2023

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

### Human performance

[18] SESAR Human Performance Assessment Process TRL0-TRL8, 21/11/2022, Edition 00.03.01

### Environment assessment

[19] SESAR Environment Assessment Process, 23/09/2019, Edition 04.00.00

### Security

### Project and programme management

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

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

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

[23] Horizon Europe ethics guidelines – essentials_1 (1_0).pptx.

## 5.2 Reference documents

This section lists the documents and information sources that were used to as input and guidance to the OSED, including Deliverables for the present Solution.

[24] Zapata, D., Vechtel, D., Bauer, T., Koloschin, A., Nelson, D.: "SESAR 3 ER 1 Green GEAR – Final OSED – Geometric Altimetry", Deliverable D3.5, ed. 02.00, submitted 30th April 2025.

[25] Zapata Arenas, D., Rouquette, P., Nelson, T., Bauer, T.: "SESAR 3 ER 1 Green GEAR – ERR – Geometric Altimetry", Deliverable D3.3, ed. 01.00, 28th February 2025.

[26] ALBATROSS web page: https://www.sesarju.eu/projects/ALBATROSS

[27] ALBATROSS DEMO Report (https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e50231e0bf&appId=PPGMS)

[28] EUROCAE ED-78A Guidelines for Approval of the Provision and Use of Air Traffic Services supported by Data Communications, December 2020.

[29] EASA Safety Information Bulletin (SIB) No. 2022-02R2, https://ad.easa.europa.eu/ad/2022-02R2

[30] Abdelmoula F.; Scholz M.: LNAS - a pilot assistance system for low noise approaches with minimal fuel consumption, 31st Congress of the International Council of the aeronautical Sciences, Brazil, September 2018.

[31] Gerber, M.; Schreiber Y.; Abdelmoula F.; Kühne C. G.; Jäger D.; Wunderli, J. M.: Energy-optimized approaches: a challenge from the perspectives of pilots and air traffic controllers. CEAS Aeronaut J, 5th September 2022, DOI: https://doi.org/10.1007/s13272-022-00607-0.

[32] ICAO Doc 8168, Procedures for Air Navigation Services

[33] https://www.icao.int/safety/OPS/OPS-Section/Pages/flightprocedure.aspx

[34] https://ifatca.wiki/kb/instrument-flight-procedures/

[35] SESAR Solution PJ.02-W2-04.1/2/3 SPR-INTEROP/OSED for V2 - Part I, 31/01/2023, Edition 01.00.00

[36] Narayanan, S., Osechas, O. (2022). Enhanced Vertical Navigation Using Barometric Measurements. *Sensors*, *22*(23), 9263.

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

## A.1 Stakeholders identification and expectations

This section describes who the stakeholders are and how they are concerned by the scope of the SESAR solution.

| Stakeholder | Involvement | Why it matters to the stakeholder |
|---|---|---|
| Academic/Industrial research groups | Solution partners | Further the development of airspace concepts that derive future benefits to aviation stakeholders. |
| Aircraft manufacturers | Solution partners | The need to develop aircraft capabilities to enable the concept for potential benefits to their airline customers. |
| Airlines | Interested in outcome of validation | Improved IFPs enabling environmental benefits. Reduction in manual pilot action reduces risk of human error. |
| ANSPs | Solution partners | Improved airspace design enabling environmental benefits and increase airspace capacity. Improved predictability reduces ATCO workload. Reduction in manual pilot action reduces safety risk. |
| Avionics suppliers | Interested in outcome of validation | The need to develop avionics and Flight Management System capabilities to enable the concept for potential benefits to their airline customers. |
| Communities neighbouring airports | Interested in outcome of validation | Potential reduction in noise impact. |

**Table 6: stakeholders' expectations and involvement**

## A.2 Benefits impact mechanisms (BIM)

These Benefit Impact Mechanisms describe the target end state (Section 3.3.2.1) in a universal geometric environment following method 2 identified in Section 3.1.1.



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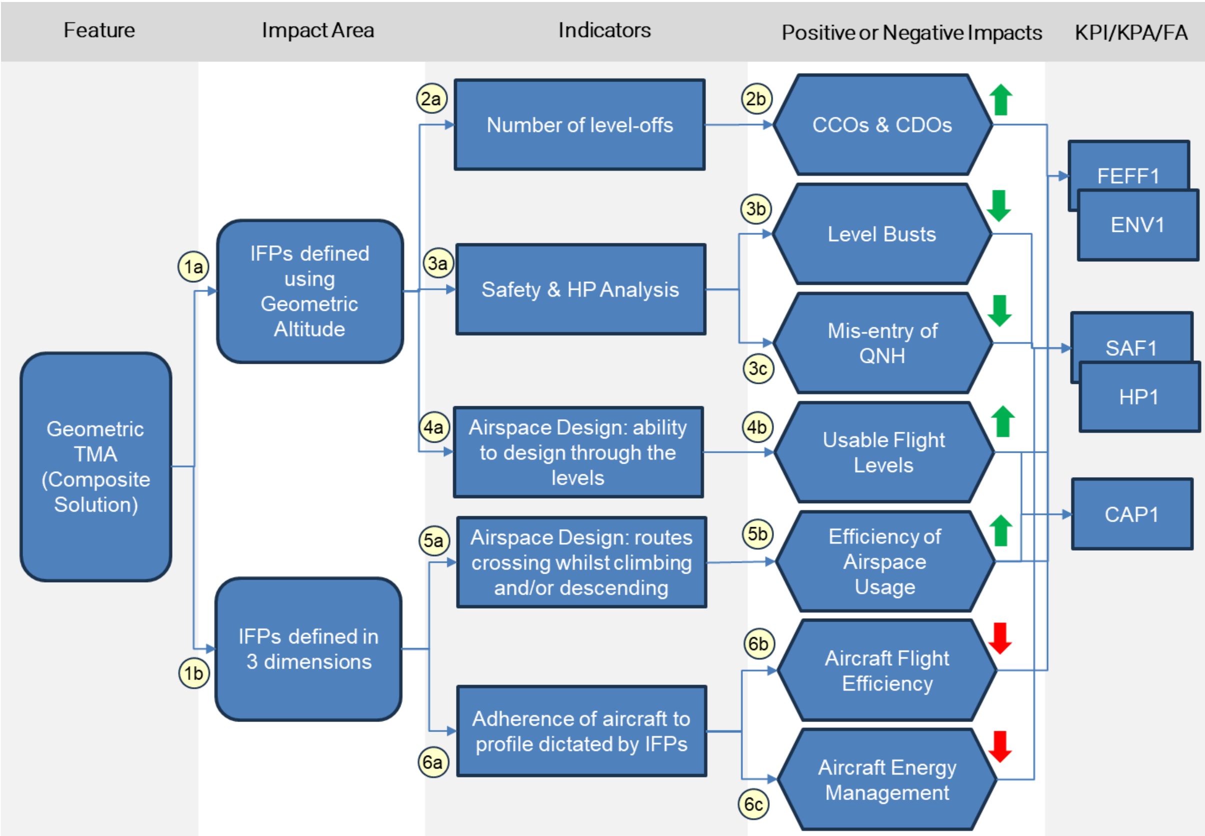


1a. Enables Instrument Flight Procedures (IFPs) to be defined using Geometric Altitude constraints.

1b. Enables STARs and Initial Approaches to be defined with vertical performance requirements

2a. Climbs and Descents will not be constrained by the uncertainties of atmospheric conditions or the Transition Layer, reducing the number of level segments required for separation purposes.

2b. Improved vertical profiles on SID, STAR and IAP procedures leads to fuel and $CO_2$ reduction.

3a. Safety and human performance benefits through reduced risk of manual error.

3b. The reduced reliance on manual datum switching reduces the risk of Level Busts.

3c. The reduced reliance on manual data entry reduces the risk of mis-entry of QNH.

4a. Able to use levels that were previously ‘buffer zones’ around the Transition Layer.

4b. Additional usable levels enable more efficient procedures whilst maintaining capacity.

5a. Design of airspace in 3 dimensions will enable crossing tracks to continue climbing or descending.

5b. The improved design options enable more efficient procedures whilst maintaining capacity.

6a. Assigning vertical accuracy requirements forces aircraft to more tightly adhere to the IFP profile.

6b. Reduces the fuel and $CO_2$ efficiency for the individual flight

6c. Increases the risk of energy or speed management issues for the pilot to manage in descent.



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