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AGENDA ITEM 4: AIR NAVIGATION

SAFEGUARDING NAVIGATIONAL SAFETY AND OPERATIONAL RESILIENCE AMIDST INCREASING GNSS INTERFERENCE

(Presented by the Association of Asia Pacific Airlines (AAPA) and the Civil Air Navigation Services Organisation (CANSO))

SUMMARY

This paper raises concerns about the growing vulnerability of GNSS signals—including incidents of GPS spoofing—which have disrupted performance-based navigation (PBN) capabilities and affected enroute and terminal procedures. These risks highlight critical safety gaps resulting from over-reliance on GNSS, particularly airports that depend solely on GNSS without Category I Instrument Landing System (ILS) infrastructure. This paper urges States to review such plans and advocate for the establishment of regional minimal operational networks (MONs) of conventional NAVAIDs to mitigate GNSS RFI risks.

SAFEGUARDING NAVIGATIONAL SAFETY AND OPERATIONAL RESILIENCE AMIDST INCREASING GNSS INTERFERENCE

1. INTRODUCTION

1.1 ICAO has encouraged States to implement PBN procedures since the adoption of Assembly Resolution A36-23. The aviation industry has made commendable progress in advancing PBN and reducing reliance on ground-based navigation systems. In the EU, there is an implementing regulation for PBN (PBN-IR; EU 2018/1048). However, recent real-world threats—particularly the growing trend of GNSS signal interference and GPS spoofing—has introduced new safety concerns.

1.2 These interference events have led to situations where aircraft are unable to perform GNSS-dependent procedures, including RNP approaches and departures, resulting in diversions and degraded enroute navigation. For an approach that is not considered a low visibility approach requiring Cat II or III equipment, and without ILS Cat I as a fallback, the margin for safe and efficient operations is significantly reduced if only RNP approaches are available at the destination airport.

2. DISCUSSION

2.1 **Escalating GPS Spoofing Threats.**

Instances of GPS spoofing and jamming are becoming more widespread and sophisticated. The result is that aircraft may lose GNSS-based navigation accuracy and integrity—making them unable to meet the RNP criteria for PBN. Spoofed positions can cause navigational errors, disrupt flight management systems, and compromise pilot situational awareness.

2.2 Operational Impact and Aircraft Diversions

Numerous aircraft have experienced diversions or unstable approaches at airports lacking ground-based navigation aids, particularly where ILS Cat I was never installed, was NOTAMed inoperative or has been withdrawn. These disruptions have significant safety, operational, and economic consequences, especially during adverse weather conditions where vertical guidance is essential.

2.3 Over-Dependence on GNSS

The ICAO Assembly resolution and EU implementing regulation have rightly envisioned a future where PBN would enable more efficient, flexible routing. However, the assumption that GNSS signals would remain globally reliable has proven increasingly fragile. The progressive decommissioning of ground navigation aids including Cat I ILS based on these assumptions now needs re-evaluation.

2.4 CANSO Minimum Operational Network (MON) Guidelines and Strategic Relevance

2.4.1 The Civil Air Navigation Services Organisation (CANSO) has recently published its 'Guidelines for Implementing a Minimum Operational Network (MON)', offering high-level direction for ANSPs on preserving terrestrial navigation capabilities in the event of GNSS outages. These guidelines recognise the global trend of GNSS reliance within PBN transitions while highlighting the essential role of conventional navigation aids (NAVAIDs), such as VOR, DME and ILS, in contingency planning.

2.4.2 The MON guidelines call for maintaining sufficient ground-based infrastructure and ensuring compatibility with airborne equipage to meet minimum navigation service levels in contingency scenarios. ILS CAT I procedures, although not a core PBN component, provide vital resiliency during GNSS degradation.

2.4.3 The insights from this document reinforce the recommendations of this Safety Paper: namely, that States should evaluate retention of some conventional navigation aids and ILS CAT I infrastructure as part of a robust MON strategy.

2.4.4 While aircraft are equipped with IRS, VOR, DME, and ILS receivers, navigational updating subsequent to GPS spoofing is possible provided the ground-based equipment is available and/or not been decommissioned. Ensuring suitable ground based navigational equipment creates the additional safety resilience required in degraded GNSS environments.

3. ACTION BY THE CONFERENCE

3.1 The Conference is invited to:

a) urge ICAO and States to consider current and future risks related to GNSS RFI when reviewing plans for decommissioning conventional navigational aids, particularly those relating to ILS Cat I infrastructure;

b) recommend States establish regional minimal operational networks (MONs) of conventional NAVAIDs to mitigate GNSS RFI risks;

c) encourage investments in multi-layered navigational resilience, including the retention of terrestrial-based aids such as ILS, VOR, and DME as a part of a robust contingency framework; and

d) urge ICAO to step up engagement with Member States to ensure effective mitigation and contingency planning measures are implemented.

<u>References:</u>

Attachment 1: 'Guidelines for Implementing a Minimum Operational Network (MON).

— END —

CANSO

GUIDELINES FOR IMPLEMENTING A MINIMUM OPERATIONAL NETWORK (MON)

Using Conventional Navigation AIDS (NAVAID) for Contingency during Global Navigation Satellite System (GNSS) Outages

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Foreword

The CANSO Guidelines for Implementing a Minimum Operational Network (MON) using Conventional Navigation Aids (NAVAID) for Contingency During Global Navigation Satellite System (GNSS) Outages is a high-level guidance document based on the review of several international MON concepts, which are included in the appendices. Understanding GNSS vulnerabilities and Air Traffic Management (ATM) reversionary scenarios is essential to define a Navigation Minimum Operational Network (NAV MON). This document details the technical capabilities and limitations of each specific navigation technology, particularly their coverage. Integration of a MON definition with the airspace, avionics equipage and navigation infrastructure planning are essential factors to be considered. The CANSO NAV MON concept is designed to provide only a contingency capability independent of Air Traffic Service (ATS) Surveillance availability, thus no communication, navigation and surveillance (CNS) trade-offs are discussed.

Executive Summary

The strategy behind a transition from conventional NAVAID referenced navigation to Performance Based Navigation (PBN) offered significant efficiency benefits to Air Navigation Service Providers (ANSP) and their customers. These benefits have included more direct routing, parallel tracks, and greater flexibility to design routes optimised to meet operational needs. The primary enabler of Area Navigation (RNAV) and Required Navigation Performance (RNP) was the establishment of the GNSS ecosystem. The transition to PBN has provided ANSPs with the opportunity to rationalise their inventory of conventional NAVAIDs, reducing infrastructure sustainment costs. However, due to the vulnerabilities of GNSS, particularly Radio Frequency Interference (RFI), it has been determined essential to retain a minimum number of conventional NAVAIDs as part of a MON but also where necessary install NAVAIDs to provide a minimum coverage. This strategy will provide users with options during potential GNSS RFI outages.

The CANSO team reviewed various national and regional MON concepts provided by CANSO members, including concepts from the Netherlands, France, Spain, the United States of America, Australia and Canada, a regional concept from EUROCONTROL and ICAO guidelines. Insights from these concepts were used to develop this high-level guidance document to assist ANSPs and regulators in conducting an operational analysis of contingency operations to mitigate potential GNSS RFI outages.

A MON is designed to provide a contingency capability independent of ATS Surveillance availability. As a contingency capability, conventional NAVAIDs can be rationalised. However, to retain a MON designed to efficiently provide reversion service, it is important to recognise that a MON is not intended to serve as the primary navigation service, but as a recovery capability that aircraft can revert to, when necessary, independent of GNSS.

It is critically important for ATM and infrastructure managers to collaborate to ensure that appropriate position, navigation, timing (PNT) services are provided to support continued operations during GNSS outages. The definition of the MON strategy should consider the type and level of capability of airspace users operating in their area of responsibility. Key considerations addressed in this document include navigation infrastructure planning, adjacent state capabilities and coverage, the role of NAVAIDs in PBN, airborne equipage, user community consideration, civil-military coordination, airspace concept and navaid infrastructure evolution.

In high-traffic environments, some States have identified the need to maintain DME/DME as their main PBN reversion capability. Many States have also determined a need to maintain a residual VOR or VOR/DME infrastructure network to support users with PBN capabilities. It is typically not feasible, nor is it the goal for contingency operations, to provide a level of capability equivalent to GNSS.

These MON guidelines detail the importance for infrastructure planners to work with airspace and procedure design colleagues in enabling PBN capabilities for both normal and contingency operations. This collaboration should address implementation challenges as well as conventional application changes. Two approaches can be taken: a top-down approach, with airspace design independent of infrastructure constraints, and a bottom-up approach, considering existing infrastructure.

Infrastructure realisation is driven by lifecycle planning and cost/benefit analysis. ANSPs are encouraged to develop an infrastructure optimisation plan, which includes provisions for establishing and sustaining a MON. Elements of an infrastructure rationalisation plan must be integrated into the framework of a PBN transition plan. ANSPs must understand the evolution of navigation infrastructures and the type of operations enabled by both existing and future NAVAIDs. This comprehensive understanding will enable ANSPs to develop effective rationalisation and decommissioning plans.

This guidance document addresses strategies for the continuation of PBN capabilities as the basis for GNSS resilience. Whether in regions having a high density of VOR/DMEs or VORTACs and a high traffic density, or in areas of low operational density and limited NAVAID coverage across their airspace, which may address MON planning differently.

This guidance document includes examples of different national MON concepts (United States, Canada, France, Spain, Netherlands, Australia) for consideration when developing a national plan.

Contents

1. Introduction

The transition from conventional NAVAIDs-referenced navigation to Performance Based Navigation (PBN) has provided significant efficiency benefits to ANSPs and their customers. These benefits include more direct routing, parallel tracks, and greater flexibility to design routes optimised to meet operational needs. The primary enabler of RNAV and RNP is the GNSS. The transition to PBN has also provided ANSPs with the opportunity to rationalise the inventory of conventional NAVAIDs to reduce infrastructure sustainment costs. Given the vulnerabilities of GNSS, particularly to RFI, it has been deemed essential to retain a minimum number of conventional NAVAIDs as part of a MON and, where necessary, to install additional NAVAIDs to ensure minimum coverage. This strategy will provide users with options during potential GNSS RFI outages.

2. Purpose

The purpose of this document is to provide guidance material and share best practices with CANSO members on establishing and implementing a MON as a backup for GNSS outages to enable aircraft to navigate through or around GNSS outage areas and minimise pilot and controller workload during GNSS outage event. The MON should not be limited to supporting conventional applications but should also provide for RNAV coverage for various route specifications based on considering a states' airspace size and infrastructure. MON planning should encompass enroute and approach operations, ensuring conventional NAVAIDS can support the required services.

3. Background

The Global Air Navigation Plan or GANP (ICAO Doc 9750) is described as "ICAO's highest air navigation strategic document and the plan to drive the evolution of the global air navigation system, in line with the Global Air Traffic Management Operational Concept (GATMOC, ICAO Doc 9854) and the Manual on Air Traffic Management System Requirements (ICAO Doc 9882)". The GANP has the objective of delivering a future, harmonised global navigation capability based on RNAV and PBN supported by the GNSS.

"The current single frequency GNSS capability provides the most accurate source of positioning that is available on a global basis. With suitable augmentation, as standardised within annexes, single frequency GNSS has the capability to support all phases of flight. The current GNSS has an extremely high availability, although it does not have adequate resilience to several vulnerabilities, most notably RFI and solar events causing ionospheric disturbances. Until a solution to ensure adequate GNSS resilience is available, it is essential that a terrestrial navigation infrastructure, suitably dimensioned to be capable of maintaining safety and continuity of aircraft operations, be provided."[1]

The overview of the GANP context indicates that the role of ground-based NAVAIDs will evolve to support contingencies during potential GNSS disruptions. As a contingency capability, conventional NAVAIDs can be rationalised. However, to retain a MON designed to efficiently provide reversion service, it is important to recognise that a MON is not intended to serve as the primary navigation service, but as a recovery capability that aircraft can revert to, independent of GNSS.

1 ICAO Global Air Navigation Plan (GANP)

4. Methodology

To develop these guidelines, the CANSO team reviewed various national and regional MON concepts provided by CANSO members, including concepts from the Netherlands, France, Spain, The United States of America, Australia and Canada, a regional concept from EUROCONTROL and ICAO guidelines. Insights from these concepts were used to develop a high-level guidance document to assist ANSPs and regulators in conducting operational analysis for contingency operations during potential GNSS outages.

4.1 ICAO/Regional/National Guidance

ICAO Annex 10 (Aeronautical Telecommunications), Volume 1 (Radio Aids to Navigation - Seventh Edition, July 2018), Attachment H defines a global "Strategy for rationalisation of conventional radio navigation aids and evolution toward supporting performance-based navigation". The objective of Attachment H is to provide guidance to the States for both the rationalisation and back-up of the terrestrial NAVAID infrastructure. The recommendations include the new roles foreseen for each type of NAVAID as part of the reversionary terrestrial infrastructure capable of maintaining safety and an adequate level of operations to support contingency operations.

Evolution Strategy (from ICAO Annex 10, Attachment H):

Before an ANSP can develop a proposed infrastructure MON solution, they need to consult aircraft operators and international organisations to ensure safety, efficiency and cost-effectiveness of the proposed solutions. Based on the above, the recommended strategy is to:

a. Rationalise NDB and VOR and associated conventional Instrument Flight Procedures.

b. Align rationalisation planning with equipment life cycles and PBN implementation planning.

c. Replace conventional instrument approach procedures without vertical guidance with vertically guided approach procedures.

d. Evolve the existing DME infrastructure towards providing a backup PBN capability complementary to GNSS for aircraft equipped for DME/DME navigation.

e. Repurpose the VOR network to provide an aircraft with only a conventional navigation capability (e.g. without DME navigation) a method of navigation during a GNSS outage.

f. Enable each region to develop operational requirements and an implementation strategy for NAVAID rationalisation in accordance with the global strategy.

5. Minimum Operational Network (MON) Considerations

It is critically important for ATM and infrastructure managers to collaborate to ensure appropriate PNT services will support continued operations during GNSS outages. The definition of the MON strategy and plans should consider the type of airspace users operating in each area. For example, if a single type of air carrier aircraft dominates regional operations and enough DMEs are available, then the MON can be structured to provide DME navigation to enable aircraft to continue RNAV or RNP operations with minor impacts. Conversely, if General Aviation (GA) aircraft, which are not typically equipped for DME navigation, dominate regional operations, then the MON configuration should be based on VOR and associated conventional instrument flight procedures.

5.1 GNSS Vulnerability Considerations

GNSS vulnerabilities can arise from constellation weakness, RFI or disturbances in the ionosphere are the most likely cause of future GNSS outages and should be a primary consideration when planning and developing contingency procedures. RFI may result from intentional interference caused by spoofing or jamming from scheduled testing or military operations, or unintentional interference caused by equipment failure, illegal use of Personal Privacy Devices or radio operator error.

Mitigating GNSS outages is a challenging task for ANSPs. ANSPs must ensure an adequate service maintaining a ground-based navigation infrastructure supports PBN applications. Rationalisation of ground-based navigational aids must ensure a MON is capable to provide safe contingency operations and service provision during GNSS outages. If States and their regulators determine, based on evidence from their GNSS monitoring, that GNSS cannot be considered reliable as a primary means of navigation in a certain region, alternative measures should be considered.

The expected evolution of GNSS towards Dual Frequency Multiple Constellation (DFMC) will enhance robustness and resilience against several phenomena, yet it will not guarantee a complete solution for addressing RFI. Consequently, additional mitigation measures, such as the maintenance of a MON, will remain necessary.

5.1.1 Reversionary Scenarios

ANSPs should develop reversionary scenarios to help identify appropriate mitigations to RFI and meet the operational requirements of each airspace, while also emphasising regional cooperation. Reversionary scenarios should include variables such as traffic volume, aircraft types, terrain constraints, and navigation infrastructure. Mitigations should be considered for each phase of flight, assuming various GNSS failures scenarios (cause, geographic scope, duration, etc.) and should detail how aircraft and ATC will safely transition to contingency operations and resume normal operations after an outage.

In high-traffic environments, some States have identified DME/DME as their main PBN reversion capability. Many States also plan to provide a residual VOR or VOR/DME infrastructure network to support users with PBN capabilities. Operational procedures for these reversion capabilities are under development. It is typically not feasible, nor is it the goal for contingency operations, to provide an equivalent capability to GNSS.

Contingency operations depend on a resilient PNT capability independent of GNSS that will ensure safety and minimise the impact of a GNSS disruption. To maintain GNSS-independent navigational infrastructure, ANSPs must ensure that all necessary elements for safety, recovery and continued operations are maintained. NAVAID rationalisation must offer cost-effective resiliency with adequate redundancy to meet safety appropriate for aircraft operating within the airspace system. Economic considerations may necessitate more redundant capabilities for air carrier operations to mitigate the financial impacts of aircraft diversions or excessive delays during GNSS outages.

5. Minimum Operational Network (MON) Considerations (continued)

5.2 Navigation Infrastructure Planning

The PBN concept as outlined in ICAO Doc 9613, defines the performance requirements that are identified as Navigation Specifications (NavSpec). These specifications determine the available navigation sensors and equipment needed to meet the performance requirements. Each navigation specification is supported by its associated NAVAID infrastructure. Conventional ground-based NAVAID infrastructure includes DME, VOR, NDB, and ILS.

Focusing on future developments, GNSS infrastructure is evolving to include multiple constellations, which includes GPS, BeiDou, Galileo, and GLONASS, as well as standardised augmentations such as satellite-based augmentation system (SBAS) and ground-based augmentation systems (GBAS) to support these multiple frequency signals. However, the transition to Multiple Constellation Double Frequency (MCDF) GNSS systems will take decades before aircraft fully equipped with the necessary technology can fully benefit from these advancements.

5.2.1 Adjacent State Coverage

ANSPs that share NAVAID services with neighbouring States should consider establishing agreements to include NAVAIDs from the adjoining State in its navigation solution and MON strategy. Collaboration between ANSPs from neighbouring States is essential for designing routes and procedures that cross international boundaries. Additionally, reliance on another State's NAVAID infrastructure for GNSS contingency can help reduce the cost of implementation and life-cycle maintenance of its own NAVAID infrastructure. The shared use of NAVAIDs may require the establishment of bilateral agreements between the neighbouring ANSPs. ICAO has identified this relationship as a contingency requirement under Regional Air Navigation Plans.

5.2.2 NAVAID Role in PBN

Table 1 below summarises different conventional NAVAIDs that have varying capabilities to support PBN operations. Appendix B provides a detailed summary of the current and future roles of ground-based NAVAID including their traditional navigation aid capabilities for enroute and approach operations.

Table 1: Ground based NAVAID Role in PBN and Resiliency

NAVAID	PBN Capability.
NDB	NDB has no role in PBN.
VOR	VOR has a limited role in PBN, supporting only one navigation specification, RNAV 5, which is primarily used in the enroute phase of flight. The PBN IR[2] requires RNAV 5 for all enroute ATS routes (excluding SIDS/ STARs) by 2024 in Europe.
DME	DME/DME supports RNAV 5, RNAV 2 and RNAV 1 navigation specifications. DME/DME is the most suitable terrestrial NAVAID configuration that can support PBN capabilities for appropriately equipped aircraft. DME/DME provides an equivalent capability to GNSS for RNAV applications, and a suitable reversionary capability for RNP applications requiring an accuracy performance of ±1 NM (95 per cent) laterally.
ILS Cat I	ILS CAT I procedures are not considered PBN applications but provide resiliency.
ILS Cat II/III	Cat II/III approach procedures are not considered PBN applications but provide resiliency.

2 PBN Implementing Rule, EU Regulation 2018/1048

5. Minimum Operational Network (MON) Considerations (continued)

5.2.2 NAVAID Role in PBN (continued)

Table 2 below identifies which ground-based NAVAID can be used to support specific PBN specifications. The navigation specifications performance requirements determine which positioning source/sensor (e.g. navigation aid and/or aircraft integration with Inertial Reference Unit (IRU), can be used. The on-board navigation sensors must be compatible with the infrastructure to achieve the prescribed navigation performance within the NAVAID coverage area.

Table 2: NAVAID Infrastructure (Required/Optional) supporting PBN applications

	GNSS (i.e. GPS)	IRS	DME/DME	DME/DME/IRU	VOR/DME
RNAV 5	O	O	O	O	O
RNAV 2 and 1	O		O	O	
RNP 1	R		O	O	
RNP APCH (Baro)	R				
RNP APCH (SBAS)	R with SBAS				
RNP AR OPR	R	O			
RNP 0.3 (Helicopters)	R				

Note 1: Infrastructure must match on-board equipage.

Note 2: To be determined (TBD) The use of DME/DME for this navigation specification requires a specific State authorisation. EUROCAE work groups 107 and 85 are in the process of determining potential European standards for the use of DME/DME for RNP applications (infrastructure/avionics respectively).

Note 3: Conventional navigation can provide guidance on the missed approach, and exceptionally, this may be supported by NDB.

Note 4: IRU required where the lateral navigation accuracy is less than 0.3 NM in the approach phase and less than one NM in the missed approach.

5.3 Airborne Equipage Considerations

An analysis of the airborne equipage capabilities should be considered as part of the MON planning to ensure that after the rationalisation of NAVAIDS, enough users can still use the procedures. It is important to survey the avionics capabilities of the usual fleet in each scenario to ensure that the means provided by the MON allow the pursued level of service in nominal and contingency scenarios is achieved, considering the PBN specifications to be deployed and the redundancy of sensors available.

An aircraft fleet survey was conducted by IATA, EUROCONTROL, and the UK CAA to inform the development of the Future Airspace Strategy (FAS). The survey indicated most aircraft met their RNAV 1 capability using GNSS, with approximately two per cent relying on DME/DME for their RNAV 1 position fixing capability. Most of these aircraft are equipped with an Inertial Navigation System or Inertial Reference System (INS or IRS).

5. Minimum Operational Network (MON) Considerations (continued)

5.3 Airborne Equipage Considerations (continued)

In the event of a GNSS outage, the ANSP is required to assess the safety impacts to aircraft operations and implement mitigations by either providing alternate PNT, such as DME/DME, VOR/DME and/or other procedures (e.g. Tactical vectoring using surveillance).

In areas with limited NAVAID infrastructure, ANSPs may target a practicable level of redundancy by designating 'critical' DMEs for a designated instrument flight procedure. This approach allows ANSPs to avoid providing DME coverage for airspace which would otherwise require an excessive investment in DME infrastructure. ANSPs may also credit ATC surveillance and aircraft equipped with INS, in combination with DME infrastructure with very low failure rates, to meet resiliency needs and to avoid costly investments in redundant VOR/ DME infrastructure.

ANSPs can work directly with the user community operating within their airspace to identify the current state of CNS avionics or analyse information contained within ICAO flight plans submitted by users. However, the varied quality of declared communication capabilities in Flight Plans (FPL), is based on the capabilities provided by the various operators in the FPL, without the possibility to validate the accuracy and completeness of the information.

5.4 User Community Considerations

NAVAID rationalisation activities should include coordination with all affected parties to ensure unacceptable risks are not introduced during implementation. Interested parties may include aviation training centres, military operators, local flying clubs, and other potentially affected parties. Timely and routine communication with interested parties should be conducted to explain the overall concept, the expected outcomes, and the expected benefits.

5.5 Civil-Military Co-ordination

Military and civil air traffic services and infrastructure support military operations in both peace- and crisis-time. NAVAID rationalisation, such as the removal of TACANs, may have a negative effect on military operations. Therefore, ANSPs should coordinate with military counterparts when developing realisation plans. Encouraging civil military working arrangements is crucial to ensure effective communication and coordination at all levels. Authorities should agree on a common compliance matrix to identify and address gaps and implement necessary mitigations.

5.6 Airspace Concept and NAVAID Infrastructure Evolution

An airspace concept outlines the intended operations within a given airspace. Airspace concepts are developed to satisfy strategic objectives such as safety, capacity, or flight efficiency. The development of the airspace concept is driven by operational requirements, available CNS infrastructure and the types of aircraft expected to operate within the airspace.

It is important to recognise that airspace concepts include practical details about the organisation of the airspace and its operations, in addition to the CNS/ ATM assumptions on which it is based. Some concepts specifically address the coordination required between the airspace design, procedure design, and the infrastructure planning teams.

Airspace planners must stay informed of evolving infrastructure plans, including plans related to the maintenance and renewal of NAVAIDs at the end of their lifecycle, to ensure all needed considerations have been accounted for. While the evolution airspace and infrastructure may not be fully synchronised, ANSPs must ensure effective communication and collaboration among all service providers, regulators, and users.

6. MON Implementation Guidelines

PBN is the core requirement for the future airspace concept. ICAO Document 9992 provides step-by-step guidance on the application of PBN during the development of an airspace concept.

Until 2030, many airspace users will only have a single frequency, single constellation receivers (SF-SC) using the US NAVSTAR Global Positioning System (GPS). Therefore, consideration must be given to the possible loss of this signal and how to maintain ATM operations using only ground-based NAVAIDs. GNSS vulnerability will consistently need to be mitigated: while technical resilience and robustness can be achieved by placing more demands on the system, operational procedures (ATM/Flight crew) are also critical to maintaining an acceptable level of safety. This applies equally to SF-SC or dual-frequency multi-constellation (DF-MC) environments.

Ground based and space-based infrastructure provides positioning for PBN operations. Regardless of the positioning source, whether satellite or ground-based Navaids, two criteria must be fulfilled:

i. The aircraft's navigation sensor must match the navigation infrastructure available.

ii. The aircraft must be certified, and crew must be authorised for the intended PBN operation.

It is important for infrastructure planners to collaborate with their airspace and procedure design colleagues to determine a basic level of capabilities required facilitate PBN implementation for both normal and contingency operations. These efforts should encompass PBN implementation changes and adjustments regarding conventional applications.

Two approaches can be applied:

1. **Top-Down Approach:** In this method, RNAV or RNP routes are placed, spaced, and crossing points are selected independently of existing infrastructure constraints. This allows for a flexible approach to airspace optimisation. Part of the route placement iterations are refined with input from the procedure designer, and after multiple iterations, the infrastructure optimisation team can determine the NAVAID coverage requirements.
2. **Bottom-up Approach:** In this method, existing infrastructure drives route planning. A feasibility study may indicate where NAVAID coverage is insufficient or not supported due to cost, thereby limiting where certain routes can be placed.

Additionally, performance criteria must be considered. A generic set of target performance requirements should be identified and clearly defined for each specific airspace volume, based on the intended normal and contingency operations. These performance requirements will guide the definition of the technical specifications for individual NAVAIDs and the design of the infrastructure network.

By incorporating these inputs and the considerations, a preliminary infrastructure configuration can be established along with the corresponding implementation timelines.

6.1 Infrastructure Rationalisation Objectives

When performing analysis to rationalise the NAVAID inventory, efforts should focus on minimising costs by decommissioning problematic NAVAIDs rather than fully capable systems. ANSPs should consider the following when selecting NAVAIDs for decommissioning:

a. Systems at the end of the lifecycle (priority for decommissioning or replacement if retained).

b. Depreciation costs.

c. Optimising cost of ownership, including co-locating new DMEs at existing operational sites.

d. Facilities with maintenance issues (consider relocation or decommissioning).

e. Remote sites with difficult access.

f. Land lease/ownership issues.

g. Building Restriction Area issues.

h. Tree growth and encroachment on NAVAID installation clear zones.

However, the overarching priority should always be to maintain or improving the safety levels, both in nominal and contingency operations.

6. MON Implementation Guidelines (continued)

6.1.1 Cost-Benefit Analysis (CBA)

Financial and costs considerations should be integrated into a CBA and should account for the availability and reliability of existing NAVAIDs, and the cost of infrastructure for sharing data. The CBA parameters will be driven by the specific local estimates. During the transition phase, an impact assessment should consider the co-existence of legacy and new sensors, ensuring that their configuration avoid "duplicated" services.

The CBA enables stakeholders to assess the benefits of the infrastructure optimisation at local, regional, or network levels, reflecting the costs and benefits of the decommissioning or replacement components with more cost-effective alternatives. Additionally, it can evaluate operational services and benefits provided by new infrastructure. The CBA could also include metrics to estimate the equivalent reduction in CO_2 emissions resulting from the decreased power consumption of the new optimised infrastructure with more power-efficient components

6.1.2 Infrastructure Life-Cycle Planning

The implementation of a MON should be carefully planned to minimise disruption to existing infrastructure plans. Long range navigation strategies and implementation plans should consider both primary and contingency navigation operations to avoid unnecessary costs and schedule impacts. NAVAID sustainment activities to replace aging systems should be planned based on the end-state inventory of systems needed for primary and contingency operations. This approach should reduce the number of existing systems replaced, thereby lowering overall procurement and life-cycle maintenance costs.

For facilities near international boarders, it is important to inform and coordinate with adjacent ANSPs well in advance to allow then to plan any required changes accordingly. For example, for international ATS routes that are dependent on a VOR and the VOR is decommissioned, resulting in a change to an RNAV route or the route's cancellation, the adjacent ANSP will need to know so they can adjust their airspace structure accordingly. When airspace changes are required on both sides of a FIR boundary, it is also imperative that both ANSPs plan their changes to become effective on the same Aeronautical Information Regulation and Control (AIRAC) date.

6. MON Implementation Guidelines (continued)

6.2 Transition Planning

ANSPs are encouraged to develop an infrastructure optimisation plan and make provisions for establishing and sustaining a MON. Portions of the infrastructure rationalisation plan must flow into the relevant parts of the PBN transition plan. ANSPs must develop a complete understanding of the navigation infrastructure evolution and the intended type of operations enabled by each NAVAID. This understanding will enable ANSPs to develop rationalisation and decommissioning plans effectively.

This guidance addresses the goal of maintaining PBN capability as being the basis of GNSS resilience for regions that have a high density of VOR/DMEs or VORTACs and a high traffic density, and in areas of low population density and limited DME coverage, MON planning will be different and may not for example be able to consider ILS rationalisation.

Because GNSS is vulnerable to certain threats, infrastructure managers seek to understand GNSS vulnerability. This can be due to a constellation weakness, radio frequency interference (RFI) or Ionospheric Interference. Key mitigations are achieved by ensuring technical resilience and robustness, there is also certain reliance on operational ATM/Flight crew contingency procedures to maintain an acceptable level of safety. RFI is of greatest significance to Contingency Procedures for GNSS reversion, as RFI is the most likely cause of GNSS outage.

A PBN transition plan is important and should be a major component of NAVAID infrastructure planning and the development of an airspace concept.

A PBN transition plan is comprised of three elements:

1. The Navigation Specification, which provides the certification and operational standards for the RNAV or RNP application.

2. The NAVAID Infrastructure, which provides the positioning for the required RNAV or RNP specification.

3. The Navigation Application, which implements the use of the Navigation Specification and Infrastructure together in the form of PBN instrument flight procedures.

NAVAID infrastructure managers must ensure sufficient PNT services provide aircraft sensors with enough data to enable safe PBN operations. ANSPs are responsible for operating and sustaining ground-based NAVAIDs needed to support the MON.

NAVAID rationalisation activities require careful implementation. For example, divesting a VOR may require cancellation or amendment of many existing instrument flight procedures. Changes to the operating environment directly affect aircraft operations, so it is imperative to ensure all existing instrument flight procedures dependencies are addressed before removing the NAVAID from service. A VOR may support numerous ATS routes, terminal and approach procedures Existing procedures may need to be cancelled and replaced or amended. Typically, VOR-based routes will be replaced with RNAV routes that can be flown using GNSS and conventional NAVAIDs (DME). VOR-based routes can also be amended to connect with other VORs if sufficient signal coverage exists. Mitigating the affected instrument flight procedures for a single VOR could require years of coordination before the NAVAID can be removed from service.

Frequent communication and coordination with NAVAID providers, instrument procedure designers, flight inspection, and Air Traffic authorities is imperative to ensure transition activities are performed efficiently.

Appendix A - MON Implementation Examples
1. United States of America VOR MON

The U.S. VOR MON provides resiliency during GNSS outages by providing a conventional backup capability to enable aircraft to safely recover to designated MON airports, enable aircraft to fly through or around GNSS outage areas, and minimise pilot and controller workload during GNSS outage events. Since VORs do not support RNAV operations, pilots must transition from RNAV to conventional navigation when encountering GNSS outages.

Reduction of VORs in the U.S. was accomplished primarily by modifying the Standard Service Volume (SSV) to leverage existing signal coverage at 5000 feet AGL that the original SSV did not. By extending the low altitude coverage, the same VOR service coverage could be provided with approximately 30 percent fewer systems.

Operational Capabilities

The VOR MON concept was designed to provide the following operational capabilities during GNSS outages:

a. Safe recovery (landing) of aircraft flying in Instrument Meteorological Conditions (IMC) under IFR operations.

b. Flight operations continue without a significant increase in workload for either the pilot or the air traffic controller during a GNSS outage event.

c. Strategic modification of flight paths or trajectories to avoid areas of GNSS outage and manage demand within the GNSS outage area, and

d. Continued dispatch of air carrier operations to deny an economic target for an intentional jammer.

MON VOR Selection Criteria

The criteria used to model the coverage and develop a list of VORs that would comprise the MON included the following:

e. MON will provide VOR signal reception at 5,000 feet Above Ground Level (AGL) and above.

f. MON VORs will be spaced no more than 70 nm apart consistent with signal reception range at 5,000 feet AGL; and,

g. Aircraft will always be within 100 nm of a designated MON airport.

h. MON airports must have a GNSS-independent instrument approach (VOR, ILS, LOC, without DME required) and transition routing from the enroute structure.

i. Retain VORs in most of the Western UU.S. Designated Mountain Area (WUSDMA), Alaska, Hawaii, Puerto Rico, the U.S. Virgin Islands, Guam, Grand Turk, and Samoa.

j. Retain VORs that support international arrival airways from the Atlantic, Pacific, and the Caribbean, where necessary.

k. Retain High Altitude class VORs where possible.

2. Canada

NAV CANADA commissioned an Aeronautical Study "NAVAID Modernisation" which is the basis for Canada's MON planning. The study was completed in 2017. Below a quote on the findings of the study.

"Transport Canada is supportive of and accepts the ICAO Performance Based Navigation (PBN) initiative and the need for globally harmonised operations. Transport Canada, NAV CANADA and the Canadian aviation industry are working together to implement an ICAO State PBN plan for Canada.

The NAV CANADA PBN Operations Plan outlines the overarching plan for the way forward and this proposed system further defines the specific means to address both normal and exceptional recovery operations.

NAV CANADA recognises the robust nature of satellite-based navigation and has developed guiding principles to support a navigation infrastructure that will continue to provide a safe and efficient network under all operational scenarios. The critical path elements under a degraded operation are:

- A recovery network of VORs and NDBs that will support navigation from NAVAID to NAVAID and/ or to an area of surveillance coverage to a recovery airport served with a ground-based instrument approach procedure.
- A network of recovery NAVAID and airports; and
- Navigation and surveillance coverage at 10,000 ft ASL in Canadian Domestic Airspace (CDA).

The goal is to retain a recovery network of ground-based navigation aids to meet aviation needs. Within this network there would be a set of recovery airports with approach capabilities not dependent on GNSS. Recovery airports will be selected based on:

- Geographic location
- Runway/Apron capacity
- Useable instrument approaches
- Availability of aviation weather information
- Common routings

The NAVAID used to facilitate this recovery activity would be ground-based; either a NDB or VOR to enable navigation from up to 100 NM at 10,000 Ft ASL to a suitable or recovery airport. The NAVAID may also support the primary instrument approach for the recovery airport.

In the unlikely event of GNSS degraded performance, aircraft that are not within line-of-sight range of either a ground-based navigation aid or surveillance facility and do not have a self-contained navigation capability, may use dead reckoning for up to 100 NM to re-enter a NAVAID signal or surveillance coverage area. This will be employed as an acceptable recovery manoeuvre.

Reliance on ILS as the primary means of achieving precision approach will continue. However, the use of a NDB as part of the ILS approach will be eliminated and replaced with DME as required.

3. DSNA France

DSNA presentation during CANSO WG Sept 2021 provided the following information on - GNSS reversion concept of operations, and conventional aids infrastructure rationalisation.

Conventional aids rationalisation process, Contingency due to e.g. wide-scale loss of GNSS

From 6 June 2030: (EU) PBN IR:

- Exclusive use of PBN.
- Contingency use only of conventional procedures (except ILS CAT II/III).

From 6 June 2030:

- Adaptation of conventional aids networks, transition to MON process.

MON (Minimal Operating Networks):

- ILS MON of 38 aerodromes already implemented.
- VOR MON to be implemented, according to a CONOPS "loss of GNSS" to be developed.

CONOPS developed with ATC centres:

- Sizing case of the wide-scale loss of GNSS with no possibility of circle-to land/VPT.
- Use of means of navigation independent from the GNSS (VOR, DME) and associated surveillance and communication infrastructure.

In the CONOPS:

- Unequipped [equipped] aircraft means an aircraft that does not have [has] PBN [DME/DME] or [DME/DME and INS] certified navigation capability for the published routes.
- GNSS loss means wide-scale GNSS loss.
- ATC guidance means guidance from ATS surveillance means independent of the GNSS (e.g. "Secondary Surveillance Radar").
- "GNSS loss minimal network" includes ILS MON aerodromes and a few aerodromes outside ILS MON deemed pertinent for diverting traffic from ILS MON aerodromes whose parking areas would be saturated; the possibility of providing each non-ILS runway end of these aerodromes with a VOR/DME procedure is to be considered.

CONOPS applied with ATC centres:

VOR needed for ATC guidance and holdings in enroute and terminal controlled airspace; missed APP for all ILS/VOR approaches; navigation in uncontrolled airspace.

Establish VOR MON promoting:

- VOR-DME vs DME-free VOR.
- DVOR vs CVOR.
- VOR/VOR-DME with extensive DOC (Declaration of Operational Coverage).
- Multiple use VOR.
- Maintaining VOR where radio contact is not guaranteed.

Enhance and optimise DME network to ensure DME/DME coverage above FL115 and in terminal-controlled airspace.

- Maintaining the DME on a site from which a VOR is removed.
- Installation by 2030 of additional DME on currently DME-free VOR sites or other sites (e.g. former NDB sites).

Loss of GNSS presentation also included information on the DSNA concept of operations "Loss of GNSS Emergency Phase and Traffic Resumption Phase.

4. ENAIRE Spain

ENAIRE developed a high-level document regarding the Spanish MON, from the introduction.

- The concept developed regards only navigation infrastructure owned by ENAIRE, and NDB stations owned by the main Spanish aerodrome operator, Aena. Stations owned by other aerodrome operators or military entities are not addressed for the time being.
- The level of development of the concept is still at a high-level, as the work methodology here developed is still under study and has not been ratified and assumed by all the potentially involved parts from ENAIRE and/or national authorities

  Also, it must be considered that the study of rationalisation cases can be assessed at a general level to seek opportunities based on a series of principles, but most of these opportunities are still to be subjected to user's consultation, which could change the outcome initially assessed.
- MON planification is heavily connected to Spanish PBN implementation plan, which is a complex process involving multiple actors, and therefore subject to a considerable level of variation in dates. As future implementations clarify, the feasibility of rationalisation opportunities will be clearer, and thus, the MON outline will be more defined.

Below the Outline (details can be found in the reference document).

1. Introduction
2. Methodology
   a. General approach
   b. Assumptions
3. MON Background
   a. ICAO/Regional/National guidance
   b. Nav infrastructure/systems/GNSS outages/ Scenarios
   c. Aircraft capabilities
   d. Airspace concept
4. MON Implementation Guidelines
   a. National/National Nav Strategy
      i. Airspace Concept
      ii. PBN Implementation
   b. National Nav Infrastructure
      i. DME stations' role and current DME/DME coverage
      ii. VOR stations' role and current VOR/DME coverage
      iii. NDB stations' role
      iv. ILS stations' role
   c. Adjacent state coverage
   d. Infrastructure planning
   e. User community

5. LVNL Netherlands

The LVNL update was provided in Form of briefing slides to the CANSO PBN WG 8 September 2021.

LVNL considers the Navigation Infrastructure main to be GNSS, the fallback DME/DME and last resort VOR.

Goal: Continue FRA airspace, Routes, SIDs & STARs with 100 percent capacity.

The DME network requirements are:

- DME stations, RNAV1 in TMAs, 20 NM, 2000 ft
- + Cross border DMEs
- + MIL TACANs
- Maintain to Annex 10
- Service Agreements

The VOR minimum operational network goals is:

- Terminate flights safely to the closest 'MON airport'
- Maintain temporal reduced conventional service

The VOR MON requirements are:

- 4 DVOR stations
- RNAV5 in FIR
- 50 NM, FL 050
- + Cross border VORs
- Maintain to Annex 10
- Service Agreements

LVNL MON 'Final Operational Concept' is under development paced to European PBN Regulation and Operational Excellence Programme.

6. Airservices Australia

MON information was provided per email.

The Australian MON is called the Back-up Navigation Network (BNN). Australian transition to GNSS as the primary means of communication occurred with regulatory changes coming into effect in 2016. A large programme of Instrument Approach Procedure (IAP) design occurred to ensure that there would be sufficient alternate IAPs available at locations where navigation aids were to be removed. The BNN then went through a process to decommission navigation aids that did not form part of the BNN.

Issues:

- Replacement of navaids with waypoints requires redesign and amendment of the published route/s
- Recalculation of LSALTs to GNSS based navigation (RNP2) and for the new routes where they moved
- Concentration of training to aerodromes where navaids are available increased traffic numbers at the remaining locations
- Use of GNSS for an NDB approach – pilots are approved to do this; however, it is invisible to ATC which method is being used, and the separation standards did not support the direct replacement of GNSS vice NDB tolerances (an issue particularly at locations where there was a controlled aerodrome with no surveillance)
- Regular ongoing review of the navigation aid network must continue to ensure that we have appropriate navaids in appropriate locations.

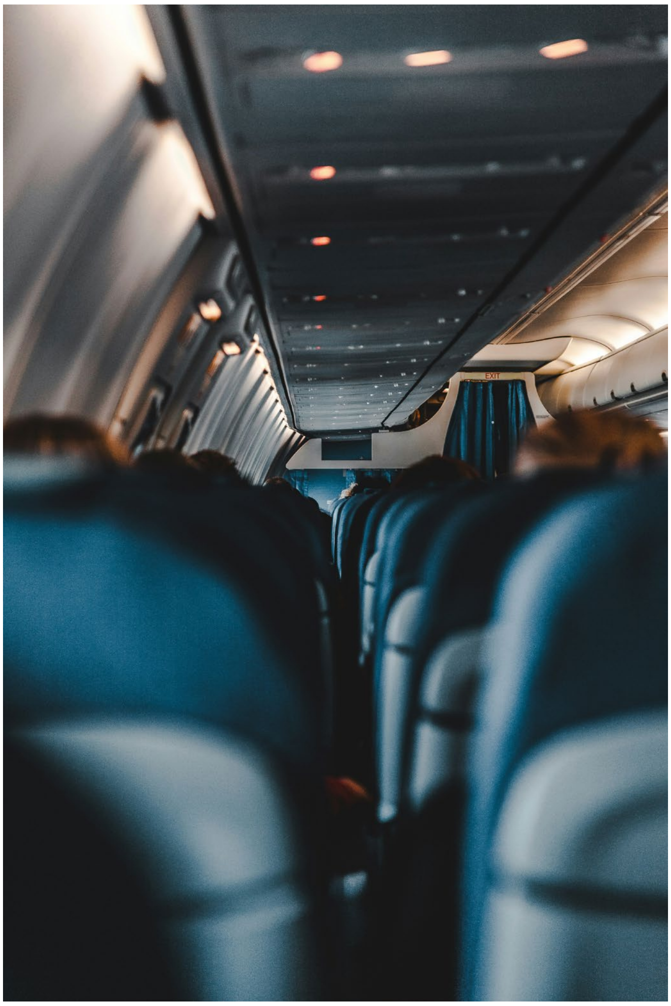
Appendix B - Role of NAVAIDS
1. Distance Measuring Equipment (DME)

1.1 DME/DME Current Coverage

DMEs are widely used to support different flight procedures, both conventional and PBN.

For conventional procedures DME supports ILS/DME, VOR/DME and NDB/DME procedures. Paired with a VOR, ILS or NDB, it can support conventional procedures by providing range when co-located with a VOR, NDB or ILS. For these types of procedure, DME is not the main enabler; therefore, the operational requirements for DME will result mainly from the analysis of the operational roles of ILS, VOR and NDB. Stand-alone it can enable the flying of DME arcs.

For PBN procedures DME/DME enables the following specifications: RNAV 5, RNAV 2, RNAV 1 (which serves also as RNP 1 reversion). However, where authorised by the State it can support RNP 1 and if applicable, it can support RNP AR missed approach.



1.2 DME/DME Future Coverage

In the future, the main role of DME NAVAIDs will be to support reversion for PBN operations in case of GNSS failure. Therefore, the main objective should be the definition of the DME/DME performance in airspace volumes where PBN operations are to continue.

The DME/DME performance requirements can be defined in terms of accuracy, integrity, continuity, and availability of the navigation service. This performance level should be defined for each airspace volume served, based on the type of application to be supported and while considering continuity objectives set by the airspace concept. While the required navigation accuracy generates constraints on the geometry of the DME/DME pairs, it should be noted that the RNAV navigation specifications do not include integrity requirements for the DME/DME signal-in-space. However, the expected continuity and availability of service will drive the number and location of DMEs required to meet DME/DME RNAV coverage and redundancy requirements.

The following minimum set of considerations is recommended when identifying the future operational roles of the DME network:

a. Determine the enroute and terminal airspace where DME/DME RNAV service is needed for contingency operations during GNSS outages.

b. Identify the PBN NavSpec needed to support RNAV contingency operations.

   i. GRNAV 5 operations in Free Route Airspace (FRA) or along ATS routes in En Route airspace volumes.

   ii. RNAV 1 operations (SIDs/STARs) in terminal airspace volumes.

   iii. RNAV 2 for enroute ATS routes.

   iv. RNP 1 reversion operations (RNAV 1, SIDs/STARs) terminal airspace volumes.

c. Identify the conventional NAVAIDs with DME where DME/DME RNAV service is desired.

d. Identify airports where approach and landing operations must continue during GNSS outages.

e. Identify where additional DMEs are required to support PBN instrument flight procedures.

2. Very High Frequency Omni Directional Radio Range (VOR)

2.1 VOR Current Coverage

VORs are currently used to support different flight procedures, both conventional and PBN.

For conventional procedures paired (or not) with a DME, VORs can support enroute operations (low level ATS routes), SIDs/STARs, non-precision approaches (NPA), missed approach procedures and even the transition up to intercepting the ILS. In all the previous cases they provide bearing information and enable homing to a beacon. When co-located with a DME, range and bearing information is available.

For PBN procedures the only PBN navigation specification enabled by VOR, provided a co-located DME is present, is RNAV 5. VORs can be used in the enroute phase of flight (at or near the bottom of the enroute airspace, where achieving DME/DME coverage is challenging).

2.2 VOR Future Coverage

As mentioned before, the only PBN navigation specification enabled by VORs is RNAV 5 (provided that a DME is co-located). Given these limitations, the ease in route phase to achieve proper DME/DME coverage, and the fact that only a few aircraft operators are certified to use exclusively RNAV 5 capabilities based on VOR/DME, a deep analysis is required to assess which VOR facilities should be retained to support either enroute, terminal or approach and landing operations, which will be conventional in the most cases.

The main residual operational roles of the VOR in context of the PBN are:

a. Providing alternative means of navigation during contingency operations.

b. Allow the operation of non-PBN capable aircraft during the transition to PBN.

As part of the overall MON strategy, it is recommended to perform a VOR network rationalisation analysis and identify where VOR(/DME) is needed to support:

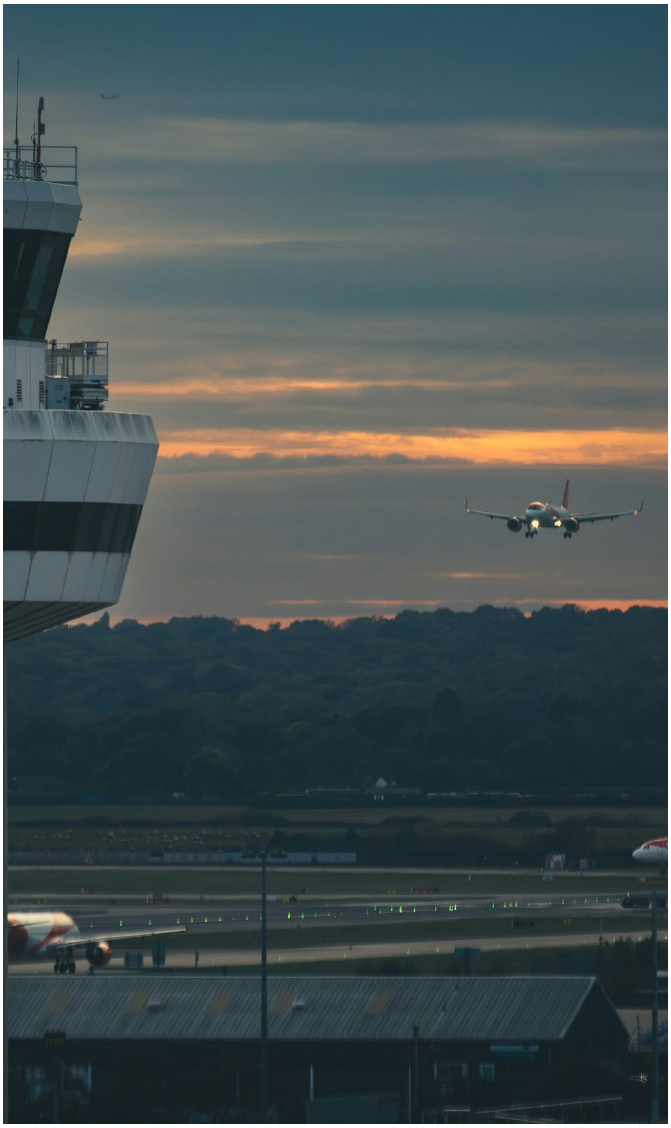
a. En route and TMA airspaces.

b. RNAV 5 operations in FRA or on ATS routes.

c. Conventional ATS routes defined by VOR/DME which are required to be maintained.

d. Operations of State aircraft or aircraft of lower capabilities on ATS Routes.

e. Conventional instrument approach procedures at alternates for major aerodromes and/or for aerodromes where only RNP APCH procedures are planned.



3. NDBs

NDBs do not support PBN operations and their use as an aid to enroute navigation, terminal area operations or as an approach aid is generally considered obsolete. An increasing number of aircraft no longer provide an ADF capability on- board. Therefore, the retention of NDB-based ATS routes and procedures is not recommended. However, if a need for NDBs is identified in the airspace concept, the reason for this must be fully explored and justified. Additionally, the required facilities (including co-located DMEs) should also be identified.

4. ILS

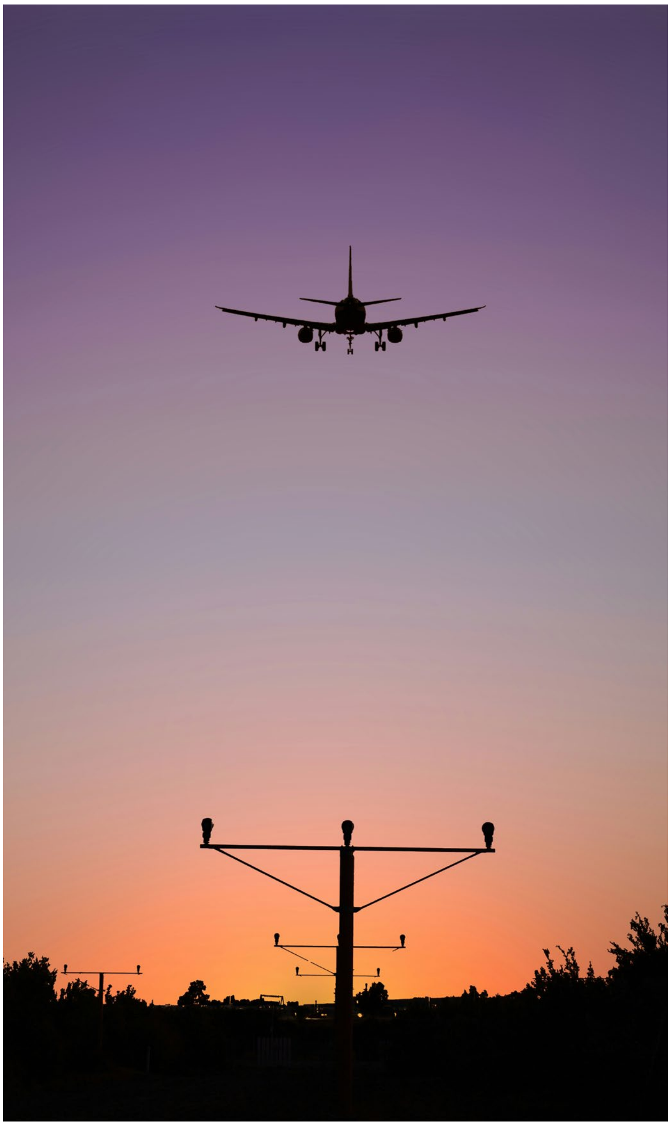
4.1 ILS Current Coverage

Instrument Landing Systems (ILS) support Precision Approaches and Non-Precision Approaches (NPAs) for localiser (LOC) only approaches. They can be co-located with DMEs to provide range information. They provide lateral and vertical path guidance for a precision approach and can provide lateral path guidance for NPAs.

It is assumed that ILS will remain the primary means of navigation in low visibility operations (CAT II/III). As e.g. mandated in the European Union by EU IR 2018/1048 with effect from July 2030, RNP APCH to LPV (Localiser Performance with Vertical guidance) minima may replace ILS CAT I precision approach provided the appropriate SBAS coverage is locally available, and a significative number of aircrafts are equipped with SBAS capabilities. Same case could be considered for GBAS CAT I, though the deployment of this minima is not subject of a mandate. ILS CAT I may remain in these cases as a contingency mean depending on the business case considered. ICAO DOC 9992 (Manual on the use of PBN in Airspace Design) requires extensive analysis of fleet equipage prior to making implementation decisions. Example: Where RNP APCH does not have the same minima as ILS approaches (other than Cat I) due to operational limitations those airports where capacity and/or low visibility conditions are key, the ILS Approaches may be maintained.

4.2 ILS Future Coverage

At airports where all approaches are based on GNSS (i.e. RNP APCH or GBAS), a GNSS outage could have a serious impact on operations. At most airports with air carrier operations, ILS will continue to provide the only means for Category-II/III operations ILS rationalisation opportunities exist at ILS CAT I runways at airports where most aircraft are equipped to fly SBAS LPV procedures, and it is not deemed necessary as a reversion contingency mean. Rationalisation decision will be driven by safety, capacity, efficiency, and economic considerations. The evolution of the ILS/DME network must be considered when planning the evolution of the overall DME network because of most ILS facilities are co-located with a Low Power DME (LPDME). The possibility to add these DME facilities to support RNAV operations should be considered, following an analysis of the fleet equipage and changes in the operational management of these ILS/DME facilities.



Appendix C - Reference Documents

ICAO DOC 9750 Global Air Navigation Plan (GANP)

ICAO DOC 9854 Global Air Traffic Management Operational Concept

ICAO DOC 9882 Manual on Air Traffic Management System Requirements

ICAO DOC 9992 Manual on the Use of PBN in Airspace Design

ICAO Annex 10, Volume I Radio Navigation Aids, Seventh Edition, July 2018

ICAO Annex 11, Air Traffic Services

ICAO Performance-based Navigation Manual, ICAO, Doc 9613, Edition 4, 2013

FAA PERFORMANCE BASED NAVIGATION, PBN NAS NAVIGATION STRATEGY 2016

European Navaid Infrastructure Planning Handbook including Minimum Operational Network (MON), PBN HANDBOOK No. 4

European GNSS Contingency/Reversion Handbook for PBN Operations, PBN HANDBOOK No. 6

European Airspace Concept Handbook for PBN Implementation, PBN Handbook No 1

European GNSS Contingency/Reversion for PBN Operations, PBN Handbook No 6

European Route Spacing Handbook, PBN Handbook No 3

EUROCONTROL Guidelines for RNAV 1 Infrastructure Assessment (EUROCONTROL - GUID – 0114)

EUROCONTROL Minimum Operating Network Concept and Design Criteria, 22-04-2202

NAV CANADA, Aeronautical Study “NAVAID Modernisation”, August 2017

DSNA Briefing CANSO PBN WG – 8 September 2021, “GNSS reversion concept of operations - Conventional aids infrastructure rationalisation”

ENAIRE, CANSO MON ENAIRE Feedback Doc, 6 June 2023

LVNL Netherlands, Briefing CANSO PBN WG – 8 September 2021 “MON Concept in The Netherlands”

Appendix D - Abbreviations

ANSP	Air Navigation Service Provider
ATM	Air Traffic Management
AR	Authorisation Required
ASBU	Aviation System Block Upgrade
AU	Airspace User
CBA	Cost Benefit Analysis
CNS	Communications, Navigation and Surveillance
CS-ACNS	Certification Specification for Airborne CNS
DME	Distance Measuring Equipment
FMS	Flight Management System
GANP	Global Air Navigation Plan
GBAS	Ground Based Augmentation System
GLS	GNSS Landing System
GNSS	Global Satellite Navigation System
GPS	Global Positioning System
IAP	Instrument Approach Procedure
ICAO	International Civil Aviation Organisation
IFP	Instrument Flight Procedure
ILS	Instrument Landing System
INS	Inertial Navigation System
IR	Implementing Regulation
IRS	Inertial Reference System
IRU	Inertial Reference Unit
LNAV	Lateral Navigation
LNAV/ VNAV	Lateral Navigation/Vertical Navigation
LOA	Letter of Acceptance
LOC	Localiser
LP	Localiser Performance
LPV	Localiser Performance with Vertical Guidance
MC	Multi Constellation
MF	Multi Frequency
MON	Minimum Operational Network
MOPS	Minimum Operational Performance Standards
NAV	Navigation
NAVAID	Navigation Aid
NDB	Non-Direction Beacon
NM	Nautical Mile
NPA	Non-Precision Approach
OEM	Original Equipment Manufacturer
PA	Precision Approach
PBN	Performance-Based Navigation
RNAV	Area Navigation
RNP	Required Navigation Performance
RNP ARCH	Required Navigation Performance Approach
SARPS	Standards and Recommended Practices
SBAS	Satellite Based Augmentation System
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
STAR	Standard Instrument Arrival Route
TACAN	Tactical Air Navigation System
VOR	Very-High Frequency (VHF) Omni-directional Radio Range
VORTAC	Very-High Frequency (VHF) Omni-directional Radio Range/Tactical Air Navigation System
VNAV	Vertical Navigation

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