EUROCONTROL

European Airspace Concept Handbook for PBN Implementation

PBN HANDBOOK No. 1

SUPPORTING EUROPEAN AVIATION

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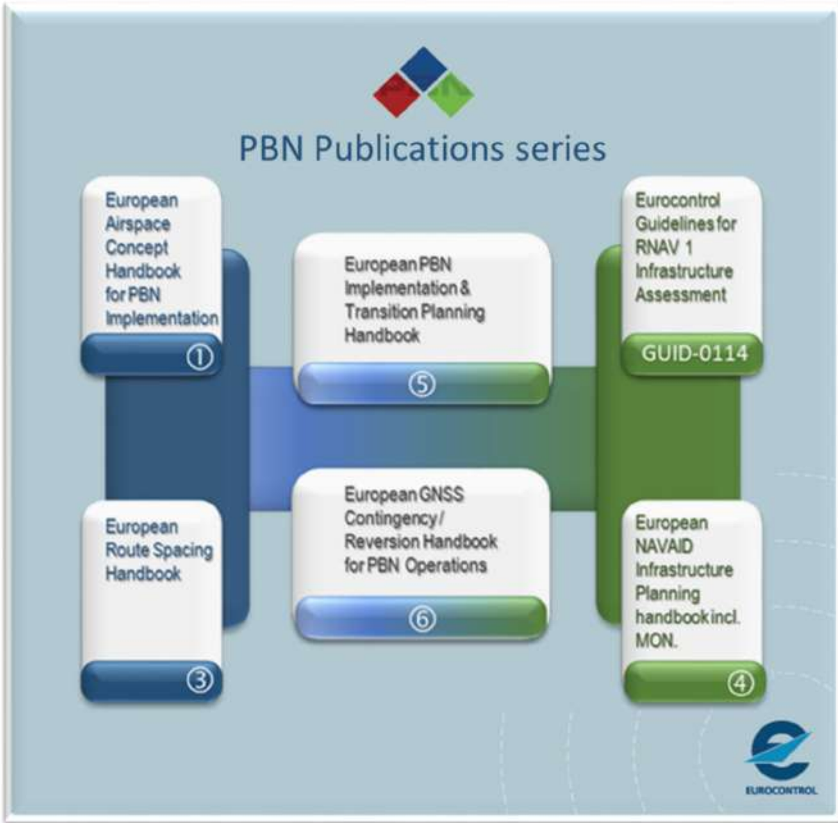

This document is one of a series of inter-related PBN publications, each of which can be used independently. Handbooks 1 & 3 are mainly aimed at ATM/operational audiences, whilst the EUROCONTROL Guidelines for RNAV 1 Infrastructure Assessment (EUROCONTROL - GUID – 0114) and Handbook No 4 primarily target Infrastructure Managers. Handbooks 5 & 6, provide the link between the two audiences on subjects of shared importance.

This document is Handbook **No 1**, Edition **No 4**. It supersedes all previous edition of this handbook.

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Eurocontrol: NMD

www.trainingzone.eurocontrol.int — in particular Training Catalogue '+ Navigation'

DOCUMENT CONTROL

The following table records the complete history of the successive editions of the present document.

Edition N°.	Edition Date	Reason for Change	Pages Affected
Edition 4 *draft*	2018-2020	Reflect PBN Manual upgrade; EU regulated environment; GNSS reversion; MON. Align to new PBN Handbooks 3-6. Multiple internal reviews within NAV Unit.	ALL
Edition 4 *draft*	29SEP2020	Distribution to RNDSG; APDSG, NSG & RAISG for comment;	ALL
Edition 4 *draft*	17DEC2020	Disposal of Comment Response and Disposition	ALL
Edition 4 *draft*	07FEB2021	Final revision for submission to NETOPS for approval.	ALL
Edition 4 ***Published***	21APR2021	Finalised document; approved by NETOPS with Att. 5 updates.	Document Control.; ToC; Attachment 5;

EXECUTIVE SUMMARY

Performance Based Navigation (PBN) is a powerful airspace design tool which enables the optimal placement of PBN specified area navigation ATS Routes and Instrument Flight Procedures (SIDs, STARs and IAPs). ICAO's Aviation System Block Upgrades identify Terminal Airspace optimisation using PBN as a key element. At regional level, European PBN regulation will generate major airspace change processes over this decade. For this reason, those involved in airspace design, planning and management require a broader understanding of PBN. Eurocontrol's PBN Portal at https://www.pbnportal.eu provides extensive information to this end.

Background

This Handbook's first two editions were published as supporting material to the ICAO PBN Airspace Workshops which were rolled out in ICAO regions between 2008-2012. Whilst Edition 2 of this Handbook was transformed into ICAO Doc 9992, Edition 3 of the Handbook updated and 'Europeanised' its predecessors. The founding document for all previous editions is the *Terminal Airspace Design Guidelines,* Eurocontrol, 2005 (now included in the European Route Network Improvement Plan, Part I).

Context

This 4th Edition of the Handbook reflects European developments since 2013, as well as PBN evolutions at global level. In Europe there is one main PBN regulation relevant to ANSPs: the PBN IR (PBN Implementing Regulation, EU Regulation 2018/1048). The CP1 IR[1] (Common Project One Implementing Regulation, (EU) 2021/116), regulates Free Route Airspace – which, in accordance with ICAO Doc 7030 relies on RNAV 5. Moreover, CNS evolutions increasingly (and simultaneously) rely on GNSS, which is also extensively used for PBN. For these reasons, airspace designers and planners need a greater understanding of these topics; this was the primary conclusion of the operational NETOPS GNSS contingency/reversion workshop (2019). For this reason, the 'PBN airspace methodology' of this Handbook, highlights and connects to: CNS's reliance on GNSS; contingency measures in the event of GNSS becoming unusable particularly in the context of route spacing; the use of some on-board navigation functions; the significance of the Navaid Infrastructure's robustness and resilience as well as a MON (Minimum Operational Network).

Because most of these highlighted topics are significant in themselves, stand-alone Handbooks exist for them in the Eurocontrol PBN Handbook series. This Handbook No 1, does not repeat the content of other Handbooks, but considers three of the Handbooks as 'key partners' to be used together with this one:

- European PBN Route Spacing Handbook, PBN Handbook **No. 3**
- 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**

Purpose

The 'European Airspace Concept Handbook for PBN Implementation' provides a methodology for affecting an airspace change based on PBN. **It is primarily intended for airspace planners/designers implementing PBN in European airspace.** As with previous editions, this one will hopefully also prove informative to other PBN stakeholders such as procedure designers, infrastructure managers and airspace users.

Despite highlighting the EU regulatory environment in this Handbook, the Handbook retains a broader context, and speaks to providers of ATM/ANS whether or not they are

[1] *Replaced the PCP IR (EU) 716/2014.*

regulated by the EU (thus accommodating some Eurocontrol Member States who are not EU Treaty States). Furthermore, this Handbook's prime area of focus is geared towards the new elements of the 2024 milestone of European PBN regulation i.e. terminal PBN operations. Given the specific context, purpose and principal audience, this Handbook:

- Amplifies the PBN routes of the Airspace Concept by focusing mainly on terminal operations; and
- Minimises non-PBN elements of the airspace concept such e.g. airspace volumes (CTAs or airspace reservations); FUA; special techniques such as CCO/CDO (e.g. which PBN and sound airspace design can enable); airspace classification or inter-centre letters of agreement which govern operations between centres (see ERNIP, Part I).

Scope & Timelines

The methodology contained in this handbook is comprised of 17 Activities spread over four (colour coded) phases: **PLAN**, **DESIGN**, **VALIDATE**, **IMPLEMENT**.

As PBN specified area navigation ATS Routes and Free Routes are already implemented and seeing as ICAO Doc 025 has mirrored this source methodology for the RNP approach which is also largely implemented across Europe, the scope of this Handbook focuses primarily on PBN SIDs/STARs and Instrument Approach Procedures.

In an attempt to avoid duplicating information, this Handbook mentions but does not provide details on PBN related domains such as sustainable development and mitigation of environmental impact. An extensive body of material exists on these subjects. https://www.eurocontrol.int/environment.

The first obligation on providers of ATM/ANS stemming from the PBN IR was due in December 2020 with a second obligation set for 2024. The third and final obligation is due by June 2030, by which stage the regulation requires GNSS to be the main positioning source for PBN. Because single-frequency single-constellation (SF-SC) i.e. GPS L1, will be the most prevalent form of GNSS positioning expected to be used up to, at least, 2030, references to GNSS are to be read as referring to a SF-SC GPS receiver with aircraft-based integrity monitoring unless Satellite-based Augmentation System (SBAS) is explicitly stated. References are often made to GPS for simplicity.

Conventions used in this Handbook

Each of the 17 Activities in this handbook are numbered; the font colour associates them with the phase of the methodology to which they belong.

Complementary information of a *generic* nature is provided in **green shaded insets**, and remarks related to EU PBN regulations are provided in **pale-pink shaded insets**.

The terms ANSP and providers of ATM/ANS are used interchangeably in this document. The former usually has an ICAO context and the latter a European context as reflected in the PBN IR. Similarly, the terms PBN ATS Routes and PBN specified area navigation ATS Routes are used interchangeably, area navigation ATS Routes being the more typical ICAO usage.

Recommendations

Aviation is evolving in an increasingly fast-paced and complex geo-political environment. High demands for air traffic have been significantly shaken in 2020 due to a global pandemic, and its medium to long-term impact is unknown. Despite this uncertainty, what remains clear is that national airspace change processes will continue to be complex as societal needs and desires shift. The level of rigour, public scrutiny and consultation is unlikely to diminish which will translate into longer lead-times for implementation.

Given that the EU PBN regulations are effectively triggering Europe-wide airspace changes, providers of ATM/ANS are encouraged to jointly plan airspace and PBN implementation. This provides an opportunity to optimise airspace use by maximising PBN benefits when implementing PBN.

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ABBREVIATIONS

4D	4-dimensional
ADF	Automatic Direction Finder
ADS-B	Automatic Dependent Surveillance- Broadcast
APV	Approach Procedure with Vertical Guidance
APV-Baro	Approach Procedure with Vertical Guidance with Barometric Vertical Guidance
APV-SBAS	Approach Procedure with Vertical Guidance with Satellite Based Augmentation
AR	Authorisation Required
B-RNAV	Basic Area Navigation (RNAV 5)
CBA	Cost-Benefit Analysis
CCO	Continuous Climb Operations
CDO	Continuous Descent Operations
CFIT	Controlled Flight Into Terrain
CNS	Communications, Navigation and Surveillance
CS-ACNS	Certification Specification for Airborne CNS
CRM	Collision Risk Model
D/D	DME/DME
DEMETER	DistancE Measuring Equipment TracER
DF	Dual Frequency
DME	Distance Measuring Equipment
EGNOS	European Geostationary Navigation Overlay Service
ERNIP	European Route Network Improvement Plan
FAF	Final Approach Fix
FAS	Final Approach Segment
fapfh	Fatal accidents per flight hour (a measure of risk)
FDPS	Flight Data Processing System
FL	Flight Level
FMS	Flight Management System
FRA	Free Route Airspace
FRT	Fixed-Radius Transition
FUA	Flexible Use of Airspace
FVP	Flight Validation Pilot
GBAS	Ground Based Augmentation System
GLS	GNSS Landing System
GNSS	Global Satellite Navigation System
GPS	Global Positioning System
IAF	Initial Approach Fix

IAP	Instrument Approach Procedure
ICAO	International Civil Aviation Organization
IF	Intermediate Fix
IFP	Instrument Flight Procedure
ILS	Instrument Landing System
IRE	Instrument Runway End
IRS/INS	Inertial Reference System/Inertial Navigation System
IRU	Inertial Reference Unit
LNAV	Lateral Navigation
LNAV/VNAV	Lateral Navigation/Vertical Navigation
LPV	Localizer Performance with Vertical guidance
LVP	Low Visibility Procedures
MC	Multi Constellation
MF	Multi Frequency
MSA	Minimum Sector Altitude
NAV	Navigation
NAVAID	Navaid
NDB	Non Directional Beacon
NM	Nautical Mile
NPA	Non Precision Approach
NPR	Noise Preferential Routes
NSA	National Supervisory Authority
PA	Precision Approach
PANS	Procedures of Air Navigation Services
PBN	Performance-Based Navigation
PBNSG	Performance-Based Navigation Study Group
RDPS	Radar Data Processing System
RF	Radius to Fix
RNAV	Area Navigation
RNP	Required Navigation Performance
RNP APCH	Required Navigation Performance Approach
SARPS	Standards And Recommended Practices
SBAS	Satellite Based Augmentation System
SID	Standard Instrument Departure
SIS	Signal In Space
TLS	Target Level of Safety (usually expressed as fapfh for route spacing/configuration)
TMA	Terminal Control Area
VOR	Very-High Frequency (VHF) Omni-directional Radio Range
VNAV	Vertical Navigation
xLS	Precision landing system such as ILS, GLS, MLS

DOCUMENT REFERENCES

Document Full title	*Short title used in document text*
European PBN Route Spacing Handbook, PBN Handbook No. 3	*Route Spacing Handbook*
European Navaid Infrastructure Planning Handbook including Minimum Operational Network (MON), PBN Handbook No. 4	*Infrastructure Planning Handbook.*
European GNSS Contingency/Reversion for PBN Operations, PBN Handbook No. 6	*GNSS Reversion Handbook*
Eurocontrol Guidelines for RNAV 1 Infrastructure Assessment (EUROCONTROL - GUID – 0114).	*RNAV 1 Infrastructure Assessment*
ICAO Annex 11, Air Traffic Services	*Annex 11*
ICAO PANS-ATM, Doc 4444	*PANS-ATM or Doc 4444*
ICAO Manual on Testing of Navigation Aids, (Doc 8071).	*Doc 8071*.
ICAO Performance-based Navigation Manual, ICAO, Doc 9613, Edition 4, 2013	*PBN Manual*
ICAO, ATS Planning Manual, Doc 9426	*ATS Planning Manual*
ICAO, Manual on the Use of Performance Based Navigation (PBN) in Airspace Design (Doc 9992, 2013 Edition);	*Doc 9992*
ICAO Quality Assurance Manual for Flight Procedure Design, (Doc 9906 Vol 1-6)	*Doc 9906*
Eurocontrol Terminal Airspace Design Guidelines (Ed. 2.0, 2005);	*Terminal Airspace Design Guidelines*
European Route Network Improvement Plan Part I	*ERNIP Part I*

1. CONTEXT

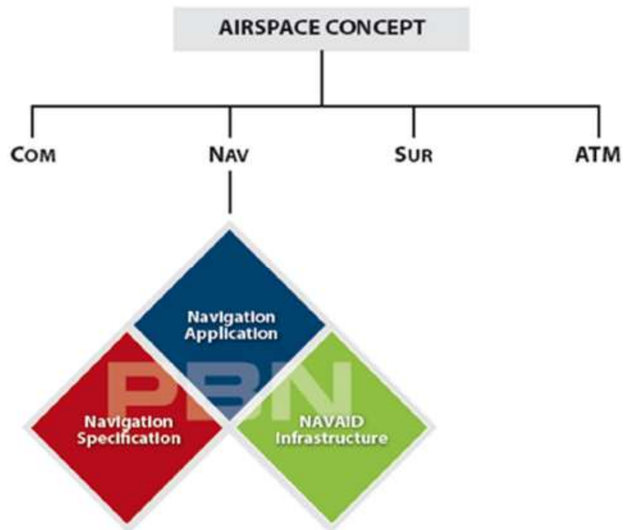
The use of area navigation techniques is a pre-requisite of PBN, which stipulates requirements to use RNAV and RNP systems, and how they should be used. PBN is a key **enabler** for **airspace design and planning** and as such is a powerful tool for airspace designers. Use of RNAV or RNP make it possible to place routes in optimum locations, whether these are used for departure, cruise, arrival, approach or missed approach. This optimum placement is enabled by PBN in three dimensions, thus enabling routes to be strategically deconflicted. The net effect is the potential to unlock bottle-necks, maximise traffic throughput, and enhance flight efficiency and environmental mitigation. This systemisation potential is the potent benefit of PBN for air traffic organisation, but clear policy criteria are needed for implementers to ensure these benefits can be realised.

1.1 ICAO's PBN Concept

ICAO's PBN Concept replaced the RNP Concept; it was introduced through publication of the PBN Manual (ICAO Doc 9613) in 2008. The PBN Concept is geared to respond to strategic objectives translated into operational, airspace and industrial requirements aligned to ICAO's strategic orientations.

To these ends, ICAO's PBN concept identifies three components: the **Navigation Application** which is enabled by two sub components: the **NAVAID Infrastructure** and the **Navigation Specification**.

The **Navigation Application** identifies the navigation requirements resulting from the Airspace Concept such as routes and procedures



(e.g. FRA, PBN specified area navigation ATS routes and Instrument Flight Procedures).

The **NAVAID Infrastructure** refers to ground- and space-based navigation aids (Navaids) and provides information which the RNAV or RNP system uses to estimate position with the objective of achieving the performance required by the **Navigation Specification**.

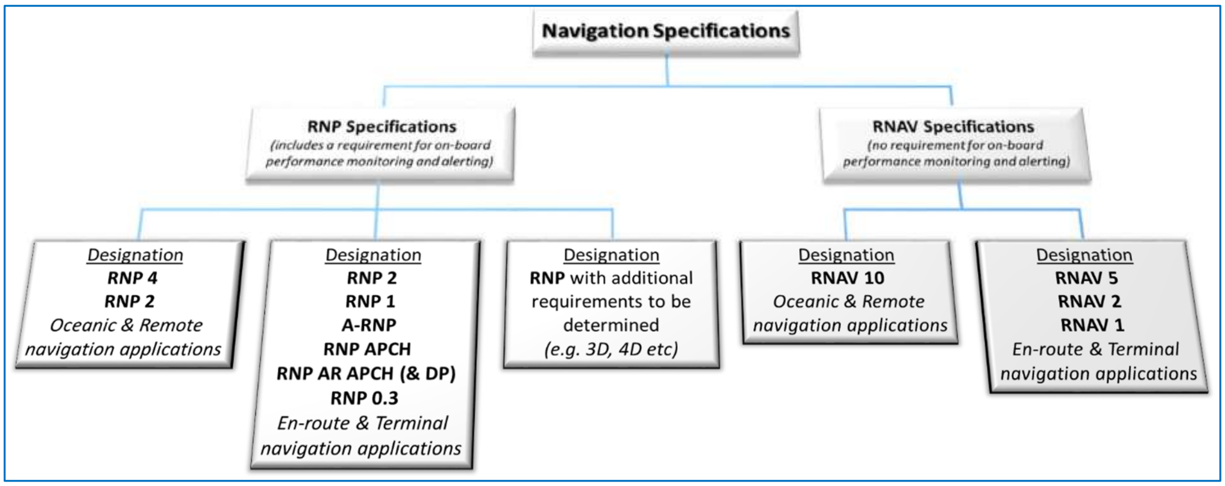
The **Navigation Specification** is a technical and operational specification that identifies the required performance and functionality of the area navigation equipment and associated aircraft avionics together with flight crew requirements. It also identifies the navigation sensors required to operate using the **NAVAID Infrastructure** to meet the operational needs identified in the Airspace Concept. The **Navigation Specification** provides material which States can use as a basis for developing their certification and authorisation documentation.

1.2 PBN Specifications

The PBN Manual contains eleven navigation specifications so as to ensure global interoperability. Seven of these are RNP specifications (below, left) and four of these are RNAV specifications (below, right). These navigation specifications serve as the basis for States to promulgate standardised certification material.

Documented in Volume II of the PBN Manual, each of these navigation specifications is roughly 20 pages in length and contains core and contextual material. Core material includes performance requirements (accuracy, integrity and continuity) of the RNAV or RNP system, the functionalities needed to meet the requirements of the Navigation Application, the authorisation process, aircraft eligibility and operational authorisation. Contextual type of material relates primarily to Air Navigation Service Providers (providers of ATM/ANS) considerations and includes requirements related to the Navigation, Communication and Surveillance Infrastructures, air traffic controller training, ATS system monitoring and aeronautical publication.

Note: More information about PBN Is published at the Eurocontrol Training Zone (https://trainingzone.eurocontrol.int)



1.3 Airspace Concept

The PBN Manual describes the Airspace Concept as a formal way to set out and respond to operational airspace change requirements. **As such, the development of the Airspace Concept is a key step in PBN implementation because PBN ATS routes, SIDs/STARs are the backbone of the airspace organisation**. From a provider of ATM/ANS's perspective, PBN is one of several enablers of the Airspace Concept. From an aircraft and flight crew perspective, PBN clarifies and provides a uniform structure to requirements for airworthiness certification and operational authorisation for use of **RNAV or RNP systems** in airspace implementations.

An **Airspace Concept** describes the intended operations within an airspace. Airspace Concepts are developed to satisfy strategic objectives such as safety, capacity or flight efficiency and environmental mitigation; these strategic objectives correspond to some of the Key Performance Areas (KPAs) identified by both ICAO and the European Commission. Airspace Concepts include details of the practical

organisation of the airspace and its operations as well as the CNS/ATM assumptions on which it is based. Practical organisation of the airspace includes the **PBN route configuration and spacing**, **route interaction** as well as **separation minima** and **obstacle clearance**. Thus in a PBN context, the core of an Airspace Concept is the placement, protection and management of PBN Routes to permit operations on strategically deconflicted traffic flows which ensure safety and efficiency.

Once fully developed, an Airspace Concept provides a detailed description of the target airspace organisation and operations within that airspace and can be anything from five pages in length (for extremely simple airspace changes) to a document of several hundred pages.

Note: More information on the Airspace Concept is published at the Eurocontrol Training Zone; more information on Route Spacing is published in the Route Spacing Handbook (PBN Handbook No. 3).

1.4 Global PBN drivers

The ICAO Resolution at the 36th Assembly and the subsequent rollout of ICAO's PBN Concept in 2008 effectively triggered the launch of PBN. The update to the ICAO Resolution at the 37th Assembly provided more impetus to PBN implementation. Whilst not mandatory, it reflected shared international objectives and ambitions at high level, for the uptake of PBN, promoting approaches with vertical guidance for safety reasons and encouraging the extensive use of RNAV and/or RNP in other flight phases. Currently, PBN remains an important enabler in ICAO's Aviation System Block Upgrades (ASBU).

1.5 Regional PBN drivers

ICAO's European Region has an active PBN Consolidation Task Force (PBNC-TF) holds joint meetings with Eurocontrol's Navigation Sub Group (NSG). The first mandate of the task force dealt with the requirement for the development of national PBN Implementation Plans as identified in ICAO Resolution 37-11, and the second mandate of the task-force is managing the regional RNP instrument approach chart naming change. Several Eurocontrol groups support PBN implementation in Europe: NSG together with the Network Operations Team (NETOPS) and Route Network Development Sub-Group (RNDSG). At a European Union level, PBN on routes and procedures is *primarily* regulated through the PBN IR (PBN Implementing Regulation, (EU) 2018/1048)[2]. The obligations stipulated by this regulation include PBN specified area navigation ATS Routes, SIDs/STARs and approach procedures. The obligations imposed by these regulations are reflected in the Table, below2018/1048). The obligations stipulated by this regulation include PBN specified area navigation ATS Routes, SIDs/STARs and approach procedures. The obligations imposed by these regulations are reflected in the Table, below:

[2] CP 1 which will continue to include Free Routes but exclude PBN.

PBN IR Article 4 & 7 Applicability with AUR.2005		Applies 03/12/2020	Applies 25/01/2024	Applies 06/06/2030
Art 4	Transition Plan (*or significant updates*) approved (*living document*)[1]	X[1]	X[1]	X[1]
AUR.2005 1/2/3	RNP APCH at IREs without Precision Approach (PA)	X		
	RNP APCH at all IREs (with PA)		X	
AUR.2005 4/5	RNAV 1 or RNP 1 (+ RF if required) SID and STAR - one per IRE		X	
	RNAV 1 or RNP 1 (+RF if required) for all SID and STARs			X
AUR.2005 6	RNAV 5 ATS Routes (excl. SIDs/STARs) at and above FL150[2]	X		
	RNAV 5 ATS Routes (excl. SIDs/STARs) below FL150		X	
AUR.2005 7	Helicopter RNP 0.3 or RNAV 1 or RNP 1 (+RF if required) SID/STAR - one per IRE		X	
	Helicopter RNP 0.3 or RNAV 1 or RNP 1 (+RF if required) for all SID/STAR			X
	Helicopter RNP 0.3 or RNAV 1 or RNP 1 ATS Routes (excl. SIDs/STARs) below FL150		X	

Note 1 - The transition plan will have several iterations; Article 4 requires that the draft/significant updates to the plan must be approved by the competent authority ***early enough*** *to provide sufficient time for the ANSPs to meet the identified implementation date. (Sufficient time would include accounting for the AIRAC cycle dates, publication and regulatory approval and compliance with other national requirements - see the PBN Portal for an example of the implementation scheduling and time required: https://pbnportal.eu/epbn/main/PBN-Tools/Planning-Estimation.html). The planned implementation dates detailed in the transition plans should be commensurate with the target date obligations.*

Note 2 - CP 1 requires FRA to be implemented with two milestones: 2022 & 2025. FRA is associated with RNAV 5 through the ICAO EUR requirement for RNAV 5 published in ICAO Doc 7030. (CP 1's revised FRA requirements replace previous requirements in the PCP IR).

EU regulations introduce significant changes in European ATM:

(1) The mandates have been driven by operational requirements and provides a clear 2030 EU goal whereby all routes and procedures are to be predicated on PBN, primarily relying on GNSS as the positioning source.

(2) All phases of flight have been regulated rather than particular airspaces or selected technologies.

(3) For the PBN IR, a network-wide approach is taken and the Eurocontrol Network Manager plays a central coordinating role to ensure that 'individual' providers of ATM/ANS PBN transition plans (approved by the competent authority) are consulted between providers of ATM/ANS as well as other stakeholders.

(4) Helicopters are regulated primarily to cater for operations in the North Sea and Alpine areas.

The emphasis on GNSS as the primary navigation infrastructure means that particular attention will need to be paid to GPS Reversion/Contingency should the signal-in-space (SIS) be interrupted. *For more information see GNSS Reversion handbook.*

1.6 Benefits

The development and implementation of a PBN-based Airspace Concept makes significant contributions in terms of safety, environment, capacity and flight efficiency. For example:

- PBN's **partnership** approach to developing the Airspace Concept ensures that conflicting requirements are tackled in an integrated manner and that diverse interests are addressed without compromising safety, environmental mitigation, flight efficiency and capacity requirements.

- **Safety** is enhanced by ensuring that the placement of PBN specified area navigation ATS Routes and Instrument Flight Procedures services both Air Traffic Management and Obstacle Clearance requirements. Furthermore, situational awareness is enhanced in the approach phase of flight through PBN. Stabilised approaches improve safety with the availability of vertical guidance in the final approach segment which reduces CFIT.

- **Environmental** mitigation can be improved by granting environmental needs the same level of importance as capacity enhancement when defining the operations in an airspace and affecting the airspace design. Well designed flight paths can potentially reduce greenhouse gases, fuel burn and the noise footprint.

- **Capacity** and Flight **Efficiency** are enhanced by freedom to place PBN specified area navigation ATS Routes and Instrument Flight Procedures in the optimum location in both the lateral and vertical dimensions. Strategic de-confliction of routes and procedures is enabled by PBN.

- **Access** to airports is improved particularly in obstacle rich environments.

- **Cost-savings** might become possible when optimising the airspace using PBN and therefore enabling Navaid decommissioning. However, sufficient Navaids are required to ensure airspace and airport access and to cater for GNSS reversion.

2. METHODOLOGY FOR PBN IMPLEMENTATION

Airspace Concept development is driven by strategic objectives such as Safety, Capacity, Flight and ATM Efficiency, Environmental mitigation and Access which are 'translated' into operational requirements. Determining the operational requirements is therefore a natural first Activity in the methodology. Whilst operational requirements may be considered as being driven by ATM or flight operations requirements, strategic objectives may have political or geo-political origins. Whatever the source of the strategic objectives, trade-offs and prioritisation of strategic objectives is often needed where these conflict. **The maintenance of safety remains paramount and cannot be diluted by compromise.** But safety can be achieved in different ways.

This Handbook contains the Airspace Concept Methodology for PBN Implementation. This methodology is made up of 17 Activities, many of which are **iterative.** They are spread across four phases of **Planning**, **Design**, **Validation** and **Implementation**.

This methodology is neither linear nor closed: factors external to the project and outside the control of the airspace design team, can and do influence the project's objectives and scope, its evolution and implementation. Examples of these influencing factors include environmental requirements from local communities or regional targets, regulatory requirements (e.g. national or EU, examples of the latter being the PBN Implementing Regulation), procedure design criteria, avionics capability and aircraft certification as well as politics.

PUBLIC AWARENESS AND PUBLIC CONSULTATION

The governments of many European States have requirements for providers of ATM/ANS to extensively consult with the general public when making airspace changes, particularly around airports. To this end, some providers of ATM/ANS have developed significant expertise in awareness and consultation with the general public. These consultation processes can be extensive and time consuming, and can affect the duration of projects and, in some cases, even limit the ability to change how an airspace is designed and the evolution of operations within it. Some requirements demand repetitive/phased consultation throughout the life-cycle of the project in an attempt to enhance the probability of a project's success.

Given national peculiarities, there is no single European blue-print for these processes, but this PBN Handbook No 1 includes prompts for the implementation team(s) as to when to undertake public consultation or airspace user consultation during the project life-cycle (though these may be different from State to State). The key point to be made is that PBN implementation teams must allow time for consultation when planning their projects. Readers are referred to the Eurocontrol Guidance Material on Collaborative Environmental Management (CEM).

Iteration and Planning

Iteration is key to Airspace Concept development which does not follow a linear process. Effective planning is the cornerstone to successful implementation and **Planning** is undertaken before starting the Airspace Design, Validation and Implementation. **Planning is the first phase and cannot be skipped.** It must be a comprehensive (and therefore tends to being quite a lengthy) process because sound preparation is one of the pre-requisites to successful Airspace Concept development and PBN implementation. Careful consideration is needed in terms of *what* needs to be done and organising of the necessary *time and resources* to do it. **Iterations** of planned activities are also key. The activities included in the methodology for developing an Airspace Concept rely on several **iterations** and refinement by moving backwards and forwards between the 17 activities.

It must not be forgotten that PBN is not the exclusive contributor to an airspace concept. PBN is just *one* of several C-N-S and other enablers – which must inter-relate and interact.

Managerial considerations

An Airspace Design Team needs to be organised and well managed with proper administration to ensure that, as is often necessary, this team can efficiently and effectively interact with other teams within a greater managerial framework. This is because PBN is *one* of many enablers in a multi-disciplinary and inter-connected aviation industry. As such, PBN Implementation Projects can be undertaken in a variety of **managerial 'frameworks'** or '**projects'.** Some of these frameworks or projects may not even reference PBN. Being primarily an airspace tool means that PBN is a critical ingredient to an airspace upgrade but such upgrades are often part of a greater umbrella project. By way of illustration, the following table shows project **examples** *and* associated PBN aspects and potential effects on planning.

Project Examples (Operational Requirements/PBN Project Objectives)	Effects on Planning
Addition of a new runway at an airport. The Airspace Design team implement new RNAV or RNP SIDs/STARs as well as a supporting airspace structure for the new runway.	Such projects typically have umbrella steering committees with several sub-project teams e.g. civil engineering, lighting and signalling; infrastructure planning; ATM (incl. PBN) etc. The Implementation date is likely to be decided by the Steering Group. Typically, these projects last several years.
Environmental mitigation measures are ordered by a national court or government ministry. Such projects can be politically loaded. PBN SIDs/STARs usually needed.	These projects can suddenly become high priority with accelerated implementation requirements due to political pressure which may include close public scrutiny of route placement.
EU regulation of PBN requirements which usually responds to strategic longer term supra-national objectives. PBN SIDs/STARs mandated.	These projects will require extensive consultation and debate for appropriate stakeholder engagement. Project planning should consider the need for additional time to allow for what may be protracted consultations needed to achieve successful implementation.
ATM triggers an airspace change e.g. Continuous Climb and Continuous Descent Operations (CCO and CDO) are needed – and can be enabled by PBN SIDs/STARs.	Such managerial structures are typically simple, with the implementation date chosen by the team responsible for PBN implementation. More complex projects need phasing, e.g. start with RNAV SIDs/STARs and migrate these to RNP.
Regulatory requirement triggers an airspace change e.g. PBN IR which requires, by 2030, all SIDs/STARs, ATS routes and procedures to be based on PBN.	Typically, these are large scale national projects needing careful coordination as several terminal areas will be upgraded to comply with the regulation. The national airspace structure and that of the European network will be affected. In these cases, a centralised national management team may be created to coordinate all the individual projects, and a team responsible for PBN implementation at each site will run its part of the project. {The accumulation of these local projects would be the national project coordinated through the Network Manager}. Importantly, given the timelines of the regulation, these projects would have phases and synergies both intra-national, supra-nationally and at Network Manager level.

Find Help: Read and Write

The development of an airspace concept for PBN implementation can be an onerous and intimidating task. Many feel overwhelmed when asked to join an airspace design team for the first time, or when they learn that they are to implement PBN which is new to them. Inevitably, many people look for **HELP!** They search literature, the internet, and ask colleagues for material to help them. An excellent source of help is the PBN Portal: https://pbnportal.eu

This Handbook also seeks to provide that sought after assistance, but the methodology promoted is only truly beneficial if those involved in airspace concept development for PBN Implementation work collaboratively together.

PBN projects do not happen quickly. This is one of the reasons why it is important to **write up** everything that occurs during the project. Keep a meticulous document trace of meetings, decisions, steps and activities as they evolve. Here the writing does not only concern the technical airspace concept development; it also refers to progress reports, minutes of team meetings, decisions taken and so on.

‘Administrative’ tasks are not favoured by operational personnel as a rule, but without keeping a streamlined administrative record, the project is guaranteed to over-run in the best case, and fail in the worst. Writing things down saves a great deal of time, avoids considerable conflict and ensures that the PBN implementation exercise runs smoothly. Crucial is the only adequate word for taking care of administrative elements: these projects are time consuming, can stretch over several years and often team members change with time. So the key is to keep a robust document trail tracking the progress *as well as* the airspace concept document updated as it evolves. Good administration includes having an electronic filing system on a shared drive/SharePoint/cloud where everyone has access, however, there is only *one* person who can add folders, files and documents. Typical folders could include, for example: Airspace Concept Evolution; Team Meetings; Public Meetings; Stakeholders – Key Partners. Furthermore, all documents and files should be stored with relevant names and dates, and any graphics created or used should be clearly labelled with document chapter names. A good organiser on the team is a much needed asset and usually an under-estimated individual.

PHASE 1: PLANNING

Activity 1

Agree Operational Requirement(s)

An underlying assumption in this Handbook is that airspace changes are triggered by operational requirements based on *strategic objectives*. Some examples of **operational requirements** include: addition of a new runway in a terminal area (i.e. the corresponding *strategic objective* may be to increase airport capacity); reduction of aircraft noise over a residential area (this *strategic objective* could be to reduce environmental impact over a particular area) or permit operations at an airport during low visibility conditions (i.e. improved access). Operational requirements tend to be reasonably high level and are often decided at a high managerial level. These requirements drive the project objectives, scope and timelines, they may be adapted through iterations following the analysis of the Reference Scenario (Activity 4).

The EU's PBN regulatory requirements can be viewed as the means for meeting a European wide PBN operational requirement. These implementing rules determine how and what Member States must do to meet the main PBN project objectives.

Strategic Objective	Operational Requirement	PBN Project Objectives (Examples)
Increase **capacity**	Addition of new runway	Airspace redesign to include RNP SIDs/STARs to the new runway and adaptation of existing PBN ATS routes
Reduce **environmental impact**	Reduce noise by 20% over area X	Design of de-conflicted RNAV 1 SIDs/STARs to enable CCO and CDO
Increase **flight and ATM efficiency**	Increase throughput by 15%	Implement Free Route Airspace and adapt sectorisation for workload management
Increase **safety to IREs with only NPAs**	Stable Approaches	Introduce RNP APCH
Increase **flight efficiency**	Reduce levelling off flight segments by 50%	Redesign RNP 1 SID/STAR interactions; move SIDs clear of holding areas enabling CCO/CDOs.
Increase **access**	Provide alternative to conventional NPA	Develop RNP APCH Procedures
Improve capacity on EUR ATS Route Network	Ensure 10% sector capacity	EU Regulatory Compliance with PBN. Publish PBN SIDs/STARs and RNP Approaches procedures

PBN Project objectives *must* include objectives for contingency operations in the event of PBN operations no longer being possible. Such an 'impossibility' could be due to various reasons and affect one or many aircraft for a long or short time. For example: one aircraft could lose its GPS receiver which means only it would be affected. In contrast, a GPS constellation outage would affect PBN compliance capability for all aircraft relying solely on GPS positioning in their RNAV or RNP system. These considerations and variables are discussed in detail in the *GNSS Reversion Handbook, No. 6*.

Fixing operational requirements for PBN implementation is extremely important and consistent with the requirements of the PBN IR which requires Contingency Measures to be provided for in the PBN Implementation (see Article 6)

Activity 2

Create the Airspace Design Team

In order to tackle the operational requirements, an Airspace Concept will need to be developed, validated and implemented. Such an Airspace Concept, addressing all of the requirements, cannot be developed by one individual; Airspace Concepts, from inception to implementation, are produced by an integrated **Airspace Design Team** working together. Each team member contributes his or her in-depth specialist PBN knowledge to the overall PBN project e.g. an ATCo would not be expected to have PBN related aircraft performance knowledge which is the domain of pilots which may be flight validation/technical pilots, or pilots from the lead carrier, which depending on the project, may be airline operators, business aviation or general aviation, as appropriate (see inset 'Team Members – Adaptive roles', next page). No team member, not even the Team Leader, is expected to know everything about PBN but together the team makes the whole. Typically, the team is lead by an ATM specialist with an in-depth operational knowledge of the specific airspace under review and a sound 'big picture' knowledge of PBN. This specialist requires the support of **Core** and **Ancillary** team members**,** (see picture)**. Core team members** are responsible for the overall project and ideally work on it 'full time'. **Ancillary team members** support the core team in specific activities at particular times and their support will be requested as needed. **Roles** and **responsibilities** of team members should be clearly defined and understood. If team members are unfamiliar with PBN, then adequate PBN training should be provided prior to the project starting. Ideally, the addition of an administrative assistant to the team saves a great deal of time, ensures the documentation is kept up to date and tracked!

Core team members must work together; and listen to airspace user needs. Ideally, **all** team members should work with each other. This is crucial when developing contingency procedures which rely on infrastructure investment decisions (taken by the Infrastructure Design Team in consultation with the airspace design team). All relevant information must come back to the team.

PBN's reliance on GNSS and possible reversion to ground-Navaids means that **Navaid Infrastructure Planners** must be involved in airspace change plans and that the **Airspace Design Team**, must, in turn, be informed and understand the implications of infrastructure evolution plans including, for example, renewal or decommissioning of Navaids at end of life. The pressures affecting Infrastructure Planners may be different to those affecting Airspace Designers, so communication is key.

Because the infrastructure is so essential to PBN, the **Infrastructure Manager** is a critical ancillary team member (captured as COM/NAV/SUR Engineers in the above diagram). PBN cannot be realised without coverage from an appropriate Navaid infrastructure because this infrastructure provides *positioning* for PBN. ATM (and PBN) are not the Infrastructure Managers only 'clients': Infrastructure Managers have their own processes and pressures for evolving the Navaid infrastructure in cooperation with Surveillance and Communication colleagues. Cost is often a key infrastructure evolution driver, however spectrum availability is increasingly becoming a key pressure point, hence the unequivocal need for a two-way transparent flow of information between the Airspace Design Team and the Infrastructure Optimisation team.

The Infrastructure Optimisation Team is identified in the methodology described in the *Infrastructure Planning Handbook (No. 4).* Although this airspace methodology and the infrastructure methodology will seldom be aligned in time, information exchange between the two work areas must remain coherent, timely and transparent. The Airspace Design Team must appreciate that infrastructure evolution will often consider non-ATM aspects.

Team Members – Adaptive roles

Each phase of the project will require different kinds of input from involved experts. Using the pilot community as an example, the pilot team member(s) would, in Activity 1 (Agree Operational Requirements), provide generic input. In Activity 6, Enablers, Constraints and Assumptions, the pilot's input would relate to the fleet equipage, what it means and how it should be interpreted; knowledge on expected fleet evolution would be extremely beneficial to the project. When placing the routes conceptually, in Activity 7, Design Routes and Holds, the pilot's input would be expected to relate to the management of the aircraft considering track miles to touchdown, descent and climb profiles, turn performance and capabilities as well as flyability. In Activity 8, Initial Procedure Design and more so in the Validation Phase Activity 12, Finalise Procedure Design, the pilot's input is very technical. Here, she or he works closely with the procedure designer to cross check calculations and assumptions made during the procedure design; this is the realm of the flight validation pilot (FVP). The 'change' in the kind of input provided, as well as the level of granularity, applies to all experts who are part of the team. In some cases, this may require a replacement of personnel to ensure the correct level of granularity for the Activity in question.

Key Partners – adjacent ANSPs/providers of ATM/ANS

Airspace design best practice is confirmed in Article 4 of the PBN IR: consultation is required between adjacent providers of ATM/ANS implementing PBN (and therefore undertaking an airspace change). These consultations are key; they should ensure the seamless and coherent *lateral and vertical* **connectivity** between adjacent airspaces. At the very least, this interactivity avoids creating conflicting traffic flows between adjacent airspaces.

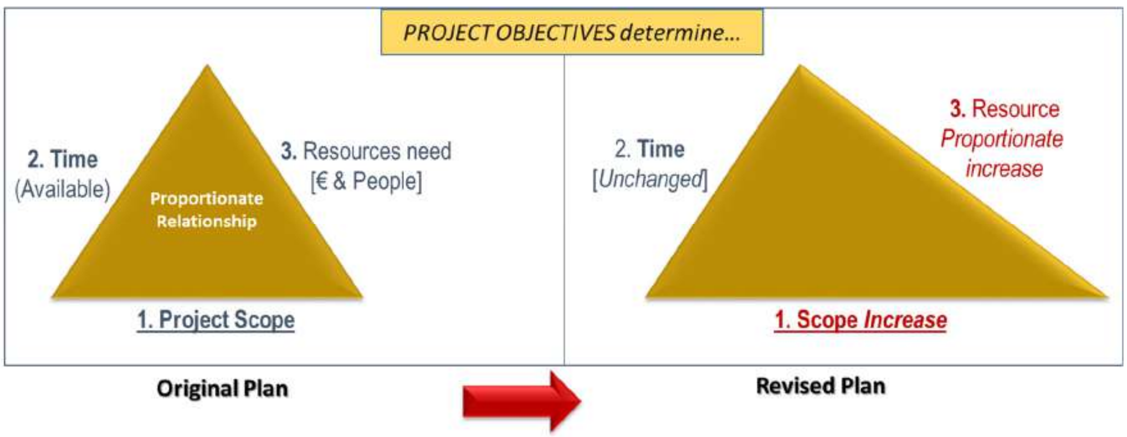
Providers of ATM/ANS of adjacent airspaces are not inside the core team unless airspace proximity makes it essential e.g. when the adjacent airspaces effectively operate so inter-dependently that it is not possible to separate them. This typically happens in larger terminal airspace systems. If the adjacent provider of ATM/ANS is under a different (national) administration, close cooperation should be assured. Trans-national Teams can and have been formed with great success.

Activity 3

Decide project objectives, scope, resources & time scales

PROJECT OBJECTIVES *drive* project scope and time/resources needed

One of the first tasks of the airspace design team is to decide the objectives of the airspace project. **Project objectives** are derived from the operational requirements which have triggered the project. PBN **project objectives** drive the PBN **Project Scope** as well as **time** and **resources needed.** If a PBN project is undertaken as a standalone project, the PBN Project objectives are the 'only' influence on the other three elements. Generally, however, PBN projects are rolled into other projects such as cyclical airspace upgrades.



Once the **project objectives** are agreed, estimations are made and a relationship is created between the Project **Scope** and the **Time** (available or needed) and the **resources** available (or needed). A change in any of these three elements *scope* or *time* or *resources* will affect the other two – but should never impact adversely on safety. Naturally, a change in project objectives affects all three elements, scope, time and resources. Activity 3 is a critical step, which is often refined **iteratively** during the project as 'surprises' can arise which can alter resource or timing needs.

PBN project objectives also directly input into Activity 5, Safety and *Performance* Criteria and they strongly influence the Infrastructure Performance Criteria requirements undertaken in the Infrastructure Optimisation Team's Activity IA-5. Hence the absolute requirement to undertake **iterations between *this* (airspace) methodology's Activities 3 and 5 and the Infrastructure Optimisation Team's activity IA-5.**

1. Project scope

Deciding project scope can be challenging. Experience has shown that the definition of a project's scope and remaining within the limits of that scope can be extremely difficult. Inadvertent scope 'spread' is a project risk in almost every implementation and it often causes the failure of projects. Once the scope of the project has been decided, it is important to avoid changing the project objectives as this invariably results in a need to increase the scope which, in turn, causes resource issues, cost overruns and delays. For this reason it is critical to decide what needs to be done to achieve the project objectives and to agree – and stick to – a specific body of work to reach those objectives. Note, however, that unforeseen circumstances may cause a project's objective's to change significantly e.g. the anticipated increase in traffic by a low-cost carrier is no longer expected. In such a case, the objective would change and this would significantly impact the project's scope and its relationship with time and resources.

Activity 3

It is repeated for emphasis that the project's **scope** can be strongly affected if there is a significant change to the initial **time** and **resources** made available to complete the project. These three elements are *inter-related*. If any one of them change, the remaining two must be adjusted – whilst ensuring coherency between the Operational Requirements in Activity 1, the project objective, scope and timelines as well as IA-5, mentioned previously.

In a regulated PBN environment, the PBN implementation project objectives and scope are typically well defined and the challenge becomes meeting the deadline (timescales).

2. Time Scales

Two possibilities exist as regards **time,** either:

- the team decides its implementation date based on all the work that needs to be completed (here, the **time needed** is calculated); or
- the implementation date is fixed beforehand and the team's challenge is to fit the work into the **available time** to the implementation date.

More pressure exists on the team members when '**available time**' is the defined (because time is effectively limited). Time pressures may mean that more resources have to be given to the project (this could be financial or personnel) or that the scope will need to be reduced to fit the available time.

The challenge of working against the clock is that the number of variables in a PBN project can result in unwanted surprises. Take, for example, a case where the airspace design phase has identified the need for a new DME to provide coverage throughout a terminal airspace.

- The installation and commissioning of an additional DME could take up to two years to achieve if it is necessary to find an available frequency and a location (and perhaps build an access road and provide a power supply). Procurement processes for equipment can be lengthy, as can the delivery time and civil works needed to build the site, installation, calibration (both ground and flight inspection) until final commissioning for use, by the competent authority.
- Similarly, the time needed in some cases for public consultation can be extensive e.g. the placement of SIDs/STARs may be a sensitive issue for a particular community and necessitate comprehensive environmental impact analysis; ATS routes over a nature reserve below a specific altitude can become an issue of visual or tranquillity 'intrusion' and result in the need for complex negotiations.

These examples could result in the *time needed* reaching beyond the implementation date. These are just two examples of why it is so important to work with different PBN experts (infrastructure managers included) so as to avoid under-estimations of time – or cost). A key message for project teams is that if there is not enough time there are at least two solutions: **reduce** the project's scope or **increase the resources.** A third solution could be to phase the project over a longer time, achieving the objectives in time slices. But this is not an easy challenge, and it should not be under-estimated.

Mindful of the unpredictability of some of these timescales, a Sample Project Task list with time estimations is provided at Attachment 1 as well as an interactive version on the PBN Portal. Both show

Activity 3

simplified examples of project time estimations. Project managers can utilise the web-based 'Planning Estimation Tool' (https://pbnportal.eu/epbn/main/PBN-Tools/Planning-Estimation.html) and adjust the number of days required for each activity to meet their own needs.

Experience has shown, that only 10% of projects start on time and meet their target date. Due to extensive pressures on human resources, there is a tendency to 'just-in-time' and to under-estimate the time needed for PBN implementation. In reality, if one starts at the implementation date and calculates backwards 56 days for the AIRAC Cycle Dates, then deducts days for ATCO training, system upgrades, procedure design and validation, airspace concept validation through RTS, the airspace design process and the Planning phase – and then one adds in public consultation, it is easy to see why complex terminal projects take 5-10 years to implement. In contrast, the publication of an RNP APCH could take just 5 months – providing no one objects to the flight path.

In a *regulated PBN environment, the project* <u>*timescales*</u> *are typically well defined and are clearly specified in the PBN IR which has three milestones of 2020, 2024 and 2030. Milestones are of crucial importance in that sufficient lead-in time is provided to permit the regulation to be implemented by the due date. Different navigation applications can have different lead times. For example, an implementation of RNP APCH in the Final Approach Segment is a much simpler 'airspace change' than the re-design and implementation of RNAV 1 SIDs/STARs for which the time needed for public consultation and environmental mitigation may be significantly longer.*

In a regulated environment, some providers of ATM/ANS could, following their cost-benefit analysis (CBA), consider that the regulation's scope does not meet their requirements. They may, for example, already have implementations which precede the implementation date due to some local or national operational need. Alternatively, they may have implemented a level of service exceeding the regulatory requirements, or they may find that the regulatory requirements are excessive. These different perspectives are unlikely to occur if the regulator is the national regulator. More typically, this situation may arise where the regulator is regional or global. In such an instance the national regulator has a decisive role to play, particularly because this regulator bears responsibility for the provision of ATS in its area of jurisdiction.

Key Partners such as adjacent providers of ATM/ANS must be consulted on the timing of the intended implementation. Uncoordinated timing can prove extremely difficult and even unsafe. There is a case of an ANSP in Europe affecting a change without discussing this with the neighbouring provider of ATM/ANS who was also undertaking a project and not talking to the first ANSP. The result: both were surprised when two of their SIDs met each other head-on at the airspace boundary – at similar flight levels.

3. Resources (People and Money)

It remains consistently challenging and difficult to obtain staffing for airspace design projects. This is because staff needed for these project include operational ATCOs and pilots and both have rostering obligations that take precedence. Additionally, if one considers the wide spread of expertise of the 'members' of the airspace design team, all have obligations in their own fields. The only reasonable way to achieve a PBN implementation project is to dedicate a core team to the project full time – allowing for the ATCOs to retain currency through a weekly or monthly check, and to exploit the advantages of electronic tools and remote consultation means (via internet applications) to facilitate consultation between team members. What is critical is that a core group of people have the project as their top priority task so that continuity can be assured.

KEY POINT: Looking ahead and anticipation is <u>critically important</u> for planning. Any medium to large airspace changes (PBN related or not) require validation – see Phase 3, Validation. A common way of validating an airspace concept is to use fast- and real-time simulators. Research simulators are a rarity in Europe. For this reason, it is crucial that the airspace design team identifies the need for simulations and books simulator slots well in advance. For example, the time needed for a fast-time simulation could be 3-4 months for preparation and a one week run. Real-time Simulations on the other hand, can take 6-8 months to prepare, two weeks of runs, followed by 1-2 months of data analysis and report writing. Not booking simulator slots beforehand can (and has) delay validation and therefore project implementation.

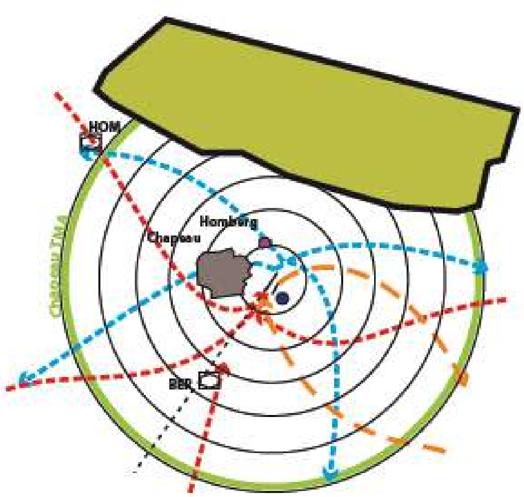
Activity 4

Analyse the Reference Scenario

Analysis of the reference scenario consists of **data collection** and **analysis**, the analysis being both critical and constructive. The goal of this analysis is to create a benchmark against which the future airspace concept performance is compared and to retain the positive components of current operations.

The Reference Scenario is sometimes called the base case, the reference case, current operations: essentially it refers to *current* airspace design and operations. This methodology uses the term **Reference Scenario.**

Collect Data



Before starting the design of the new Airspace Concept, current operations in the **<u>existing</u> airspace** – the **Reference Scenario –** must be understood and analysed. The Reference Scenario includes all existing ATS Routes, SIDs/STARs, instrument approach procedures, airspace volumes (e.g. TMA), ATC sectorisation, the air traffic data, PBN fleet equipage and capability as well as all the inter-centre and inter-unit coordination agreements. Existing contingency procedures should also be analysed so that a comparison can be made of the effectiveness of contingency measures in the new concept. Description and analysis of the airspace performance elements of the Reference Scenario are a crucial exercise – a step not to be missed or rushed. This is because analysis of the Reference Scenario in terms of the project's operations performance indicators –

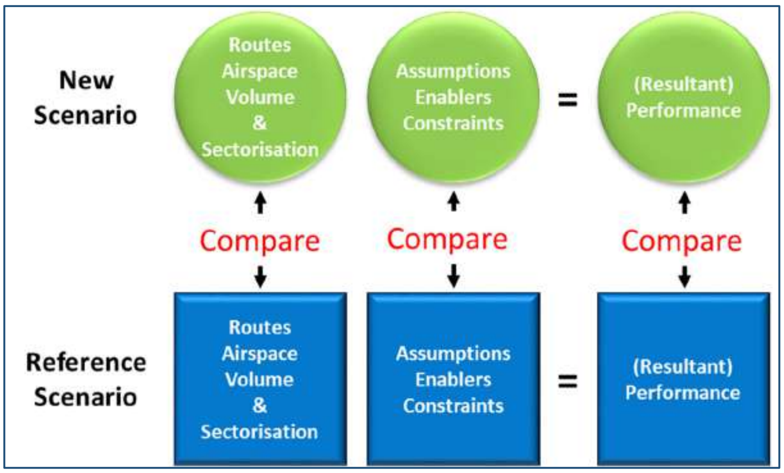
(1) Makes it possible to measure the **performance** of the current operations; and,

(2) Allows the airspace design team to know with certainty what works well in an airspace and is acceptable to ATC, and hence should be kept, and what does not work well and could be improved; and,

(3) By identifying the operational performance of the Reference Scenario, a **benchmark** is created against which the new Airspace Concept can be **compared;** and,

(4) Use of this benchmark makes it possible to measure the **performance** of the future Airspace Concept. It also becomes possible to establish whether the Safety and Performance criteria of the new Airspace Concept have been achieved.

Sometimes, the targeted/future Airspace Concept may be so different from the Reference Scenario that a comparison is not possible e.g. where ATS surveillance is introduced into a procedural environment or when a new airport is to be built with a new terminal airspace surrounding it. In the latter case, if this new airport were intended to replace or complement existing operations at another terminal area, it could be useful to compare the performance of the other terminal area versus the new terminal area.



Analysis

Analysis of the Reference Scenario should be done constructively and critically. The aim being to improve the operations rather than defend what currently exists. In this situation the role of the team leader is critical as she or he may find that mediation between strongly conflicting views is needed. Often Approach and Area controllers have different points of view; or the designers of the current airspace may be in the team and be defensive of their design and feel a need to justify it. Importantly, no Airspace Design Team should wipe the slate clean and start from scratch. Often, peculiarities have been included in the existing operations for good reason and there is no way around them. However, a redesign powered by PBN is an ideal opportunity to question everything, especially those elements of the current airspace concept which make operations complex. Whilst compromise can be a good solution to keep the peace, a *bad compromise* must be avoided. Conflicts should be resolved objectively and the right decisions made for the project.

Importantly, the team should ensure that it keeps *good* elements of the current operations and finds solutions to less efficient elements of the current operations. This may necessitate a refinement of the Objectives (and Scope) of the project, as discussed in Activity 3, and would be a typical **iteration.**

It is essential to consult **key partners** such as adjacent providers of ATM/ANS when undertaking a critical analysis of the reference scenario especially if the interactions between adjoining airspaces have complex interfaces. Many design and operational flaws which could be 'inadvertently' built into the airspace, could be avoided through simple consultation and cooperation. It is also extremely useful to ensure that the fleet analysis is done in cooperation with airline operators.

Activity 5

Safety Policy, Safety Plan and Safety and Performance Criteria

Safety

A regulator's Safety Policy drives a service provider's Safety Plan and enables Safety Criteria to be identified for normal *and* contingency operations. The Airspace Design team must decide upon the safety criteria to be used, as determined by the Safety Policy (normally set externally to the project). For the Airspace Design team, this determines how the project team will demonstrate the safety of the PBN-based Airspace Concept. If this safety policy is to be established by the Design Team it must be agreed at highest level early in the developments. Safety criteria may be **qualitative** or **quantitative** (often both are used). They must be derived for normal and contingency operations.

The Safety Policy is determined at the outset of the project. Safety Policy concerns itself with questions like:

- Which Safety Management System?
- Which Safety Assessment Methodology?
- What evidence is needed to demonstrate that the design is safe?
- Whether the airspace design meets the safety requirements for normal and contingency operations?

In a recent European PBN project, a provider of ATM/ANS used a non-ICAO methodology to determine much needed separation minima. Throughout the project, the Regulator and the provider of ATM/ANS worked together, thus ensuring that the Regulator understood and could validate the (new) methodology.

Support and guidance from the national regulatory authorities before and at set intervals during the project is extremely beneficial. It is therefore recommended that they be periodically involved in the Implementation team. The in-depth analysis of the Reference Scenario in Activity 4 provides an ideal opportunity for the regulator to provide some guidance and have direct input on what they will expect in terms of demonstration of safety of the new Airspace Concept project being undertaken.

Performance

In deciding the project's objectives and scope, it is necessary to know how a project's success can be measured i.e. what **performance criteria** must be met. Typical **performance metrics** include: airspace and aerodrome throughput (number of movements per hour); reduced track miles as a demonstration of flight efficiency; reduced turn around time at airports and reduction of the noise contour. There is a connection between strategic objectives and performance criteria and the metrics used. So – if the strategic objective is to increase capacity with the operational requirement to double throughput on runway X, if this capacity increase is demonstrated in a real-time simulation of the (new) Airspace Concept, this is a strong indication that the project will satisfy this performance criterion. Another example of a strategic objective is to increase efficiency with the specific operational requirement being to reduce 20% of the VORs whilst maintaining coverage to support existing ATS Routes.

Business continuity

When setting safety and performance criteria, the notion of business continuity is a useful one to understand. From a safety perspective, development of a contingency procedure for GPS outage may give rise to a requirement to ground all traffic. This (extreme!) solution is safe once achieved, but there is no business continuity. Alternatively, the requirement may be to ensure the same level of safety within 30 minutes of GPS loss, and to ensure that service is provided to 75% of the traffic i.e. 25% capacity reduction. These requirements could be achieved by reducing the traffic flow to match the revised performance requirements (of 75%) or by adding an additional controller to coordinate an executive ATCO that does not normally have a 'coordinator' to boost the safety need. Additional procedures could also be introduced, for example, increasing spacing on final approach.

The decision as to what level of service to provide (the 75% figure) is concerned with **business continuity**. Once contingency measures have ensured that the operations can remain safe in an airspace, then the question is how much traffic do we want to accommodate and at what cost? Will we aim for 100% traffic (likely to be very costly) or can we accept that 70% traffic is enough to ensure business continuity?

Activity 6

Agree Enablers, Constraints and Assumptions, including fleet profile

Although Enablers, Constraints and Assumptions appear quite distinct when reading the documentation of a completed project, the explanations which follow will show that it is not uncommon to confuse, in particular, Assumptions and Enablers. To remove possible confusion, Assumptions are discussed first, and Enablers last.

What are they? Are there similarities? Are CNS-ATM trade-offs possible?

Assumptions refer to elements of the operation which are based on information/trends/forecasts and are taken as given for purposes of the future airspace concept. Assumptions cover a wide field and need to take account of the expected environment applicable for the time when the new airspace operation is intended to be implemented (e.g. in 20XX). Examples of assumptions could be: traffic growth will continue; climate change will become more evident; more small airports will be opened to low-cost operations. Other assumptions are 'closer' to airspace design e.g. an assumption is made that a *current* airspace change plan which is to be implemented in 6-months time, will have been implemented by the time this PBN implementation is applicable in 4 years time. To increase the granularity even more, assumptions could be made about the percentage of the operations which take place during LVP; the location of the main traffic flows; (in 20XX, are these likely to be the same as today? If not how will they change?); the ATS Surveillance and Communication infrastructures to be used in 20XX. (Should any specific ATC System aspects be considered e.g. a maximum of four sectors are possible for the en route airspace because of

Activity 6

software limitations in the ATM system). Assumptions also exist on the traffic anticipated, runways to be used, traffic demand – we do not know but analysis of statistics and trends firm up the assumptions.

Assumptions are determined largely based on data collected during Activity 4, the Reference Scenario and added to by additional information that does not pertain to the Reference Scenario.

Assumptions must be credible because a successful airspace change and PBN implementation relies on this.

Constraints suggest the absence of certain elements of ATM/CNS or limitations created by extraneous factors. Typical constraints include high terrain, adverse weather patterns, the requirement to satisfy environmental needs (which dictate, for example, the noise-preferential runway to be used at night time) or the absence of rapid-exit-taxiways which may limit the landing rate capacity and therefore influence route placement. In general terms, constraints can be said to have a negative impact upon the ATC operational requirements of a Terminal Airspace design. At best, it may be possible to mitigate the constraints using enablers. At worst, constraints have to be accepted because there is no alternative 'solution'.

Enablers refer to any aspects of ATM/CNS that may be used to *mitigate* the constraints identified and/or any factors which may be relied upon to 'enable' ATC operations in the airspace designed. Importantly, the identification of enablers may take the form of functional requirements (which are then 'translated' into technical requirements) and require follow up work on the part of the providers of ATM/ANS, this could be outside the scope of the design project.

Enablers can be technical or operational. In either case, they can fail, develop faults or not be available for use. It is critical during this activity to discuss the availability of enablers in the event of any particular outage. For examples, ATCCs have contingency scenarios for total radar loss. An increasingly important enabler loss to be considered is that of GPS due to PBN's dependency on GPS.

Occasionally, enablers trigger a functional requirement external to the project, which generate a new technical requirement which may introduce a new constraint. This is why it is important to understand the notion of mitigation and to accept that *mitigation* can be achieved in various ways i.e. it is not always necessary to go for the most expensive enabler as a solution.

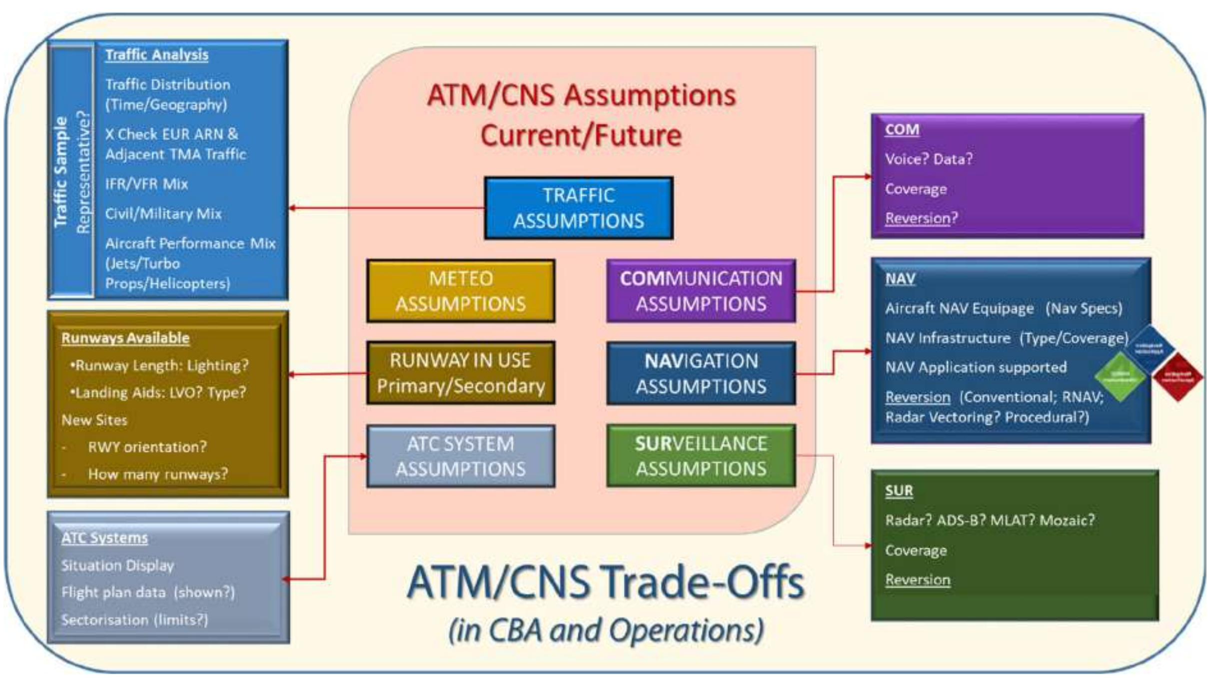
Sometimes semantics blurs the distinction between assumptions and enablers: Whilst (airspace design) **assumptions** can be viewed as 'uncertainties' (rigorously analysed and tested) which have been elevated to 'facts' to be used as a basis for the design, the role of **enablers** is two fold: to enable the airspace design *and, very importantly,* to mitigate against constraints which have been identified. For example: One RNAV 1 STAR is to be designed up to the initial approach fix and published for use in January 2024. Because this is a PBN IR requirement, an **assumption** is made by the airspace and procedure designers, that all aircraft will be certified to use that RNAV 1 STAR. It can also be argued that the enabler to fly that STAR is the the aircraft is certified and crew approved to RNAV 1.

CONSTRAINT	*Mitigation*	ENABLER	ASSUMPTIONS
Off-set NPA used because high terrain on Final Approach preventing a straight in approach.	Curved approach to final approach	RNP AR APCH with RF	State accepts GPS use; Aircraft certified and crews approved to AR.
Insufficient Navaid coverage: optimum SID/STAR not possible.	Enhance Navaid Infrastructure	New DME at Location X	DME deployed in correct time frame;
Fixed-wing and Helicopter mix causes excessive workload in CTR	Separate Fixed and Rotor Craft Routes;	Segregate RNP 0.3 Helicopter from RNAV 1 fixed-wing routes.	All rotorcraft meet RNP 0.3 specification

Trade-offs between CNS/ATM Enablers are possible and necessary: this is often discussed in a cost-benefit analysis (CBA) which underpins *any* implementation project. In a PBN project, trade-offs between CNS/ATM enablers are critical in order to properly balance cost and benefits to achieve the desired performance targets (be they safety, capacity, environmental mitigation etc). An exception might be an implementation for safety reasons such as, with PBN, for approaches with vertical guidance. The drive for vertical guidance on the final approach came from ICAO and has been put into law by the EU.

In almost all other cases, an implementation can be extremely difficult to justify if there is no return on investment, particularly where there are costs, usually in the form of enablers, to be borne by the airspace users and providers of ATM/ANS (most of which are commercialised entities in the European environment). Different business models could influence what is acceptable in terms of the time taken to realise a return on investment i.e. the delay between cost outlay and the benefit obtained.

*In Europe's **regulated PBN environment**, the "role" of a cost-benefit analysis (CBA) often relates to implementation timing. Whilst the regulation has stipulated a required level of performance (which translates into equipage/investment costs) by a due date, when this investment is to be made is often determined by a CBA.*



Activity 6

The more sophisticated and elaborate the future airspace concept, the greater the need to carefully consider all CNS *and* ATM enablers *together* in order to achieve a particular goal. PBN is *not* the only enabler; **used with other enablers** it is extremely powerful – **alone**, it can be more costly and less powerful. Enablers are varied and complex but at a higher level, see picture above, one must ask: can trade-offs be made between C-N-S elements to achieve the intended level of service? Can the safe provision of that service be met with other combinations of surveillance and communications and is this more cost effective?

*When statistically analysing fleet equipage, particularly for **regulatory compliance**, an assessment must be done for both **normal and contingency operations** i.e. the 'what if' scenario as regards a failure, such as a loss of GPS, or combined failures such as a GPS outage as well as ILS failure, for example. Using input from both operational staff and from infrastructure specialists, the airspace planner must be able to determine what alternative positioning sources are available in the event of GPS being unusable and what alternative procedures can be invoked. This forms part of the overall safety assessment undertaken for the Airspace Concept.*

To summarise, both the fleet capability and the infrastructure must be considered together and the assumptions, enablers and constraints have to be identified for normal & contingency operations. More information is available in the GNSS Reversion Handbook, No 6

Several key Assumptions and Enablers (related to future PBN operations) are singled out for additional explanation as are some other specific elements which can inadvertently have significant consequences on a project if not properly dealt with.

PBN Assumptions & Enablers 1/3: Fleet Mix and aircraft qualification

Traffic assumptions are of crucial importance to the new Airspace Concept. Traffic assumptions cover a wide variety of characteristics related to the aircraft expected to operate in the future airspace. First, the **traffic mix** must be known: what proportion is there of jets, business jets, twin turboprops, VFR single-engine trainers, military, helicopters, Medevac and RPAS? Put differently, the variety of traffic must be understood and that extends to understanding their performance profiles including their operating speed ranges, normal and maximum climb gradients and descent profiles.

*To operate on a route or procedure requiring a specific navigation performance, the aircraft must be **certified** (i.e. have demonstrated to certification authorities that it can meet the required performance). If an aircraft is (only) RNAV 1 **capable**, then the **demonstration** has not yet been done, which is why the aircraft **is not certified**. An aircraft cannot be partially certified. It either is qualified for the operation or it is not.*

Understanding the fleet mix and the navigation performance for which the aircraft fleet is **certified** is particularly important to the implementation of an airspace concept using PBN. An important subtlety exists between the notions of *capable* and *certified* – see green inset, left. Thus in this specific context, traffic assumptions related to fleet navigation **certification** are the most significant. This is because in a **non-regulated environment**, the predominant navigation capability in the fleet provides *either* the main indicator as to which ICAO navigation specifications can be selected and used as the basis for designing the airspace

Activity 6

concept to make the PBN Implementation **cost effective**. In a **regulated environment**, understanding the fleet equipage enables the planners to assess the rate of equipage, if actions are needed to accelerate equipage and subsequent certification to meet the required time-scales.

Table 1 is copied from *EASA's CS ACNS.C.PBN.101 Applicability*; it shows the principles of applicability of the new CS. The first column 'PBN specification' at 'RNP APCH' indicates, moving right, that in order to obtain airworthiness approval for RNP APCH, an applicant needs to demonstrate compliance with the criteria of Subsections 1 & 2, and the supplementary criteria of subsections 3 and 5. Furthermore, compliance with subsection 8, which addresses RF legs, is optional, as is subsection 4 which addresses vertical navigation (VNAV) outside of the Final Approach Segment (FAS). Doing the same exercise for RNP 1 shows that subsections 1 & 2 also cover the basic (non-optional) requirements for RNP 1. As RNP 1 does not address the Final Approach and since the applicant would already have had to demonstrate compliance with these basic criteria for approval of RNP APCH, there is no need to provide further compliance demonstration for RNP 1. Nevertheless, some formality would have to be complied with to ensure that the Aircraft Flight Manual correctly reflects the RNP 1 qualification.

Table 1: PBN specifications — Mandatory and optional airworthiness requirements

	Basic criteria	Supplementary criteria							
PBN specification	Subsections 1 & 2 LNAV	Subsection 3 LNAV in final approach	Subsection 4 VNAV	Subsection 5 VNAV in final approach	Subsection 6 RNP AR	Subsection 7 Advanced-RNP	Subsection 8 RF	Subsection 9 FRT	Subsection 10 Parallel offset
RNP 4	Required							*Optional*	Required
RNP 2	Required							*Optional*	*Optional*
RNP 1	Required		*Optional*				*Optional*		
RNP 0.3	Required		*Optional*				*Optional*		
RNP APCH	Required	Required	*Optional*	Required			*Optional*		
RNP AR	Required	Required	Required	Required	Required		Required		
A-RNP	Required	Required	*Optional*	Required		Required	Required	*Optional*	Required

Note: CS-ACNS (Certification Specifications for Airborne CNS) only certifies to RNP specifications. Certifications to RNAV specifications will be generally granted as part of the RNP certifications to be issued.. The European certification to RNAV 1 (P-RNAV) was JAA TGL 10 Rev 1 which has now been superseded by CS-ACNS. Today RNAV 1 equivalency is given with an RNP 1 certification.

The extent to which aircraft in the fleet are certified for the intended operations quickly reveals whether the future PBN specified area navigation ATS Routes (incl. SIDs/STARs and instrument approach procedures) will be cost effective. A high level of RNAV 1 equipage and certification was one of the prime reasons that the European Commission readily obtained agreement on RNAV 1 SIDs/STARs when formulating the PBN IR. Not only was the majority of the European fleet certified to that standard but with PBN privileges now part of the pilot's Instrument Rating (IR), the flight crews are also authorised for the operation. In short, with a mandate, the higher the number of qualified aircraft, the lower the retrofit costs so benefits can be realised more quickly. An example of a cost-benefit analysis (CBA) process is provided in Attachment 2a.

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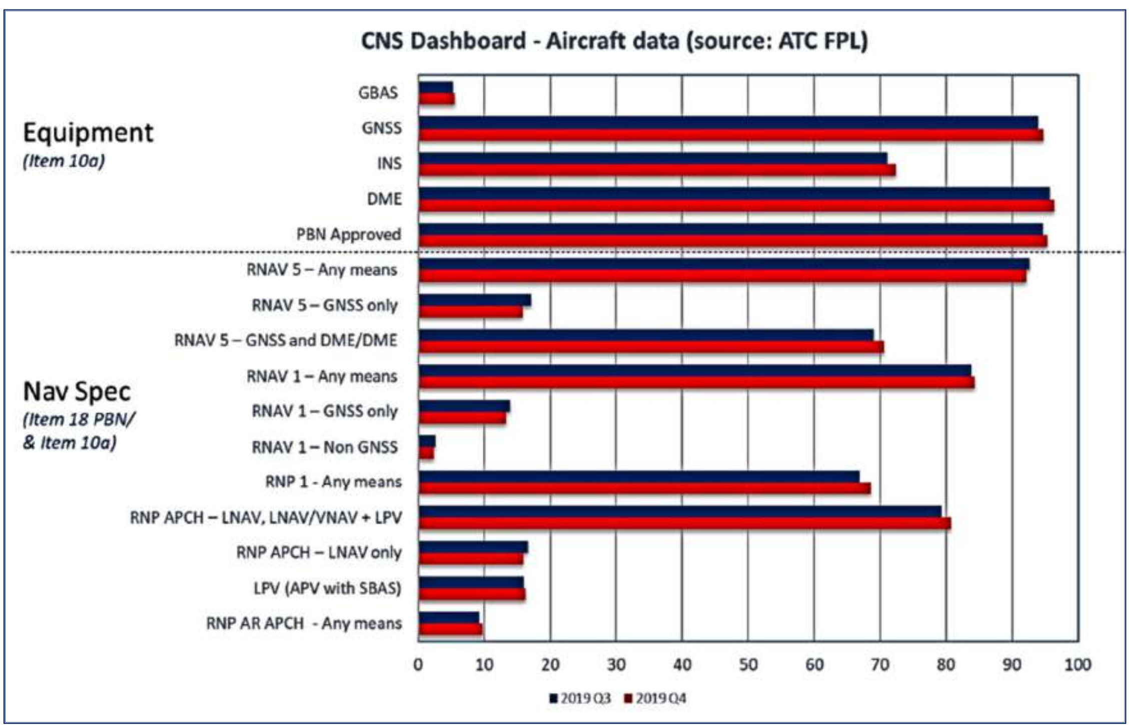
Eurocontrol's **CNS Dashboard** provides high-level views, based on flight plan data, and a sample graph is shown below. The level of aircraft capability across various navigation specifications and sensors can be seen. Comparing graphs for each Quarter allows trends to be determined. **Powerful analytical tools based on high-fidelity data are essential for sound decision making**.

*In **Europe's regulated PBN environment**, fleet equipage is crucial because the PBN IR (AUR PBN 2005) has stipulated, with specific milestones and dates, that PBN SIDs/STARs are to be designed based on the RNAV 1 specification (or RNP 1 with RF and /or altitude constraints if needed), and that PBN specified area navigation ATS Routes that are not SIDs/STARs are to be designed using RNAV 5. In those instances where RNP 1 is needed, there is a reluctance to use it because its certification burden is considered onerous. This is a spurious argument given that the explanation associated with EASA's Table 1, shows that aircraft certified for RNP APCH (which is all IFR aircraft operating in Europe by 2024), have met the demonstration requirements for RNP 1. Note however, that an RNP 1 certification does not mean that an aircraft is automatically certified for RF. Not all RNP 1 certified aircraft necessarily meet RF requirements.*

The expected *evolution* of the fleet qualification is also important. In addition to the periodic creation of these kinds of datasets for analyses, it is equally important to determine what RNAV or RNP system upgrades are expected in the period up to implementation; this is because these may affect the implementation date and significantly impact the CBA. The certification of a specific RNAV capability and maintaining pilot currency in the operation of that capability is costly for the operator. As a result, especially with regional operations, operators will only seek authorisation sufficient to meet the existing navigation requirements for the airspace. The (new) Airspace Concept may require functionality present in the software but not specified in the existing certification. While it may cost the operator to gain additional certification and to provide pilot refresher training for this new functionality, the cost is likely to be significantly less than if the aircraft required retrofitting with new equipment or software. This may have an adverse impact on implementation timescales.



Navigation Specification	Flight Phase – Navigation Application and Lateral Navigation Accuracy (NM)								Additional Functionalities (Required or Optional)					
	ATS or User Preferred Routes		Arrival Procedures	Approach				Departure Procedures						
	En route oceanic / remote	En route Continental	Arrival	Initial	Intermediate	Final	Missed[1]	Dep	RF	FRT [c]	VNAV (Final Segment)	Parallel Offset [d]	Holding	TOAC
RNAV 10	10													
RNAV 5[2]		5	5											
RNAV 2		2	2					2						
RNAV 1		1	1	1	1		1	1						
RNP 4	4									O		R[d]		
RNP 2	2	2								O		O[d]		
RNP 1[7]			1	1	1		1	1	O[a]	O				
Advanced RNP	2[3]	2 or 1	0.3	0.3	0.3		1[9]	0.3	R[a]	O		R[d]	R	
RNP APCH[4]				1	1	0.3[5]	1[8]		O[a]		O (Baro or SBAS)			
RNP AR APCH				1 – 0.1	1 – 0.1	0.3 – 0.1	1 – 0.1	1 – 0.3	R[b]		R[e] (Baro or SBAS)			
RNP 0.3[6]		0.3	0.3	0.3	0.3		0.3	0.3	O[a]					

Refer to PBN Manual, Vol II, Table II-A-1-1 for Notes

Refer to PBN Manual, Vol II, Table II-A-1-3 for Notes
Letters used instead of numbers for clarity

Source: Advanced draft of Edition 5 of the PBN Manual due for publication in 2021 {Edition requires ICAO endorsement}.

Note: PBN Manual Edition 4 currently shows Advanced RNP with a 1 NM lateral navigation accuracy in the arrival, initial, and intermediate approach. The 0.3 NM shown in this table is based on a high expectation of a change in Edition 5.

The above table shows ICAO's navigation specifications and that some RNP specifications can be 'enhanced' by the use of additional functionalities such as Radius to Fix (RF). A terminal airspace concept including closely spaced routes could, for example, most likely be achievable by an RNP specification together with a consistent and highly repeatable turn performance. This turn performance for terminal operations is called Radius-to-Fix (RF). RNP 1 and RNP APCH Navigation Specifications do not require such functionality. Therefore, to use RNP 1 + RF would necessitate a fleet analysis to determine fleet equipage and level of certification of the RF functionality i.e. a focused fleet analysis (generic IR training should have covered the RF operation, however, refresher training may be appropriate).

A similar analysis would be needed if "level" constraints were to be introduced to maximise the advantages of vertical path adherence when seeking to segregate departure and arrival routes (for example) – See Attachment 5. Level constraints typically appear on charts as altitude restrictions associated with waypoints stating 'at or above', 'at or below' or 'at'. The current ICAO Flight

*In **Europe's regulated PBN environment,** SIDs/STARs are to be designed, depending on the regulation, based on RNAV 1 for fixed-wing (with an option for RNP 1) and RNP 0.3 for helicopters; either RNP specification can include RF.*

Outside the EU regulatory context, A-RNP could bring benefits for airports with parallel runways looking to utilise RNP approaches to support independent simultaneous parallel approach operations, as the performance in the initial and intermediate phases of the approach is the same as the performance requirement of the RNP APCH in the Final Approach Segment i.e. +/- 0.3 NM. Note, the PBN IR does not permit use of the A-RNP specification.

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Plan does not provide a means for the aircrafts' vertical functionality to be declared; at best it could appear in Item 18 under NAV/ as free text.

For en route operations (be they continental or oceanic), a similar analysis is needed. A match must be made between the operational concept and the navigation application (which includes the navigation specification and the associated functionalities). If these operations are regulated by the PBN IR, then the regulation has limited operations to RNAV 5 which is not an oceanic specification. However, if it is not subject to regulation, choices can be made between typical oceanic/remote continental specifications i.e. RNP 4 or high continuity RNP 2 (or a lesser choice of RNAV 10).

Any navigation application selected for a terminal, en route and/or oceanic/remote continental airspace concept should ensure appropriate use of specification(s) per flight phase, appropriate application of associated functions and seamless connectivity between the navigation specifications so as to ensure the continuum of overall ATM operations.

Key Partners such as adjacent providers of ATM/ANS can provide useful insight into the evolution of the fleet that will transit the airspace being revised for PBN. Adjacent providers of ATM/ANS invariably 'share' the same traffic which is why it is extremely useful to obtain their input on the fleet mix. It is also essential to speak to adjacent military providers of ATM/ANS.

PBN Assumptions & Enablers 2/3: NAVAID Infrastructure availability

The Navaid Infrastructure includes all Navaids permitted by PBN, be they ground or space-based. Navaids transmit signals that are received by the appropriate on-board sensor which provides input for position estimation to the area navigation computer which may be integrated in a flight management system (FMS). The computer compares the estimated position against the aircraft's defined path and provides steering guidance to the flight crew, or auto pilot, to allow the flight path to be followed with the required level of accuracy. (More details are available in Attachment 5)

Ground-Based (or terrestrial NAVAIDS) permitted for use with navigation specifications include DME and VOR; however, VOR is only permitted for RNAV 5. NDB is not a PBN positioning source (but may be retained as a conventional positioning source for contingency operations).

Space-Based NAVAIDS are commonly referred to as GNSS (which includes augmentation systems to provide an acceptable level of integrity). Until 2030 it is expected that GPS, operating on a single frequency (L1), will be the core constellation and therefore the primary positioning source used despite the availability of GLONASS (Russia) and the evolution of the *navigation constellations* that yet are to be declared as having *Full Operational Capability (FOC)*: Galileo (EU) and Beidou III (China). Augmentation systems used in the European region include wide-area and local area augmentations (termed Satellite Based Augmentation System or Ground Based Augmentation System, SBAS and GBAS, respectively). The European wide-area augmentation system, EGNOS, augmenting GPS is only specifically required for meeting one of the Navigation specifications (RNP APCH/LPV). Locally, GBAS stations may be used as a positioning source for PBN.

Navigation specifications are supported by specific Navaids. This is spelt out in the PBN Manual and in EASA's CS.ACNS – see Table 1 shown previously. The only navigation specification with full sensor flexibility is RNAV 5. The sensor flexibility reduces with more demanding navigation specifications. The table also shows that only GNSS (GPS with augmentation) is able to meet the requirements of any navigation

Activity 6

specification. Because GPS is available globally, it is essential to ensure GPS is permitted for aviation use. The steps required to do this are described in detail in the ICAO GNSS Manual (ICAO Doc 9849).

Tying specific Navaids to a navigation specification appears to contradict one of the original aims of PBN which was to permit aircraft to use any available sensor (e.g., Navaid and/or aircraft integration with IRU, (inertial reference unit)) to meet the performance requirements of the required navigation specification. This apparent contradiction is the result of the fact that only certain sensors can provide the level of positional accuracy required to meet particular navigation specifications i.e. only a specified set of sensor combinations can achieve the performance requirements of certain navigation specifications. On the NAVAID infrastructure side, this means that for each aircraft sensor choice offered, suitable navigation facilities need to be available to provide coverage in the airspace.

Consequently, matching up the local fleet avionics capability with a particular navigation specification requires that the infrastructure is available to support all potential airspace users. Specifically, Air Navigation Service Providers should provide VOR/DME infrastructure for RNAV 5, and DME/DME infrastructure for RNAV 5, RNAV 1 and potentially also RNP 1 reversion if their infrastructure optimisation plans so permit. However, if it would be cost prohibitive or impractical (terrain limitations etc.) to provide a specific type of infrastructure coverage, then this limitation of sensor choice will need to be declared in the AIP, with the consequence that airspace users that do not have the required sensor combination could not operate on those routes or procedures.

Aligning airspace requirements with aircraft PBN equipage and available NAVAID infrastructure is the interactive process implied by the PBN triangle and fully developed in the European *Infrastructure Planning Handbook, No 4.*

Normally the Navaid engineering department performs the assessment of available infrastructure – and to this end Eurocontrol's DEMETER tool is a complimentary resource. Infrastructure assessment is undertaken with procedure designers and flight inspection services. If facility changes are required to enable a certain application, such as the installation of a new DME or the relocation of an existing facility, sufficient lead time is required.

Consequently, this interaction should take place as early as possible to determine the initial feasibility of the infrastructure to meet airspace requirements. If Infrastructure planners are simultaneously undertaking an infrastructure optimisation project, their output from their methodology's IA-4 (Analysis of the Baseline Infrastructure) is crucial as their baseline is the same as the one ATM uses for PBN implementation (See the *Infrastructure Planning Handbook*). A simplified overview of the infrastructure assessment process is given in Attachment 6. The kind of infrastructure input for Activity 6 includes what kind of coverage the Navaids

NAVAID → / NAV SPEC ↓	GNSS	IRU	D/D	D/D/I	V/D
RNAV 10	✓	✓			
RNAV 5	✓	✓	✓	✓	✓
RNAV 2 & 1	✓		✓	✓	
RNP 4	✓				
RNP 2	✓		✓	✓	
RNP 1	✓		✓	✓	
Advanced RNP	✓		✓	✓	
RNP APCH (LNAV, LNAV/VNAV)	✓				
RNP APCH (LP, LPV)	✓+ SBAS				
RNP AR APCH	✓	✓			
RNP 0.3	✓				

The above table is based on the ICAO Navigation Specifications in the PBN Manual (though a local implementation would specify acceptable sensors).

A Tick with Pink Background - sensor mandatory

A Tick with Green Background - Sensor use subject to ANSP approval, appropriate infrastructure & aircraft capability

A Tick with no background colour - Sensor optional *(one or more - choice of operator).*

D = DME; V = VOR; I = IRU (Inertial Reference Unit) provide, and by the same token, the PBN operational needs in terms of coverage requirements (in three dimensions) must be declared to the infrastructure managers as soon as possible. When ATM is setting their requirements, it should be remembered that providing suitable coverage from terrestrial Navaids becomes increasingly difficult at lower altitudes.

Operational requirements are not the only drivers which determine the target Navaid infrastructure; other strategic elements may be imposed on infrastructure managers. Examples include, national plans not to replace VORs at end of life; regulations requiring xx% reduction of a particular kind of Navaid to free up spectrum, or by technological strategies involving CNS objectives and trade-offs as well as spectrum realities.

> *INS, IRU or IRS?*
>
> *INS is the term used in the older self-contained inertial navigation systems such as those found on the DC10 and L10-11, which have all but disappeared. Today, the system providing an aircraft the ability to navigate without external references is called an Inertial Reference System (IRS). This is a collective term for dual or triple IRUs. In other words, the S is the System and the U is the Unit.*

Activity 2 has shown that ATCOs form part of the core of the Airspace Design Team. ATCOs are used to interacting primarily with operational partners (such as airspace users, airports, procedure designers and sometimes airport neighbours). As such, ATCOs can remain unaware of the non-operational influences that affect infrastructure managers, unlike their operational counterparts. Infrastructure managers mainly interact with technical standards organisations, industrial consortia, and the ministries responsible for telecommunication and flight inspection entities. The pressures facing these different stakeholders, as well as operational ATCOs, can be challenging – particularly because ATCOs and technical infrastructure managers often use a different vocabulary, when discussing the same thing. The GNSS Reversion Handbook, No 6, has a section dedicated to contrasting vocabulary.

Key Partners such as adjacent providers of ATM/ANS can share DMEs, for example, provided that this is properly coordinated and the necessary formalities are observed e.g. letters of agreement are in place. This could reduce infrastructure costs – see Attachment 6 to this handbook, and the Eurocontrol Infrastructure Planning Handbook, No 4.

PBN Assumptions & Enablers 3/3: Increasing reliance on GPS and MON

EU regulations related to PBN clearly indicate that GNSS will become the primary navigation infrastructure over the next decade and that contingency measures must be provided in the event that GNSS becomes unusable for PBN. *See the GNSS Reversion Handbook (No 6).*

By 2030, GNSS will be PBN's main positioning source. Nevertheless, it is necessary to ensure that a minimum operational network (MON) of terrestrial Navaids remains available for contingency operations and to support normal operations for those aircraft which are either not PBN certified or not GPS equipped. The MON available for contingency operations is there to ensure safety, in some instances, and business continuity, in others, when GPS becomes unusable. MON is critical for infrastructure managers, which means that it also becomes critical for ATM staff implementing PBN. PBN does not work without an infrastructure to provide positioning information to the aircraft operating within the airspace. This is why

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ATM and Infrastructure managers must work together to make sure that coherency exists between expectations and reality of both the supporting infrastructure and operations (normal and contingency). The *Infrastructure Planning Handbook* explains MON.

Communication & Surveillance Assumptions

For decades, CNS technologies operated independently, kept separate for safety reasons so as to avoid a common point of failure. The logic employed was that if one of the three failed, the other two should remain available.

That reality has changed considerably in the last two decades as GPS has increasingly become a shared enabler between C-N-S. Surveillance and Communication applications such as Automatic Data Surveillance (ADS) and DataLinks also use GPS information, and the GPS timing element can be critical in some C-N-S applications. The GPS commonality is not the only limitation of the growing inter-dependence and integration: the spectrum used by the three fields of technology is becoming an increasing source of competition between C-N-S, with commercial communication evolutions (e.g. GSM, 5G) increasingly demanding access to that part of the spectrum traditionally reserved for aviation.

> *The infrastructure available during a GPS outage is particularly relevant to the question of contingency planning. All navigation specifications permit the use of GPS, but the RNP Specifications require its use. Thus, an area outage of GPS, or severe interference could disrupt operations if most of the aircraft operating in the airspace are relying on GPS for positioning. The situation becomes more acute if ADS-B surveillance is used exclusively to provide ATS surveillance.*
>
> *The increased reliance on GPS across CNS means that these elements must be considered fully in the airspace concept development. See the European GNSS Contingency/Reversion Handbook for PBN Operations, Handbook No 6*

Inasmuch as area navigation underpins PBN, GPS is the anchor of RNP applications and the one navigation sensor that can be used for all navigation applications and one particular surveillance application, ADS-B. This is why particular attention must be paid to GPS being taken as a 'given' for use by PBN. That it is there to be used is undoubted – but that the impact of its use and potential outages due to interference or technical fault must be understood particularly as virtually all of ATM's supporting technologies increasingly rely on its availability e.g. message time-stamping for datalink communications and space-based ADS-B for oceanic separation standards. (See *GNSS Reversion Handbook*).

Key partners such as adjacent providers of ATM/ANS can and do share surveillance and communication data and infrastructure which is an effective way to share costs. 'Sharing' and pooling of surveillance occurs across ECAC, and during a project, care should be taken that Infrastructure decommissioning decisions do not negatively impact on the adjacent providers of ATM/ANS's primary or contingency infrastructure.

In summary, it can be said that the cost-efficient deployment of assets: COM, NAV and SUR cannot occur **without prior coordination between the domains in support of an ATM requirement. This is because trade-offs between COM-NAV-SUR are possible and often cost-effective [*idem,* between Key Partners]**

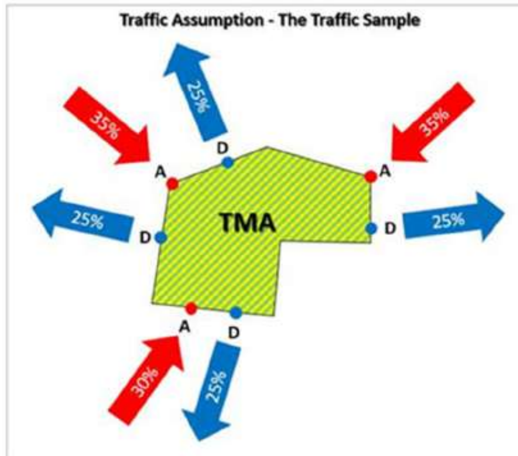
and this balancing act between the three key enablers and ATM requirements and systems must be exploited to the full. Safety remains unchallenged as the key strategic objective: but what can be debated and discussed is *how* it is achieved because there are a variety of ways to achieve the same TLS (Target Level of Safety) and/or operational objective.

Activity 6

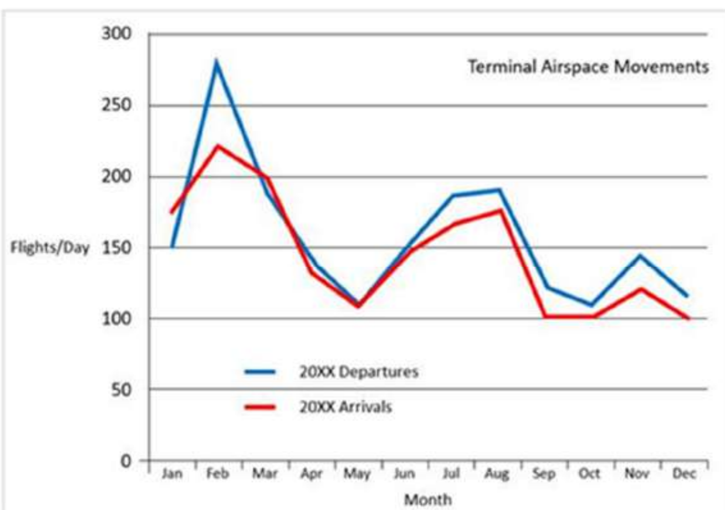
This rounds off the discussion about CNS/ATM trade-offs initiated at the start of this Activity on page 28.

Traffic Assumptions: The Traffic Sample

The traffic sample for the new Airspace Concept is as important as the knowledge of the fleet composition and its navigation performance qualification. This is because RNP and RNAV route placement (be they User Preferred, ATS Routes, SIDs/STARs or Instrument Approach Procedures) aims at safely enabling maximum flight efficiency, capacity and minimum environmental impact. In a terminal area, for example, RNP or RNAV SIDs and STARs and RNP Approaches provide the link between the major en route ATS routes and the active runway (hence the importance of knowing the primary and secondary runway in use).



A traffic sample for a new Airspace Concept is usually a future or projected traffic sample i.e. one where certain assumptions are made about the fleet mix, the timing of flights, and the evolution of demand with respect to both volume and traffic pattern. Traffic samples can be a mix of extrapolating current traffic patterns and increasing or decreasing the frequency and/or based on known market evolutions notified by airlines. When traffic samples look further than the immediacy of the next year or two, forecasting is used, where again some extrapolation/market investigation can be done, and models are used to support the forecasting process. Various such models exist e.g. the econometric model,



The success of an airspace design can stand or fall on its traffic assumptions, so getting the traffic assumptions right is critical.

Despite ATC's in-depth knowledge of existing air traffic movements, future traffic samples for 20XX must be thoroughly analysed (in very futuristic cases, it may even be necessary to create a traffic sample based on market projections and geo-political scenarios). Invariably, certain characteristics will be identified in the traffic sample e.g. seasonal, weekly or daily variations in demand; changes to peak hours and relationship between arrival and departure flows (see diagram, above).

Once the Implementation team has agreed the anticipated future environment then these assumptions and agreed future enablers should continue to be the stable basis for the project. That said, regular assessments to validate these assumptions and enablers should be undertaken particularly where projects continue over several years.

For all the planning and desired stability in having a credible traffic sample/forecast as the basis for an airspace design, the airspace design team must remain constantly aware of day-to-day geo-political realities. Sudden switches in geo-politics may, in some cases, *instantly* affect current or planned traffic flows (thus necessitating the need for instant implementable scenario building and planning) or affect the traffic in the medium to longer term thus impacting the traffic sampling, projections and forecasts. In some cases, new traffic assumptions will need to be made because of the unforeseen event. Examples of disruptive events that can (and have) dramatically affect the immediate traffic flows, or projected distribution and/or forecasts include:

- The **geo-political upheaval** in late 1980s which saw the opening of previously closed borders. This dramatically and almost instantly introduced new traffic flows and shifted existing flows due to the availability of new travel destinations that the population had previously been unable to travel to.

- A sudden **political conflict** flares and extends into protracted political instability and potentially war, with no fly zones being introduced. This too affects where the routes are placed and the volatility can be extremely challenging for providers of ATM/ANS located adjacent to these areas;

- **Volcanic ash** clouds have, to date, typically affected traffic flows for several weeks, but depending on the winds aloft and the behaviour of the volcano, the disruption can reach into the medium term.

- **Public health** events such as the global pandemic (Covid-19) experienced in 2020, saw a drop of European traffic to unprecedented levels. The direct and indirect economic impact of such an event is virtually unknowable. How long will the traffic take to rebuild? At what rate will the traffic grow? Which routes will/not be used in the medium to longer term? Will certain routes disappear? These are difficult questions to which there may be no clear answers. Hence the importance of scenario building, closely following market trends. It is possible, that the economic impact of such an event is so great that 'urgent' implementation plans are shelved until it is possible to more clearly define the need based on what could prove to be a dramatically altered context.

ATM System Assumptions

In Europe, ATM systems are reasonably sophisticated. Nevertheless, some of them are not very adaptable whilst others are very flexible and can be easily adapted to meet future needs.

Therefore, as most ATM systems have limitations it is important for the Airspace Design Team to understand the ATM system limitations when embarking on a PBN/Airspace improvement project. If, for example, there are limits to the number of ATC sectors that can be defined, this is an important element to be documented and understood before embarking on the design of the routes, holds and airspace volumes which affect Sectorisation choices. Sectorisation limits could affect route placement and have an adverse impact upon capacity.

Phase 2. Airspace Design

Airspace Design *follows* completion of the Planning Phase (1). **For both en route and terminal airspace, the design of airspace is an iterative process which places significant reliance on qualitative assessment and operational judgement of Air Traffic controllers working *together with* airspace and procedure designers as well as other stakeholders such as flight validation specialists and other airspace users etc.**

Europe has an extensive availability of surveillance and communication coverage. ATS Surveillance is often multi-layered i.e. Radar and/or MLAT with or without ADS-B, which enables the airspace design to extract additional benefits from PBN. Particularly in terminal areas, RNAV or RNP SIDs/STARs can be designed to optimise SID/STAR interaction (which could replicate efficient radar vectoring paths) and reduce the need for controller intervention.

Where the routes are placed and how they interact is a function of various factors including the navigation specification required to operate on that PBN SID/STAR or ATS route and the controller's intervention capability using ATS surveillance. To ensure **connectivity** between en route and terminal routes, airspace planners must take account of different specifications being required on PBN ATS routes on the one hand (e.g. RNAV 5) and SIDs/STARs on the other (e.g. RNAV 1) because differences may affect the configuration or spacing of routes. **PBN specified area navigation ATS routes including SIDs/STARs need to be fully integrated both vertically and horizontally and an understanding of plans/strategies in the adjacent airspace is required.**

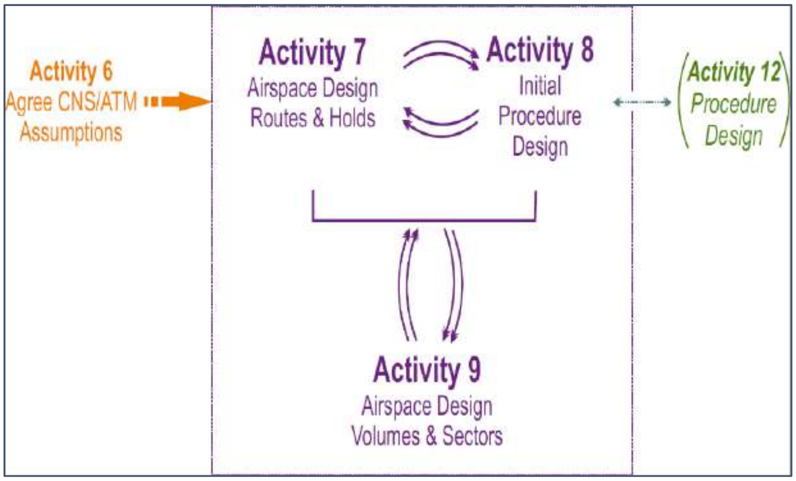
Airspace design (routes and structures) and scenario building must be discussed and ideas exchanged with **key partners such as adjacent providers of ATM/ANS as well as the Military, as applicable.** This is the only way to ensure full lateral and vertical integration of routes and their **connectivity** in an airspace. Close cooperation and information exchange (including negotiation and adaptation) is a recurring requirement for each Activity in the Design phase.

For terminal airspace changes it is important that the procedure designer participates in the conceptual design which should be led by operational controllers supported by stakeholders. The controllers/airspace planners who lead the project **must** work together with all participating stakeholders whose objectives may conflict. It is typical, for example, for different airspace users (AUs) to have conflicting objectives, and to have divergence between airline operators, environmental interests and ATM objectives. Professional differences also exist: for example, whilst operational controllers seek optimum route placement to manage the traffic throughput effectively, procedure designers want to ensure that obstacles surfaces are not compromised and that the aircraft can fly the proposed procedure; in turn, airspace users (AUs) seek minimum turn-around time and shortest distance flown, pilots want minimum restrictions whilst environmental managers seek to appease neighbourhood communities by ensuring minimum noise and emissions. These simplified examples make it obvious that consultation, cooperation, negotiation and sometimes mediation and trade-offs are needed. It also provides insight into why PBN, as part of the airspace design construct, can be so contentious and complex to implement.

Airspace design should follow a set order for PBN implementation:

(i) First, conceptually design the SIDs/STARs and ATS Routes; (**Activity 7**)

(ii) Second, propose an initial procedure design of the proposed traffic flows (**Activity 8**)



(iii) Third, an airspace volume is defined to protect the IFR flight paths (e.g. a CTA or TMA) and then this airspace volume is sectorised to manage the traffic (**Activity 9**);

As suggested by the diagram left, Activities 7 to 9 do **not** follow a linear progression. **Iteration** is the key to these three activities; the continual moving forwards and backwards between the activities until finally the airspace design is sufficiently mature to make it possible to move to Activity 10 and onward.

Activity 7

Airspace Design - Routes & Holds

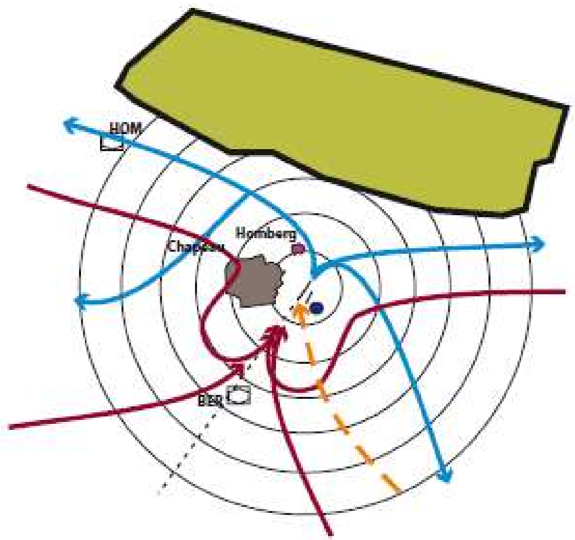
The conceptual design of traffic flows in terminal areas (which ultimately become the future PBN SIDs/STARs and ATS Routes) is the starting point of this exercise. This is an analytical & iterative process (which can be done as simply as using paper and pencil). Route placement is usually determined by the traffic demand (origin-destination), runways in use and strategic objectives – and, to a greater or lesser extent, the airspace reservations and their flexibility.

*In **Europe's regulated PBN environment**, the PBN IR (AUR PBN 2005) has stipulated, with specific milestones and dates, that PBN SIDs/STARs are to be designed based on the RNAV 1 specification (or RNP 1 with RF and /or VNAV if needed), and that PBN ATS routes that are not SIDs/STARs are to be designed using RNAV 5. The PBN IR is effectively a mandate, and compliance is required of the EU providers of ATM/ANS (the regulated parties) in accordance with the various milestones. What this means, is that the choice of PBN specification to be used is defined/limited. RNAV 1 SIDs/STARs, for example, cannot be designed using functionalities that demand more than RNAV 1. This is why the Team's procedure designer and pilots are crucial to the airspace concept design process. Between them and the ATCOs, they ensure that the design of SIDs/STARs and ATS routes remain realistic and flyable.*

In European airspace concepts, route spacing studies have determined the minimum theoretical distance that can exist between proximate tracks if aircraft operate at the same level (*see Route Spacing Handbook,* and see also *Note 1, below*). As the **Route Spacing Handbook** stresses repeatedly, **the theoretical *regional* CRM (collision risk modelling) undertaken by the generic study must be complemented by a local implementation safety assessment.** If a standard spacing is to be maintained between parallel tracks in a turning segment, there is a need for RNP 1 and the RF path terminator (use permitted by the PBN IR), but in this instance, fleet equipage and cost-vs-benefit must be established.

Activity 7

*Note 1: Generic (global) route spacings are published in PANS-ATM (these have been determined by ICAO's Separation and Airspace Safety Panel (SASP) and are supported by a set of global assumptions published in associated Circulars). Other organisations such as Eurocontrol and the FAA have given indications of applied route spacings in regional publications. The European Route Spacing Handbook is a regional route spacing document. It provides substantial detail on European methodologies and spacings theoretically achievable in ECAC using the assumptions detailed in the document. The European PBN Route Spacing Handbook can be found in the Library on the PBN Portal (https://pbnportal.eu/). **It is not intended and not desirable for any regional or international standard to be implemented without a local safety assessment.***



Note 2: The role of the procedure designer in the terminal airspace route placement is of crucial importance. This specialist advises the Team whether the intended routes match the navigation performance of both the prescribed navigation specification and the Navaid coverage and whether the routes can be designed in accordance with design criteria detailed in PANS-OPS (ICAO Doc 8168).

Note 3: In some oceanic airspace concepts, routes may be randomly (yet repeatedly) flown. Using advanced equipment, the tactical separation between aircraft is provided as a function of the aircraft's level of certification and the distance between a pair of trajectories. This sort of system has traditionally relied on ADS-C reporting in relatively low density traffic areas.

One of the greatest advantages of PBN is that ATS Routes, SIDs/STARs and instrument approach procedures do not have to pass directly over ground-based NAVAIDs. PBN makes it possible to place routes in the most optimum locations provided the necessary coverage is available from the ground- and/or space-based NAVAIDS. This 'placement' benefit provides significant advantages. It means that routes can be placed where they give flight efficiency benefits by, for example, avoiding conflicts between flows of traffic. Similarly, routes can be designed to provide shorter track miles or vertical windows at crossing points supporting continuous descent or climb operations, thereby enabling more fuel efficient profiles with reduced environmental impact (noise, CO_2 etc). It also means that parallel routes can be designed to avoid having bi-directional traffic on the same route. In addition, to provide various route options between

CONTINGENCY MEASURES

When designing Free Routes Airspace, published PBN ATS Routes, SIDs/STARs and Instrument Approach Procedures, contingency and emergency measures must be addressed in the airspace concept. Not only are contingency measures a requirement of the PBN IR (Article 6), but catering for contingency and emergencies is a required ICAO practice. To date, typical local contingency procedures for ATCOs cater, for example, for loss of surveillance, or low visibility operations. The prominence given to GNSS by the PBN IR means that contingency measures will have to cater for GNSS outages. In fact, the airspace (route) design, and the operations within the airspace will together be used to formulate the contingency procedures in the event of loss of GNSS. The topic of GNSS contingency/reversion is covered in the *European GNSS Reversion Handbook.*

Activity 7

the same origin and destination airports. Most significantly, perhaps, this placement benefit provided by PBN makes it possible to ensure the efficient connectivity between en route and terminal routes so as to provide a seamless (vertical) continuum of flight paths.

The introduction of PBN has had an unexpected consequence in some cases: in a few countries, environmental lobby groups have blamed PBN for the focusing of aircraft noise and air pollution into a narrow corridor. This is sometimes called *concentration* of traffic which means that all the traffic is required to follow the same flight path and thereby creates a repeated nuisance (emissions and noise) to the same population. An alternative strategy is that traffic can be dispersed which means that a series of routes are spread out and the noise/emissions are shared across several communities. The switching of direction of take-off (within wind limitations) or SID or STAR for the same runway used at some European airports are examples of flight path *dispersion*. The decision to concentrate (focus) routes or to disperse them is often a political decision taken at regional/local level. Therefore, the accusation that PBN is responsible is not justified. In the highly politicised arena of environmental mitigation, PBN's route placement in the vicinity of airports is seldom an operational decision, and indeed, PBN has the advantage of enabling the creation of noise reducing routes (sometimes known as noise respite routes or noise preferential routes).

Key to obtaining PBN's airspace advantages (particularly in a terminal airspace) is for arrival and departure routes (STARs/IAPs and SIDs) to be designed as a function of the interaction between them as well as servicing the traffic's desired track and ensuring obstacle clearance. Route placement for PBN does not negate best practices in route design developed over decades. Some of these are discussed below.

In the text which follows, ATS routes refer to those routes designated as per Annex 11 Appendix 1 (e.g. UL611), whilst the narrative expression 'terminal routes' generally refers to arrival, departure routes (SIDs/STARs) designated in accordance with Annex 11 Appendix 3 (e.g. KODAP 2A) and instrument approach procedures (IAPs) (designated in accordance with PANS-OPS, Doc 8168 and ICAO Circular 353).

Free Route Airspace[3]

Most European "upper" airspace is managed as Free Route Airspace (FRA) where aircraft are able to select their own trajectories using area navigation techniques in compliance with the PBN specification promulgated for operation within the FRA i.e. RNAV 5 specification in the European FRA. Separation within Free Route Airspace is ensured tactically by the ATCOs. CP1 IR (Common Project One Implementing Regulation, (EU) 2021/116)requires FRA to be implemented across the entire Single European Sky Airspace at least above FL305 by December 2022.

Contrasting fixed ATS Routes and Free Route Airspace

There are several key differences between fixed published ATS Routes and free routeing:

(i) Designation and Publication: **Fixed ATS Routes published in the AIP are designated using conventions** prescribed in ICAO Annex 11, Appendix 1 e.g. route designation, UL611. This is the basis for an 'airway record' being created in the navigation database and a performance requirement being attributed to this

[3] The CP 1 IR ATM # 3 refers to Free Routes Airspace. Currently, ECAC airspace also permits DCTs in some instances – see Attachment 4 and ERNIP Part I, which uses both terms FRA and DCT.

airway record. Free Route Airspace, which is not an ICAO construct, is published in accordance with the European Route Network Improvement Plan (ERNIP), in the States' AIPs and is more comprehensively regulated by the CP 1 IR. Waypoints which can be used for direct routeing within the FRA can also be found in the State's AIP. [The direct routeing which occurs within a FRA is effectively an application of the DCT permitted in PANS-ATM, Doc 4444 which is limited by certain conditions]. As any set of waypoints can be selected to create a user's desired path, no ATS route designator (as provided by Annex 11, Appendix 1) can be assigned.

(ii) Operations Concept: The European operational concept for fixed published ATS Routes and free route airspace is different: in the former instance, the ATS Route placement is determined to ensure the strategic de-confliction between published RNAV routes requiring a specific performance to operate on the route. Route placement and spacing is referenced in the *European Route Spacing Handbook,* and is enabled **partially** by the *performance requirement* determined by the navigation specification required. With some navigation specification, this lateral navigation performance accuracy is associated with the airway record in the navigation database. The performance required along the *designated* ATS Route is published in the AIP. In FRA, aircraft choose their trajectory between two way points (multiple flight paths may cross); the trajectories are not strategically positioned and therefore conflicts must be resolved *tactically* by ATC using ATS surveillance (there is no airway record coded in the navigation database for a path defined by the flight crew for operations in FRA). – *see Note below.*

(iii) Adherence to centreline: With fixed published ATS Routes, the aircraft is required to adhere to the centreline of the track (according to Annex 6) and meet the stated navigation performance requirement stipulated in the AIP. The ATS route's publication in the AIP must meet the requirements of Annex 15 and PANS-AIM, Doc 10066. Adherence to the route centreline is ensured by compliance with the navigation specification prescribed for the route. As previously indicated, flight paths used in FRA do not have a published track and therefore no airway record is created in the navigation database. The route is defined on-board by the aircraft's RNAV or RNP system in the FMS, and a nominal performance requirement (in Europe, RNAV 5) is set to nominally 'bound' the operation along the aircraft's defined track. In fact, an aircraft cannot fly a flight path within an FRA without an RNAV or RNP system, and use of an RNAV or RNP system means that the compliance with a navigation specification is required for the operation.

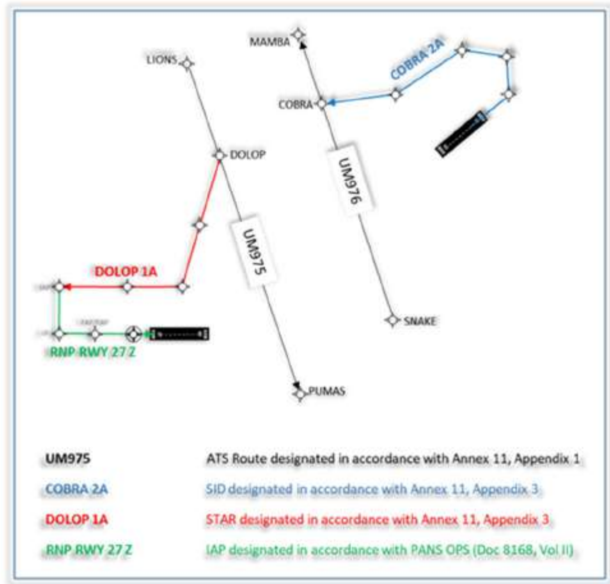
Note: The extent to which such navigation performance attributes can be ascribed to a user defined 'track', often referred to as a DCT (which has not been designated as per ICAO Annex 11, Appendix 1) is still unclear. Indications are that navigation performance and functionality can be ascribed to DCTs in some instances and not in others, but conclusions are hard to draw: In some instances, performance and functionality attributes assigned to the end waypoints of designated ATS routes can be applied along a single DCT connecting these end waypoints. For a series of subsequent DCTs for which no airway record is available in the navigation database, the system may default to a standard lateral navigation performance accuracy, normally expected to be ±2 NM in en route; however, this default is not assured across the whole aircraft fleet. (Attachment 4 of this handbook shows examples of FRA applications and connectivity models used in continental Europe today).

Continental ATS Routes

Published ATS Route networks are planned at continental, regional or area level as appropriate. The more widespread the use of a common navigation specification as a basis of the network's design, the more seamless the interface between different areas can be because the route spacing would not need to be altered. PBN does not change general good practice that uni-directional routes are better than bi-directional routes, from an ATM perspective. A parallel system of PBN specified area navigation ATS Routes across a continent can provide great benefits in that it is possible to segregate traffic or balance traffic loads on different routes. When creating a parallel route system, care must be taken where the ATC sector lines are drawn when it comes to balancing the ATC workload.

Activity 7

In generic European RNAV and RNP route spacing studies, the assumption is made that the parallel (interacting) routes are under the control of a single controller operating a single sector i.e. the ATC sector line is not drawn between the two routes so as to ensure that deviations of either route can be detected and corrected by the same controller. This means that if it became necessary to draw a sector line between the parallel routes in order to control ATC workload, the implementation safety assessment would have to address this reality and it may prove necessary to increase the spacing between the two routes. More detailed information on PBN Route Spacing between published ATS Routes is in Eurocontrol's *Route Spacing Handbook.*



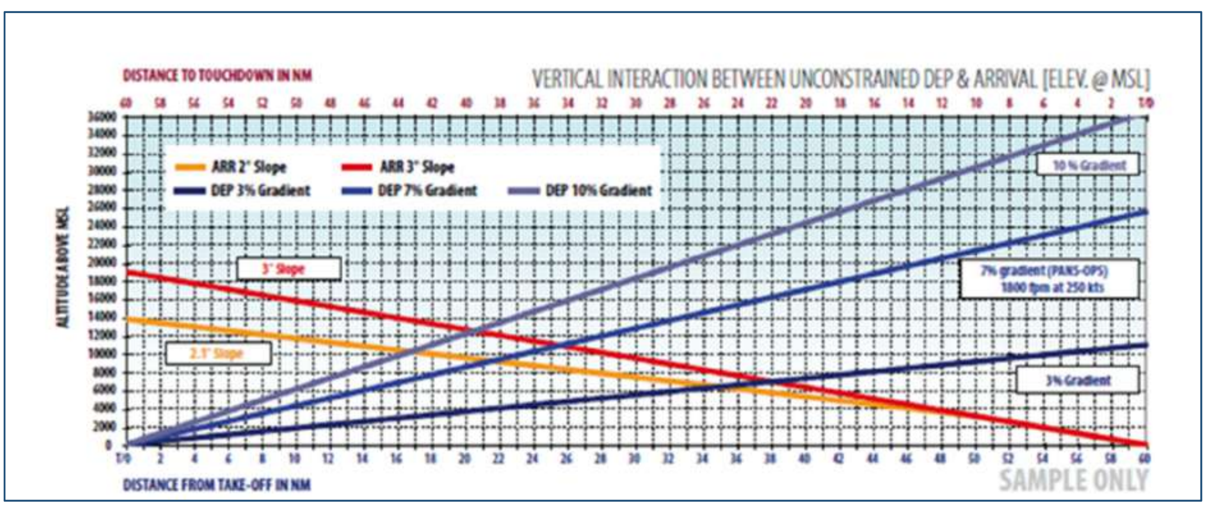
Oceanic/Remote Continental

Various airspace concepts are to be found in oceanic/remote continental airspace. Some of these provide random routing, which permits the flight crew to select the most efficient flight path based on jet streams, for example. Others may provide a more structured system such as the PBCS routes in the NAT. Attachment 4 provides more information.

Terminal routes leaving/joining FRA or ATS Routes

Continental traffic flows (above diagram) which service multiple origin and destination airports are best segregated, where possible, from the terminal routes to/from airports (red/blue routes in diagram). This is to avoid mixing overflying traffic with climbing and descending traffic or fixed en route ATS routes and/or free routeing trajectories.

Climb and Descent profiles of Terminal Routes



Activity 7

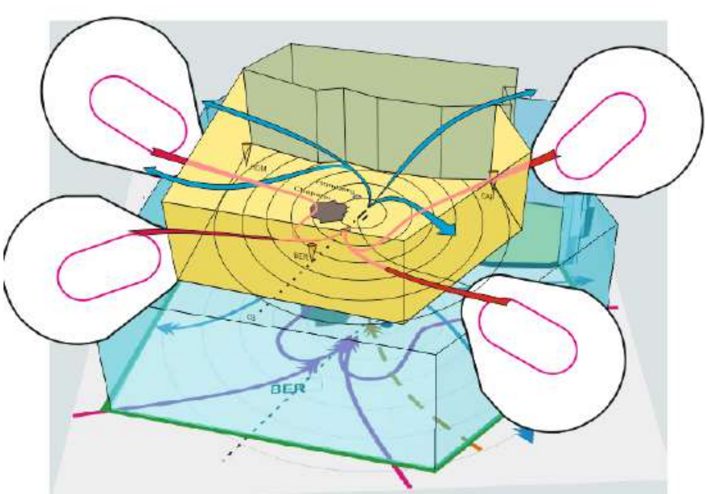
Whilst operators, environmental managers and procedure designers consider the placement of each SID/STAR and IAP in terms of flight efficiency, environmental mitigation and safety (obstacle clearance/flyability), ATC has to manage all traffic along the routes as a traffic 'population'. As such, the airspace design from an ATC perspective, needs to address the interaction between arrival and departure flows of STARs/IAPs and SIDs. The different objectives are not mutually exclusive: it is possible to design terminal routes and achieve most of the (apparently conflicting) objectives. However, care must be taken in choosing the crossing points between departure and arrival flows. The crossing point of SIDs and STARs should not constrain arriving or departing aircraft (hence, knowledge of aircraft performance is essential). The sample graph above (and at Attachment 3) shows that for particular (blue) climb gradients – 3%; 7% and 10% – and particular (red) arrival profiles – with specific speed assumptions – unconstrained arrival and departure profiles would seek to occupy the same level at various distances from the runway.

For example: if a departure on a 7% climb gradient (marked in blue on graph) had travelled 24 track miles from the departure end of the runway (read on the blue lower X axis) when it crossed the arrival on a 3° slope which was at 36 track miles from the runway (read in red on upper X axis), both aircraft would be in the region of 11,000 feet AMSL. So choosing this crossing point would not be efficient because it would restrict the departure's continuous climb and the arrival's continuous descent and would increase controller and pilot workload. The procedure designer along with operational pilots provide most of the aircraft performance data to the airspace design team. With PBN, the use of level restrictions can assist in the vertical management of instrument flight procedures, which can be of benefit in the airspace design.

A web-based, interactive version of this graph is available in the 'Tools' section of the PBN Portal (https://pbnportal.eu). Whilst this is not a procedure design tool, it can provide the first indication to the design team what vertical spacing is available at planned crossing points. Furthermore, the tool allows the team to extrapolate the optimum distance from take-off and landing for a crossing pair of climbing and arriving aircraft to ensure maximum vertical separation.

Arrival Flow Management: To hold or not to hold?

Two typical styles of arrival traffic flow management and sequencing are used in the design of busy terminal airspaces.



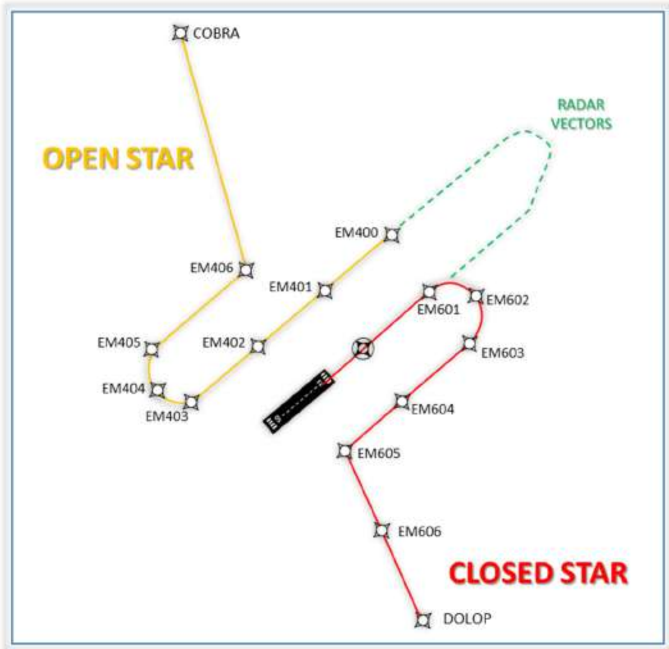
The first can be compared to a pressure cooker where a number of holding patterns are spread geographically at a similar distance from the landing runway (nominally, at four 'entry points' to the terminal area). These holding patterns 'store' the arriving aircraft and keep the pressure on the terminal airspace by feeding a continuous stream of arriving traffic from the holding stacks to the arrival/approach system with departures threaded through the arriving traffic.

The alternative is more 'elastic' in that to avoid holding aircraft, (sometimes extensively) longer terminal arrival routes are designed to the landing runway. Sometimes a hybrid of these two styles is used e.g. Point Merge. These techniques require ATS Surveillance.

There are advantages and disadvantages to both systems. Some contend that in the end the track miles flown by arriving aircraft are more or less the same irrespective of the style used to design the airspace, which may be true in given circumstances. However, when aiming to facilitate continuous descent, linear extensions on extended routing may provide the pilot with greater ability to plan the descent profile and hence provide benefits over holding, especially at lower altitudes. That said, extensive radar vectoring downwind can reduce the pilot's flexibility to provide a fuel efficient vertical profile as total distance to touchdown is unknown.

Open vs. Closed procedures

PBN makes it possible to design closed and/or open procedures. Although 'Open' or "Closed' procedures are not ICAO expressions, they are increasingly in common use. The choice of open or closed procedure needs to take account of the actual operating environment and must take into account ATC procedures.



Open procedures provide track guidance (usually) to a downwind track position from which the aircraft is tactically guided by ATC to intercept the final approach track. An Open procedure will require tactical routeing instructions to align the aircraft with the final approach track. This results in the RNAV or RNP system only being able to calculate the descent up to the final waypoint on the procedure. This means that a continuous descent operation after this point may not be possible, due to the uncertainty of the extent of path stretching by ATC; tactical information on distance-to-touchdown could alleviate this.

Closed procedures provide track guidance right up to the final approach track whereupon the aircraft usually intercepts the ILS or final approach path of a GLS or RNP APCH. The closed procedure provides the pilot with a defined distance to touch down thus supporting the RNAV or RNP system's execution of the vertical profile. Where multiple arrival routes are operated onto a single runway, ATC can be reluctant to have multiple closed procedures which automatically turn onto final approach. A work around is that closed procedures can be designed and published in a manner that anticipates alternative routeing to be given by ATC on a tactical basis. These tactical changes may be facilitated by the provision of additional waypoints allowing ATC to provide path stretching or reduction by the use of instructions 'direct to a way-point'. However, these tactical changes, needed to maximise runway capacity, will negatively impact on the vertical profile planned by the RNAV or RNP system. In addition to the vertical management difference between Open and Closed STARs, AUs may have to carry more fuel, due to regulatory requirements, where a Closed STARs has been designed with longer track distances. If controllers typically provide shortcuts, this could create fuel and emission inefficiencies due to the carriage of the additional fuel load. These inefficiencies could be solved by appropriate coordination with the AUs.

Linking Navigation Specifications

The part of the instrument approach procedure prior to the final approach segment continues to create considerable discussion, usually when using the ‘pressure cooker’ with STARs ending at a holding pattern at terminal entry, but also because sometimes two *different* navigation specifications can cover the same segments (initial and intermediate) of the IAPs.

The ‘pressure cooker’ STAR, which ends at terminal entry, creates a complication: if another predicated RNAV or RNP track is to be published from the terminal entry to the Final Approach Waypoint, this second ‘track’ cannot also be called a STAR. This is due to the fact that ICAO’s procedure designation concept, and subsequent database coding, never foresaw the need for a second ‘STAR’. Consequently, some ANSPs have designated this second ‘track’ as a ‘Transition’ (which without FMS limitations could have been designated as a ‘second STAR’). Because ‘Transitions’ have not defined by ICAO, confusion arises due to individual ANSPs using different *transition* terminology e.g. GNSS transitions, GPS Transitions, RNAV transitions, FMS Transitions, RNAV Arrivals. This problem is being addressed by the appropriate ICAO technical panels.

Where the RNAV 1 or RNP 1 STAR begins at terminal airspace entry, this nomenclature difficulty does not typically arise. The STAR would normally end by either the initial or intermediate fix after which it is possible to design either an RNP APCH to begin at the initial or intermediate approach fix and continue through to the missed approach or provide radar vectoring to the final approach segment (PA, NPA, Visual).

Notably, RNP APCH has the same lateral navigation accuracy of +/-1 NM up to the Final Approach Segment, hence the possibility of the procedure designer making different choices if this is the accuracy sought.

A comprehensive exposé of STARs/Transitions and the ‘overlap’ potential between STARs and IAPs is available on the PBN Portal (https://pbnportal.eu/epbn/main/Using-PBN/PBN-on-the-Flight-Deck/Arrival.html**). The draft Working Paper is entitled:** ***What is a STAR, What is a Transition?***

Specific Techniques

Continuous Descent and Climb Operations are techniques currently used in some designs to both mitigate environmental impact and increase flight efficiency. Both benefits are optimised thanks to PBN’s ability to place routes in the most optimum place.

Trombone shaped routeings to final approach are sometimes used as a means of sequencing traffic. The trombone shape is shown on the diagram: Open and Closed STARs.

Point Merge is another technique used to sequence traffic. Information on point merge can be found here (https://www.eurocontrol.int/concept/point-merge).

Activity 8

Initial Procedure Design

During the design of the arrival and departure traffic flows, the procedure designer begins the initial procedure design based on PANS-OPS criteria. This preliminary design considers various perspectives:

- It is necessary to determine whether the placement of the proposed routes is feasible in terms of navigation performance, turns and obstacle clearance, for example. For this analysis, local Instrument Flight Procedure design expertise is crucial because only this expert has the local knowledge of terrain and obstacles. A Flight Validation Pilot (FVP) or Datahouse could be consulted to determine how the intended procedures can be coded using ARINC 424 path terminators (applicable to RNAV and RNP IFPs). If these routes are not feasible from a procedure design perspective, they need to be modified (this is a typical example of an iteration between Activity 8 and Activity 7 – as per in the introduction to this Phase); nevertheless, in a regulated PBN environment, the prescribed navigation specification must be applied as the basis for route design and therefore in European TMAs, all SIDs and STARs must be a minimum of RNAV 1 by June 2030 at the latest.

- Part of this analysis involves ensuring that the required navigation specification matches the fleet qualification identified in Activity 6 and that both can meet the requirements of the intended design of Routes and Holds completed in Activity 7. Here again, great reliance is placed on the procedure designer and aircraft operators (or flight validation pilots (FVP)) included in the team, because if there is no match, the routes and holds will have to be modified – whilst respecting the regulatory requirements.

- Consideration must also be given to the NAVAID Infrastructure: if the navigation specification identified in Activity 6 requires GPS and/or DME/DME and the identified fleet capability identified suggests that most aircraft have DME/DME without GPS, the intended design may generate a requirement for additional DMEs. These may also be needed/used to support contingency operations. In such a case, the need for these additional DMEs could cause a delay to the project implementation date (because procurement of the necessary land and installation/calibration of a DME can take time). Alternatively, the conceptual routes and holds may have to be re-designed so as to exclude the need for one or more additional DMEs for financial or spectrum reasons; this could mean a significant change to the airspace concept.

- As regards feasibility referred to in the first bullet, it is clear by looking at the diagram of proposed SIDs/STARs (see example under Arrival Flow Management) that a particular RNAV or RNP specification would be needed for this design. The procedure designer in the airspace design team would make this clear early on; however, this is self-evident and pre-defined in a regulated environment. Certain ARINC 424 path terminators might be needed, as would an on-board navigation database. In analysing the aircraft fleet in terms of navigation performance, the analysis would thus focus on the navigation functionalities (e.g. path terminators/data base etc) needed on-board the aircraft to fly these procedures. In any case, the regulatory requirements are to be complied with which provides the procedure designer the knowledge of aircraft performance and functionalities available. However, those regulatory requirements may, in some instances, force aircraft operators to upgrade their equipment in order to comply with EU SERA regulation 5015.

A formal consultation should take place with adjacent providers of ATM/ANS once Activity 8 is completed. This is because the placement of routes is of inestimable interest to all adjacent providers of ATM/ANS and because Activities 7 and 8 are the key building blocks for the activities. Failure to undertake consultation would result in no buy in from these stakeholders. In such cases, serious consideration should be given to abandoning the project (or at least delaying it until agreement is reached).

STAKEHOLDER CONSULTATION

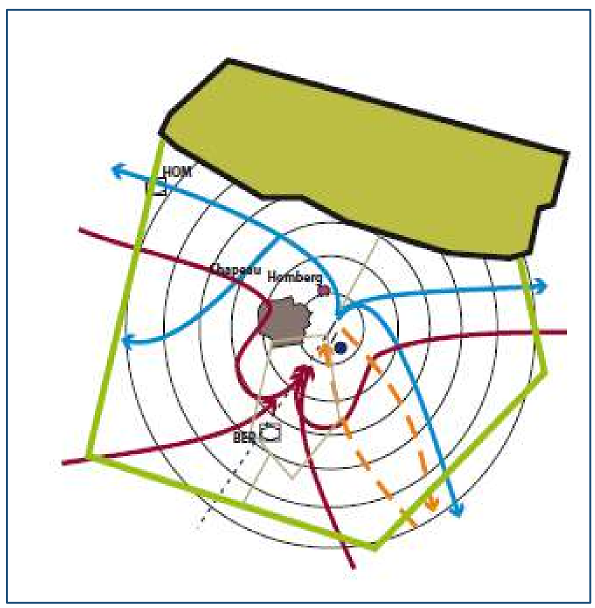
Although public consultation would be an on-going process throughout the life-cycle of the PBN implementation project, it becomes necessary to consult with specific stakeholders at various stages of the project. After Activity 8 is such a time, now that a conceptual design of routes exists. At this point of the design process, before designing the airspace volumes and sectors, it is an opportune – and very necessary – moment to undertake a formal consultation with a wider audience including airspace users. Such consultations can either take place bilaterally between the team and different users, but it is often more beneficial to organise an event where several users are present and the route design is discussed with them as well as the work done on the Cost Benefit Analysis (Activity 6), the fleet analysis and the actual placement of the route from Activity 7 and 8.

Activity 9

Airspace Design – Structures & Sectors

For completeness, mention is made of the non-PBN aspects of airspace design which occur after the routes have been designed and the navigation analysis of the design is complete: first, the design of the airspace volumes followed by the sectorisation of the airspace volume. Significantly, both of these design activities occur after the placement of the ATS and Terminal routes has been completed.

Note: *it is generally undesirable to design the routes so as to fit them in a predetermined airspace volume or sector shape as inefficient flows are likely to result. Traffic demand and the operational requirements determine route placement, then the airspace volumes are built to protect the IFR flight paths and finally the airspace volume is sectorised in order to manage ATC workload.*



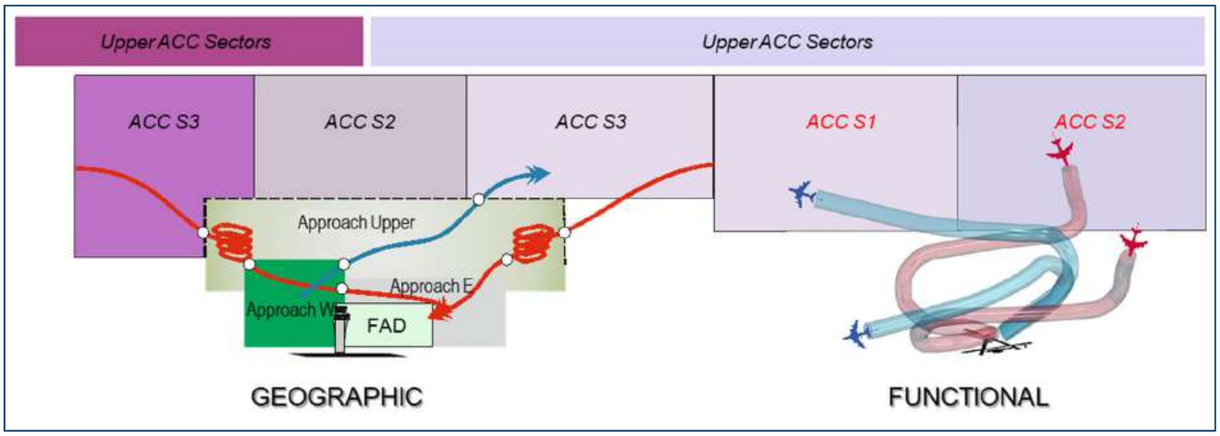
The airspace volume is created to protect IFR flight paths – both vertically and horizontally. As such it can be of any shape or size. In developing the airspace volume it may be necessary to go back and adjust the routes to ensure that they fit within the airspace volume.

Once the airspace volume is completed, then the airspace is sectorised for purposes of air traffic management. Sectorisation is done as a function of the traffic sample and traffic assignment (see Activity 6) and may be functional or geographical. Whilst en route airspace tends to be geographical, terminal airspaces tend to use either one or the other or a mixture of both.

- Geographical Sectorisation is where the airspace volume is divided into 'blocks' and a single controller is responsible for all arriving and departing traffic in a single block i.e. sector; or
- Functional "Sectorisation" is characterised by dividing the workload in the Terminal Airspace volume as a *function* of the aircraft's phase of flight. The most common type of Functional Sectorisation is where one controller is responsible for all arriving flights in the Terminal Airspace whilst another is responsible for all departing flights in the same Terminal Airspace volume.

Once the sectors are designed, it may be necessary to go back and revisit the route placement as determined by the controller workload generated by a given ATC sector design. The design of ATS routes, terminal routes, airspace volumes and ATC sectorisation is again an **iterative** process. VFR charts and the Minimum Radar Vectoring Altitude (MRVA) may also be affected.

From a purely airspace design point-of-view, neither the airspace volume nor sectors need to follow national borders. It is possible, and even desirable for reasons of flight efficiency, capacity and ATM cost effectiveness, to design cross-border airspace volumes or sectors. In such cases, the delegation of ATS will need to be considered.



Activity 10

Coherency Check: Design v. Requirements

Once the airspace design activities are complete, it is important to take a step back and verify that the design can indeed be supported by the navigation specification prescribed by regulation or identified in Activity 6.

Activity 10 should be relatively simple if Activities 6 – 9 have been done in an integrated manner and if Activity 6 has been rigorously undertaken and ensured that the identified or **regulated** navigation specification matches the fleet capabilities and is the basis for the airspace design. [The regulation could be national or supra-national].

If there is no regulated specification, Activity 10 can be used to refine the choice between two similar navigation specifications and to decide on one (perhaps the lesser) of the two. Alternatively, it may be viable to have provided for two sets of design each based on different navigation specifications. Both could then be subjected to an in-depth feasibility assessment to establish the final choice. In either case, **contingency measures** must be catered for and must be achievable. Care must be taken not to exclusively burden operational personnel (pilots and controllers) with contingency fallout. There needs to be system enablers that can be activated, on a case by case basis.

Doing a thorough cross-check to ensure the coherency of the design with the regulated requirements is crucial. It can be viewed as a last chance to ensure that a valid proposal is being put forward, rather than one that is doomed to failure because it has not been sufficiently stress tested. This shows and re-iterates the importance of **Activity 6 as *the* key to the entire airspace design process.**

The following two Tables deal with key considerations that must be addressed at this stage of the project. These considerations concern (i) ensuring that all the necessary requirements, national, regional and intra-regional have been accounted for; and (ii) consideration as to whether the now mature airspace concept will require a mandate of either aircraft equipage or mandate of publication of procedures or whether mixed operations will be acceptable. These considerations are checked again at the PROJECT CHECKPOINT after Activity 11, but at that stage, the 'regulatory compliance' element is relatively light weight, and the decision of whether to mandate or not is either confirmed or rejected. This decision is of course related to the business cost implications of the cost-benefit analysis (CBA).

Regulatory Considerations

PBN implementations can be generated/governed by Global, Regional or National requirements. In any of these cases, the national regulator has a significant role as the official overseer of PBN and other implementations.

In Europe, there are *Standardised European Rules of the Air [EU Regulation 2016/1195]*, which dictate the requirement for the aircraft and aircrew to be qualified for the route or procedure to be flown. It is cited only because this is a frequent question which arises, as some stakeholders have difficulties in understanding 'what' regulates the pilot to be qualified to fly a PBN Procedure.

- SERA 5015 IFR – Rules applicable to all IFR flights.
    - Aircraft Equipment
    - Aircraft shall be equipped with suitable instruments and navigation equipment appropriate to the route to be flown and in accordance with the applicable air operations legislation.
- COMMISSION REGULATION (EU) 2016/539 – Pilot training, testing and the periodic checking for performance-based navigation.
    - Performance-based navigation instrument rating privileges.
    - Pilots may only fly in accordance with PBN procedures after they have been granted PBN privileges as an endorsement to their instrument rating ("IR")
    - PBN privileges shall be required for every instrument rating.
- COMISSION REGULATION (EU) 2018/1048, PBN IR – requires the providers of ATM/ANS to publish RNAV (or RNP) ATS Routes, SIDs/STARs and RNP instrument approach procedures at certain milestones.

Intra-Regional Considerations

A PBN implementation for oceanic, remote continental and continental en route operations, generally requires regional or multi-regional agreement in order that connectivity and continuity with operations in adjoining airspace can ensure maximum benefits. For terminal and approach operations, the PBN implementation is more likely to occur on a single-State basis although TMAs adjacent to national borders are likely to require multinational coordination.

Note: For example, in the EU there is a regulatory obligation to implement PBN on ATS Routes, SIDs/STARs and instrument approach Procedures in Treaty states.

Where compliance with an ICAO navigation specification is prescribed for operation in an airspace or on ATS routes, these requirements shall be indicated in the State's aeronautical information publication.

Implementation Options: Is there a need to mandate a navigation specification?

One of the toughest decisions to be made by the PBN Implementation team is whether to mandate a particular navigation specification for PBN operations on the ATS routes. Typically, three options exist:

Phased implementation (no mandate)

Generally, this is more popular with airspace users (no costs are involved to retrofit). But the incentive to implement is limited and NAVAID infrastructure evolution may be slow to accommodate all the various navigation specifications (or even conventional navigation). Mixed mode capability inevitable.

Mandate navigation enabler

Generally this is more popular with providers of ATM/ANS because traffic capability is homogenous so there is a reduced need for ATM system changes. Simplicity means that all aircraft can be treated the same way, airspace design can be uniform and clearances standardised. However, the AU needs to have enough cost benefit to justify a costly retrofit.

*In **Europe's regulated PBN environment,** the PBN IR (AUR PBN 2005) has effectively mandated the use of particular navigation specifications along ATS Routes, SIDs/STARs and on instrument approach procedures. The 'mandate' is three stepped with different requirements at each milestone. The intention is that by 2030, an exclusive PBN environment will be the norm.*

Two mandate scenarios can be envisaged: an equipment mandate (where all aircraft above a certain mass are required to be approved against a particular navigation specification) or an airspace mandate (requiring all aircraft operating within an airspace volume or on routes to be approved against a particular navigation specification). Whilst equipment mandates seem more palatable, the effect is that a mixed navigation environment can in fact exist if, for example, high-end business jets were to be below the cut off mass. Mandate considerations should include:

a) Business case; *and*

b) The lead-time to be given to airspace users and, depending on the nature of the mandate, various providers of ATM/ANS; *and*

c) The extent of the mandate (local, regional or multi-regional) ; *and*

d) Safety cases; *and*

e) Implementation Plans/equipage rates (7 years notice normally needed) to avoid excessive retrofitting costs.

Mixed Mandate – net effect of the EU PBN regulations.

A "mixed-mandate" is one where a mix of conventional + PBN routes or different navigation specifications are used on the same kinds of routes in the same airspace. E.g. it is mandatory to be approved to an RNAV 1 specification for operation along SIDs/STARs and RNAV 5 along an ATS route transiting the terminal area. The issues raised under the mixed environment also pertain to such a variant. Regulation of PBN by the EU has set milestones for compliance which mean, effectively, that in the transition period lasting ± seven years, a mixed environment will need to be managed. There may be pressure from the AUs for Best Equipped Best Served (BEBS); this is not always practicable.

In remote continental/oceanic airspace mixed mandates are common e.g. where sophisticated ATM systems can determine the required spacing between random tracks or separation minima can be established between aircraft using specific approved conflict probes. This is a truly user-orientated service but difficult to achieve in high density/complex airspace.

PHASE 3. VALIDATION

By the time the airspace design is complete, the Airspace Concept has become a comprehensive body of work that needs to be validated and checked. Validation takes place in various phases: the airspace design is usually validated first; once this has been done the Instrument Flight Procedures are designed and validated. In fact, during the design phase, many of the iterations can be considered as part of on-going validation processes.

This section of the Handbook first discusses the **airspace design and ATM validation** and then addresses the **validation of instrument flight procedures**.

Airspace validation takes place at the advanced phase of the project – the home run. Successful validations are not exclusive: they include as many partners as possible especially affected **partners** such as **adjacent providers of ATM/ANS**. In Europe, many multi-state simulations have been run between adjacent providers of ATM/ANS – with great success. Not only is this cost effective but it ensures inter-State cooperation, airspace coherency and connectivity both laterally and vertically.

Activity 11

Airspace Concept Validation

The main objectives of airspace design and ATM validation are:

- To prove that the airspace design has successfully enabled efficient ATM operations in the airspace;
- To assess if the project objectives and performance targets can be achieved by implementation of the airspace design and the Airspace Concept in general;
- To identify and correct weak points in the concept (or mitigate if necessary);
- To provide evidence and proof that the design is safe i.e. to support the Safety Assessment.

As previously stated, **quantitative** and **qualitative** methods are used to evaluate safety whatever the validation method used. Both evaluation methods are needed and they are mostly undertaken at the same time as each needs information produced by the other method. As a result it is essential that the results of each evaluation/assessment are viewed holistically even if they are significantly different approaches. The theoretical distinction between them is not of importance: what is important is that a safety assessment, whatever the evaluation method used, is holistic and rigorous.

Input	Assessment Benchmark Used	Output	Validation Method
▪ Published & Proposed Airspace Design (Routes/Holds, Structures and Sectors)	Non-numerical Performance and Safety Criteria based upon ICAO SARPs, Procedures and Guidance material and National/Local regulations.	Mainly textual/ diagrammatic reasoning, argument, justification.	▪ Expert ATM/CNS judgement; ▪ Airspace Modelling; FTS/RTS; ▪ Live ATC Trials.
▪ Published and Proposed Airspace Design (Routes/Holds, Structures and Sectors) usually in computer data format representing Airspace Organisation and Traffic Samples. ▪ Surveys - radar data recordings, flight plan recordings, flight recordings, questionnaires. ▪ Statistics & forecasts - airports operations statistics, meteorological data collections, traffic demand, traffic distribution.	Absolute Numerical Performance and Safety criteria based upon Performance and Safety Criteria based upon ICAO SARPs, Procedures and Guidance material and National/Local regulations.	Numerical data (primarily).	▪ Airspace Modelling; ▪ FTS/RTS; ▪ Live ATC Trials; ▪ Flight Simulator; ▪ Data Analytical Tools; Statistical Analysis; ▪ Collision risk modelling.

There are several tools or methods available to undertake validation of the airspace concept, or the validation of specific procedures or to validate certain elements of the concept. These are:

- Airspace Modelling;
- Fast and Real-time Simulation (FTS/RTS);
- Live ATC Trials;
- Full Flight Simulators;
- Data and Statistical Analytical Tools;
- Collision Risk Modelling.

Each of these differ in terms of Cost, Realism (and complexity), Time and the number of Traffic Samples and Test Cases used – see the graph below. Generally, the more complex the simulation method used, the greater the cost, the extra time required to prepare and run the simulation and the closer to reality the

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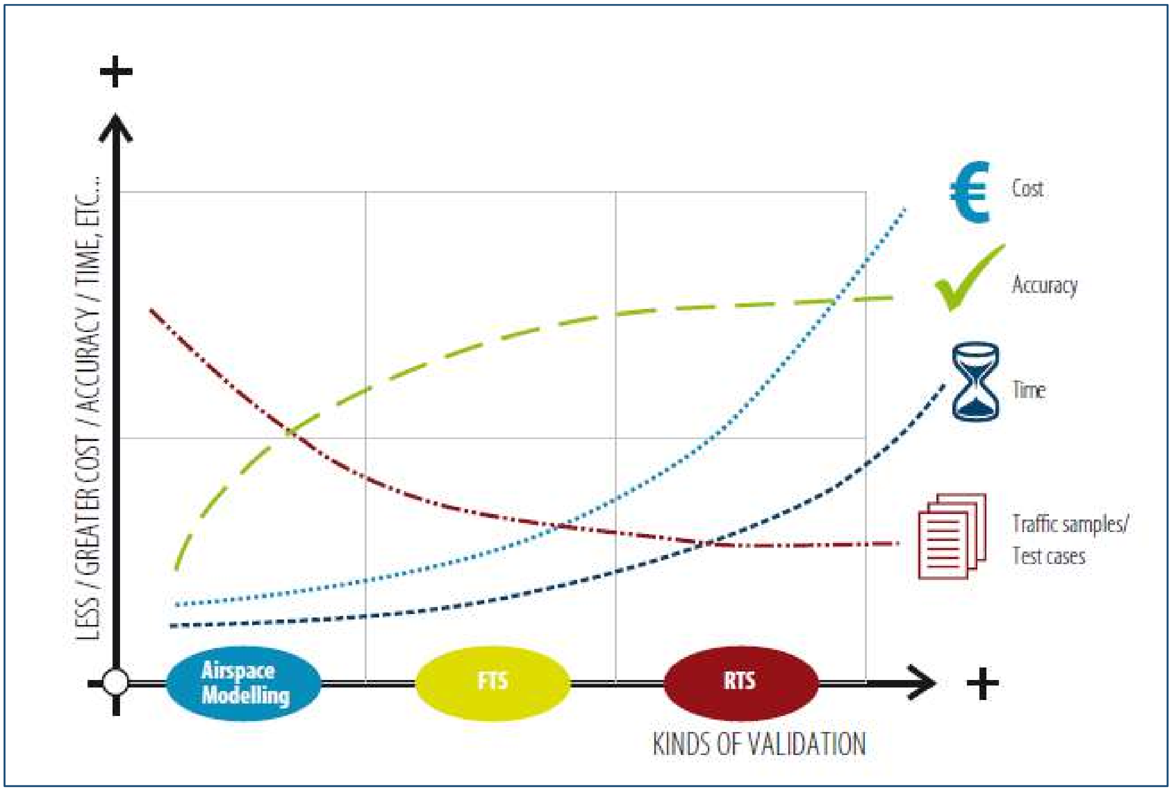
results become. In contrast, and normally for reasons related to cost/time – the number of traffic samples/test cases tend to decrease as the complexity of the simulation method used increases.



General Considerations

An important characteristic of most ATM-related computer-based validation tools is that the navigation performance of the aircraft is usually **unrealistically excellent –** *see Chapter 3, Lessons Learned (PBN ATC Simulations)*. This drawback does not impact the main aim of the validation exercise which is to check the ATM viability and safety of the proposed Airspace Concept. If specific investigation of the impact of navigation failure modes (e.g. track deviations) is desired this can be scripted into the simulation scenarios even though the route spacing criteria already take account of navigation failure modes.

The number and extent of validation methods used and their duration is directly linked to the complexity of the airspace design and the complexity of the Traffic Sample. As more changes are envisaged and the greater their safety and operational impact, the greater the requirement becomes for accurate and detailed investigation to prove their operational benefits and fulfilment of safety criteria.

For these reasons, the design team should allocate enough time in the project plan for the appropriate level of assessment (modelling, fast-time and real-time simulation, live trials). The planning should be made as flexible as possible because the results of one Validation method could heavily impact upon the next Validation step in the sequence or could lead to the suspension of the validation process and a return to the design phase. Of particular importance is the need to book simulator time slots during the project planning phase for the validation of the Airspace Concept. As mentioned in Activity 3, **research Fast- and Real-time simulators are limited resources. Many countries do not own such simulators and it is therefore important that during the project planning, a period of time for**

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validation simulations is provided for and the availability of the simulator is assured. Many projects have been delayed because of the non-availability of simulators at the crucial time.

If weaknesses are found during the validation exercise to the extent that it is necessary to return to the design phase of the project, there is merit in doing this. For a variety of reasons, not the least being cost, it is better to return to the drawing board sooner rather than later.

Airspace Modelling

The airspace modeller is seldom used as the only way to validate an airspace design, but rather tends to be the first of several validation methods used. Like most validation tools, the airspace modeller is computer based. Most frequently, the airspace modeller is used during the airspace design phase because it enables the airspace design team to visualise, in three dimensions, the placement and profile of routes, the airspace volumes and the sectorisation. This ability to see in three dimensions is extremely useful.

Airspace modelling tools can be considered as 'scaled down' versions of Fast-Time Simulators. Their main usage is to create a non-refined representation of the routes and airspace volumes (sectors) together and their interaction with a selected traffic sample. The tool generates simplified 4D trajectories (position + time) for the aircraft according to the flight plans described in the Traffic Sample (with its Rules) in a particular Airspace Organisation (with its Rules). This process is called traffic assignment. These trajectories are used together with the airspace blocks to calculate a series of statistical data such as: sector loading, route segment loading, conflicts, etc. Some more advanced airspace modelling tools can derive more precise data with regard to the workload and sector capacity.

Advantages and Disadvantages of Airspace Modelling	
Advantages	**Disadvantages**
▪ great flexibility; ▪ simple to assess various alternatives; ▪ easy Scenario adaptation and generation of Test Cases; ▪ easy to create and assess «what if» Test Cases; ▪ easy to test large number of traffic samples; ▪ can use data derived from real traffic and ATC environment.	▪ crude representation of real environment; ▪ can provide only high level statistical data; ▪ cannot replicate tactical controller interventions; ▪ basic aircraft performance; ▪ simplified trajectories; ▪ no representation of meteorological conditions; ▪ results accuracy depends heavily on the assessor ability and experience; ▪ high degree of subjectivity; ▪ difficult to involve users.

Fast-Time Simulation (FTS)

Fast-Time Simulation (FTS) is a frequently used way of validating a proposed design. It may also be used as a way of demonstrating that the safety objectives have been met. Sometimes, the use of a FTS is the first validation step.

Often used prior to RTS (real-time simulation), FTS might also be the only step used to validate the concept. Because FTS is less demanding than RTS in terms of human resources (a computer is used and not

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controllers), this is often a preferred method for improving the proposed design, identifying flaws in the design concept, and/or preparing the path to RTS or direct implementation.

FTS needs the airspace organisation and Traffic Sample to be defined for the simulated environment using specific computer language. The parameters that are needed include Routes, a traffic sample which is assigned on the routes, Airspace volumes and Sectors and Rules for aircraft behaviour.

In the simulator model, basic controller actions are described by task, which are triggered by specific events and have a time value associated with them. This value is the time required in real life for the controller to fulfil the specific action.

The simulator engine generates 4D trajectories (position + time) for each aircraft based upon flight plan information and rules stated in the Test Cases. The system checks each trajectory for certain predefined events. Examples of such predefined events may include conflicts (remembering that defining the parameters of what constitutes a conflict might need to be written into the rules), level changes, route changes, sector entry or exit. When such an event is detected, the system increments the defined counters and triggers task parameters linked to the event. For example, if the system detects that an aircraft has crossed a sector boundary, it will increase by one the number of aircraft counted in that specific sector and will trigger as active the tasks assigned to the controllers (such as hand-over, transfer of communication, identification, etc).

The simulator adds the values of the task parameter for a given Test Case and the result value gives an indication of controller workload. Usually, a controller is considered not to be overloaded if this figure does not exceed 70% of the total time of the Test Case.

The precision of workload indication is higher when the ATC modus operandi is better known and formalised, e.g. it could be described by basic tasks with clearly identified trigger events and well determined time parameters.

Advantages and Disadvantages of Fast-Time Simulation (FTS)	
Advantages	**Disadvantages**
▪ one of the most frequently used methods for sector capacity assessments; ▪ gives opportunity to collect quality data; ▪ relatively unlimited scope and great flexibility; ▪ relatively simple to assess various alternatives; ▪ relatively easy Test Case adaptation; ▪ relatively easy to test a large number of traffic samples; ▪ can use real traffic and environment data; ▪ good acceptance of the results; ▪ can evaluate the achievement of the TLS (Target Level of Safety); ▪ can inform safety case development.	▪ simplified model of "real" operation; ▪ can provide only statistical data; ▪ cannot replicate tactical controller interventions; ▪ quality of results depends heavily on the accuracy of the model; ▪ limited aircraft performance and simplified aircraft behaviour; ▪ low representation of meteorological conditions; ▪ Involving users may be difficult.

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Real-Time Simulation (RTS)

Real-Time Simulation is used in the later stages of the validation of a proposed design and it may also be used as a way of demonstrating that both the safety objectives and operational objectives can be met. Operational ATCOs are used for RTS.

Often, the real-time simulation is used as a final check of the design and as the preparatory step for the implementation. This method is used mainly because it provides live feedback from the operational air traffic controllers and for its potential high degree of realism.

A Real-Time Simulator tries to replicate as accurately as possible the real working environment of the involved air traffic controllers. The main components of a RTS platform are: the simulator engine; active controller/pseudo-pilot positions; Data- recording.

The simulator engine processes the flight plans and the inputs from the pseudo pilots and controllers and provides all positions with replicated data as obtained from operational Radar Data Processing Systems (RDPS) and Flight Data Processing Systems (FDPS).

(See also Section 3, Lessons learned).

Advantages and Disadvantages of Real-Time Simulation (RTS)	
Advantages	Disadvantages

▪ Closest simulation method to live ATC which can be used to assess/validate simulation objectives;
▪ gives opportunity to collect high quality numerical data and operational feedback from controllers and pseudo-pilots;
▪ can indicate and assess human factor related issues (furthering qualitative and quantitative assessment);
▪ automatic data collection (for quantitative assessment);
▪ unlimited scope and greater flexibility compared to live trials (further qualitative assessment);
▪ no risk to the live operation;
▪ allows testing of contingency procedures and hazards;
▪ simple to assess various alternatives;
▪ on-line feed-back and scenario adaptation;
▪ can use real traffic and environment data;
▪ good acceptance of the results by the controllers (wide scope qualitative assessment);
▪ provides extensive evidence to the proof of safety case.
	▪ Sterile environment, limited HMI (human machine interface);
	▪ limited aircraft performance and simplified (sometimes, non-realistic) aircraft behaviour;
	▪ quality of pseudo pilots affects output;
	▪ pseudo-pilots cannot replicate real flight crew performance and it can be difficult to directly involve AU due to their availability;
	▪ low representation of meteorological conditions;
	▪ human factor related drawbacks:
	    ▪ controller mind-set;
	    ▪ exercise/scenario learning curve;
	    ▪ subjectivity of assessment (mainly workload);
	    ▪ macho attitude;
	    ▪ controllers feed-back clouded by historic experience;
	    ▪ costly and time consuming.
	▪ Potentially resource intensive; often difficult to get operational controllers available for simulation.

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Live ATC Trials

Live ATC Trials are probably the least used validation method. Generally, this is because it is perceived as carrying the highest risks despite providing what is probably the highest degree of realism. When used, Live Trials tend to be aimed at assessing a very specific element of the airspace change such as a new SID or STAR or a new Sector design with a very limited traffic sample.

Advantages and Disadvantages of Live ATC Trials	
Advantages	**Disadvantages**
• it is the most accurate validation method; real data is collected; • gather feed-back from all users; • good acceptance of the results by the users.	• safety implication; • great detail required which makes preparation time consuming; • limited scope in that they tend to look at one specific aspect of an operation, without a big picture overview; • limited flexibility.

Flight Simulation

Full flight simulators are renowned for their superior realism and accuracy in reproducing all of the operational characteristics of a specific aircraft type. Normal and abnormal situations, including all of the ambient conditions encountered in actual flight, can be precisely simulated. The use of simulators has increased due to advances in technology and the significant cost savings provided by flight simulation training, compared with real flight time. Today's commercial flight simulators are so sophisticated that pilots proficient on one aircraft type can be completely trained on the simulator for a new type before ever flying the aircraft itself.

In addition to pilot training, flight simulation has an invaluable role to play in other aeronautical areas, such as research, accident investigation, aircraft design and development, operational analysis, and other activities such as space flight. Research areas include new concepts, new systems, flying qualities, and human factors. Most aircraft manufacturers use research simulators as an integral part of aircraft design, development and certification. Major aeronautical projects would now be impractical without the extensive use of flight simulation, on both cost and safety grounds.

A significant amount of the planning task for (particularly) Terminal Airspace Design can be achieved by the other assessment methods shown in this section and flight simulators.

There are several areas in which the use of a flight simulator can assist in the successful completion of Terminal Airspace projects. One example is in the achievement of credibility. In addition to the well known noise and emission effects of operations on and around runways, environmental issues are now influencing the positioning of routes (and their associated altitudes) within the complete Terminal Airspace of a growing number of aerodromes due to strong environmental lobby groups. It has become clear that it can be very difficult to convince these groups that their environmental concerns have been addressed fully by the use of mathematical models and/or fast-time simulations – and this is where flight simulators come into their own.

ACTIVITY 11

Using representative aircraft (simulators), the various options for an airspace can be extensively flown and data recorded, such as airframe configuration (which affects the noise produced by the aircraft), fuel burn, track miles flown, altitude and so on. Depending on the requirements of a project and the sophistication of the data which is gathered, the results can be fed into analysis software for such parameters as aircraft noise and emissions.

Apart from intensive, expensive live flight trials which are difficult to integrate with on-going operations, the use of the flight simulator is the closest thing to reality. The credibility factor is further enhanced if operational line pilots are used to fly the flight simulator. Once the data has been analysed, it can then be presented in the most appropriate way for the target audience.

Use of a flight simulator for airspace projects can range from simple to highly detailed. For example: flight simulators can be used to assess which alternative CDO arrival track option best enables the optimum CCO departure track of the most common type of aircraft at a particular location. In addition, full flight simulators can be used for flight validation activities (Activity 13), given that modern simulators can usually represent the most common type of aircraft used at a particular location/airport.

Noise Modelling

The increasing sensitivity to the environmental impact of transport is a reality to which aviation is no stranger. Increasingly, environmental impact assessments need to be undertaken when changes are to be made to routes within a terminal area. The changed placement of any SID/STAR/IAP or the introduction of any new procedure requires an environmental impact assessment in many countries and very often, the biggest political issue with local councils is aircraft noise.

Noise Modellers use an advanced form of fast-time simulator which is capable of calculating noise contours over a pre-defined area. These 'noise-modelling' functionalities are added to typical functionalities (such as a flight trajectory calculation) included in 'standard' fast-time simulators. An example of such a modeller is IMPACT, a Eurocontrol tool. Aircraft performance tools used by aircraft operators typically include a noise model. These noise models often use the specific flap and speed schedule which provides a realistic noise contour representation. As the AUs are one of the key stakeholders, they should be able to demonstrate the noise profile of the new design as well.

In order to generate the noise contours for each simulated aircraft in addition to the flight trajectories, the noise modeller determines (according to the aircraft model) the estimated speed, engine power setting/thrust and aircraft configuration. Based on this data and taking into account the terrain contours and other environmental conditions (time of the day, meteorological conditions, etc), the simulator calculates the noise distribution and noise level at predetermined check points.

The accuracy of the results very much depends upon the realism of the aircraft models used by the simulator and on the model used for calculating noise distribution. Aircraft trajectories can be directly derived from recorded radar data from real-live operations. Even so, modelling individual aircraft is difficult even when using advanced computational technologies. Movements are allocated to different aircraft 'types' and aircraft that are noise 'significant' (by virtue of their numbers or noise level) are represented individually by aircraft type, e.g. B747-400. Some 'types' are grouped together with those having similar noise characteristics. For each 'type', average profiles of height and speed against track distance are calculated from an analysis of radar data. These average profiles are subdivided into appropriate linear segments.

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Average ground tracks for each route are calculated based on radar data. Accurate noise exposure estimation requires a realistic simulation of the lateral scatter of flight tracks actually observed in practice. This is done by creating additional tracks which are a number of standard deviations either side of the central average track. The standard deviations and the proportions of traffic allocated to each route are determined by analysis of the radar data.

On completion of Validation in Activity 11 there is an important Project Checkpoint comprising KEY DECISIONS. These decisions are usually driven by the project team but require regulatory approval.

PROJECT CHECKPOINT: Decision 1

DECISION 1: After validation, is the Airspace Design Team SATISFIED that the airspace concept is suitable for implementation (e.g. regulatory compliance is achieved) or does the team think the project should be STOPPED and the airspace concept re-developed or, at worst, should the project be ABANDONED?

Agreement of key partners, such as adjacent providers of ATM/ANS, is important due to geographic proximity. All could be well within one state and the ANSP but unexpected external influencing factors can determine the future of the PBN implementation project. When reading the examples below, readers are reminded that the "surprise" may not occur in the target implementation area but in an area out of the project's jurisdiction and control, which affects the main decision nonetheless.

Examples of External Influencing *(which may be deciding)* Factors

During the validation process, it becomes evident whether the proposed PBN implementation is possible, and this is the most likely place to make the decision as to whether or not to go ahead with implementation. This decision is based on certain deciding factors i.e. not the least of which are whether Safety and Performance Criteria and/or regulatory compliance is achieve; whether the ATS route/procedure design meets air traffic and flight operations needs. Examples of less operational factors affecting a '**go**' decision, include.–

a) A change to the ATM system (see below), needed to support the implementation, may prove impossible to realise despite careful identification of this enabler and a go-ahead being given by ATM systems engineers;

b) Change by the lead operator concerning aircraft equipment upgrades causes the collapse of the Business Case or, for example, Navigation assumptions;

c) Dramatic political events which have nothing to do with the Airspace design and which could not have been foreseen when the Traffic Assumptions were chosen, could nullify the entire airspace concept. This could occur, for example, if the entire design concept rested on the (traffic) assumption that 80% of the traffic would enter an Airspace from the west and unforeseen political events change the geographic distribution of traffic completely;

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d) A dramatic public health situation such as experienced in 2020 with the COVID-19 pandemic which saw a 95% drop in air traffic.

An aware and fully integrated PBN Implementation team should not be caught out by surprises described in bullets a) and b), above. The economic misfortunes of airlines are seldom last minute surprises. But unforeseeable events do occur – and it is that possibility that makes it necessary to fix a go/no-go date for implementation.

PROJECT CHECKPOINT: Decisions 2 & 3

Once the first Decision Point has concluded that the project is a 'Go', other decisions must be confirmed. The 'conditions' attached for the go ahead must be clear:

Decision 2: Is it necessary to mandate PBN in the airspace or along all routes *in order for the Airspace Concept* to be achievable? The PBN IR's three stepped approach has effectively introduced a mixed environment in the airspace until 2030. Providers of ATM/ANS may consider this mix-and-match unacceptable and publish only RNAV 1 STARs and SIDs in the airspace. Thus to comply with the SERA regulation this effectively forces the aircraft to be appropriately equipped.

Decision 3: If a mixed mode has been 'validated' as achievable and workable in the airspace, will all the necessary 'enablers' required for this kind of operation be available by the implementation date?

*In **Europe's regulated PBN environment**, the PBN IR (AUR PBN 2005) has effectively mandated the use of particular navigation specifications along ATS Routes, SIDs/STARs and on instrument approach procedures. The 'mandate' is three stepped with different requirements at each milestone. The intention is that by 2030, an exclusive PBN environment will be the norm.*

The answer to these key questions affect implementation dates identified during the planning phase (Activity 3), and all stakeholders planned to operate in the airspace. This is why the decisions are taken by the Airspace Design Team together with management and it is extremely helpful to obtain regulatory input because if Mandates are required they will need regulatory endorsement.

The decision to mandate by one provider of ATM/ANS in a particular airspace will impact on adjacent providers of ATM/ANS where traffic is shared between neighbours. A mandate decision could have a very positive effect on neighbours in that they too may consider it appropriate to also have a mandate because this streamlines the airspace and enhances connectivity.

Activity 12

Finalisation of Procedure Design

Only once the ATM validation is complete *and* the Project Checkpoint Decisions give a clear GO AHEAD for the project, does the Instrument Flight Procedures specialist set about finalising the design of the IAPs and SIDs/STARs using the criteria laid out in ICAO Doc 8168 – Aircraft Operations. Being an integral member of the airspace design team from the outset, the IFP designer is familiar with the procedures to be designed, the aircraft that will fly them and the Airspace Concept into which they will fit. This activity occurs iteratively with Activities 13 a & b.

For PBN, procedure designers need to ensure that the procedures are compliant with PANS-OPS procedure design criteria in accordance with the requirements of the specific Nav Spec and that they can be coded in ARINC 424 format. Currently, this is one of the major challenges facing procedure designers. Some are not familiar with either the path terminators used to code RNAV or RNP systems or the functional capabilities of different RNAV or RNP systems. Many of the difficulties can be overcome, however, if close cooperation exists between procedure designers, Flight Validation Pilots (FVPs) and the data houses that compile and code data for the navigation database.

Once these procedures have been flight validated (Activity 13a) and the infrastructure flight inspected (Activity 13b) they are then approved by the national regulatory authority prior to publication in the State's AIP along with any changes to routes, holding areas, or airspace volumes.

When adjacent airspace changes are to switchover at the same time or within the sequential AIRAC cycle dates, it is very useful for the procedure designers of both providers of ATM/ANS to work together. It is a way of ensuring a similarity of styles and thus avoiding the possibility of ambiguity.

Another KEY PARTNER at this stage is the data house who will publish the procedures for operators or airspace users. Scheduling the preparation of procedures for coding and subsequent packing of the database may be needed due to capacity limitations of the data houses (referred to in European regulatory terms as a DAT provider).

Activity 13a

Instrument Flight Procedure Validation

This activity occurs iteratively with Activity 12 and is reliant Activity 13b where there is a requirement for ground-based NAVAID infrastructure (which might be for reversion only).

The purpose of flight procedure validation is to obtain a qualitative assessment of procedure design including obstacle, terrain and navigation data, as well as an assessment of charting and human factor considerations, including flight crew workload and flyability of the procedure.

The validation is one of the final quality assurance steps in the procedure design process for instrument flight procedures (IFP) and is essential before the procedure is published.

The **full flight procedure validation process** includes **Ground validation *and* Flight validation.**

- **Ground validation** must always be undertaken. It encompasses a systematic review of the steps and calculations involved in the procedure design as well as the impact on flight operations by the procedure. It must be performed by a person(s) trained in Flight Procedure Design and with appropriate knowledge of Flight Validation issues. Ground validation consists of an independent IFP design review.

- **Flight validation** consists of a flight operational analysis followed by a flight simulator evaluation or an evaluation flown in an aircraft (though both evaluations are not always necessary); flight operational analysis and flight validation should preferably be undertaken by the same entity. The validation process of IFP(s) must be carried out as part of the initial IFP design as well as an amendment to an existing IFP. (One of the particular challenges at this point is making a pre-production database available for flight simulation and/or the flight validation aircraft).

For detailed guidance on validation see ICAO Doc. 9906 "Quality Assurance Manual for Flight Procedure Design" Vol. 5 "Validation of Instrument Flight Procedures".

Activity 13b

Flight Inspection of the Infrastructure

This Activity supports and has iterations with Activity 12; in the European regulatory context, the PBN elements of this activity will increasingly focus upon GNSS performance and ground NAVAIDs for the provision of contingency procedures/reversion infrastructure.

Flight inspection is a totally different activity to flight procedure validation. It involves the use of specific test aircraft, which are specially equipped to measure compliance of the Navaid signals-in-space with the ICAO standards. Due to the flexibility of PBN to create routes or procedures in areas where a particular ground facility has normally not been flight inspected, it may be necessary to perform dedicated flights. Of primary interest is the actual coverage of the NAVAID infrastructure required to support the flight procedures designed by the flight procedure designer. Depending on the avionics capabilities of the test aircraft, flight inspection and flight procedure validation activities may be combined. The need for flight inspection is first identified during Activity 6 and following Activity 8. This may be subsequently revised following the infrastructure assessment conducted as part of Activity 12, when the procedure design is finalised.

The Manual on Testing of Radio NAVAIDs (ICAO Doc. 8071) provides general guidance on the extent of testing and inspection normally carried out to ensure that radio navigation systems meet the SARPs in Annex 10 – Aeronautical Telecommunications, Volume I. To what extent a Flight Inspection needs to be carried out is normally determined in the validation process.

PHASE 4. IMPLEMENTATION

The PROJECT CHECKPOINT after Activity 11 is a key marker in the project lifecycle because it indicates whether the proposed Airspace Concept can be implemented. This 4th Phase of the Project Lifecycle is now the commit stage. This involves a final confirmation that all the project objectives and performance targets can be achieved and that no 'show stoppers' have emerged. A successful review will lead to implementation: A commitment to put the new Airspace concept into place and the appropriate preparation for that operation to be completed.

The project team needs to plan for implementation, not only as regards their 'own' airspace and ANSP, but in co-operation with any affected parties which may include providers of ATM/ANS in an adjacent State.

Pre-Implementation Review

Despite the go-ahead for Implementation effectively given after Activity 11, it is logical and good practice to do a double check that the go ahead is still valid when committing to the Implementation. This 'final' check is good practice because sometimes there can be a long time between the end of Activity 11 and the start of Implementation. As such, it is strongly advised to revisit the Decisions taken at the PROJECT CHECKPOINT after Activity 11, and to be certain that the go-ahead is still valid. Additional Criteria which could adversely affect the go-ahead of the project include:

- Collapse of the main assumptions;
- Critical Enablers become void;
- Emergence of a project-critical constraint;
- Operations in the airspace of an adjacent provider of ATM/ANS operation change so radically as to negate the airspace concept.

Although it can be discouraging to be confronted with a 'no-go' decision at so late a date, it is essential that attempts should not be made to 'produce' a 'quick-fix' or 'work-around' so that implementation takes place at any cost. However difficult it might be not to proceed with implementation, a 'no-go' decision should be respected.

The route to be followed after a 'no-go' decision depends upon the reason for that decision. In extreme cases, it may be necessary to scrap an entire project and return to the planning stage. In others, it might be appropriate to return to the selection of Assumptions, Constraints and Enablers. It is also possible, that new Validation exercises will have to be developed, or a new Safety Assessment completed. Whatever the route, the work needs to be re-organised and re-planned.

If, on the other hand, **all the implementation criteria are satisfied** the Airspace design team needs to **plan for implementation** – not only as regards their 'own' airspace and provider of ATM/ANS but in co-operation with any affected parties which may, as stated, include providers of ATM/ANS in an adjacent State. Amongst items to be covered are ATC system integration and Awareness and Training material.

Activity 14

ATC System & Integration Considerations

The new Airspace Concept may require changes to the ATC system interfaces and displays to ensure controllers have the necessary information on aircraft capabilities. Such changes could include, for example:

a) Modifying the air traffic automation's Flight Data Processor (FDP);

b) Making changes, if necessary, to the Radar Data Processor (RDP);

c) Changes to the ATC situation display;

d) Changes to ATC support tools;

e) There may be a requirement for changes to providers of ATM/ANS methods for issuing NOTAMS.

Activity 15

Training and Awareness

Training consists of ensuring that the new operations can be activated with the ATCOs, pilots and all associated experts having the required level of knowledge and competence to ensure safe operations in the new environment. In some instances, ATCO training may be needed using real-time training simulators; this would require careful rostering and planning alongside ordinary controller duties.

Training should be timely and not rushed; it is an excellent vehicle for gaining acceptance of airspace users and controllers. A useful technique is to use members of the PBN Implementation team (in their specialist disciplines) as training champions. A comprehensive set of PBN materials are located at the PBN Portal (https://pbnportal.eu) and in Eurocontrol's TRAINING ZONE.

Training and the provision of awareness material is crucial when PBN is new in the environment, especially because considerable investment has been made. The need for training, explanatory material and guidance must not be underestimated as regards flight crew, controllers, AIS staff, engineering etc. In many States, training packages and computer based training have been effectively used for some aspects of education and training.

At a higher level, ICAO provides additional training material and seminars. Each Navigation Specification in the PBN Manual Volume II, Parts B and C addresses the education and training appropriate for flight crew and controllers.

Activity 16

Implementation

With proper planning and organisation, the culmination of an Airspace design project is, hopefully, a trouble-free Implementation. Nevertheless, the Airspace design team should:

[i] Ensure that there is adequate representation from among the members of the team available in the operations hall well before the implementation date, during implementation and for at least one week following implementation. This would make it possible for the airspace design team to -

- Monitor the implementation process;
- Support the Centre Supervisor/Approach Chief or Operational Manager should it become necessary to use redundancy or contingency procedures;
- Provide support and information to operational controllers and pilots.

[ii] Enable a log-keeping system for a period similar to that in [i] above, so that implementation-related difficulties may be noted and used in future project planning;

Activity 17

Post Implementation Review

After the implementation of the airspace change which has introduced PBN, the system needs to be monitored to ensure that safety is maintained and determine whether the strategic objectives are achieved. If after implementation, unforeseen events do occur, the project team should put mitigation measures in place as soon as possible. In exceptional circumstances, this could require the withdrawal of RNAV or RNP operations while specific problems are addressed.

A System Safety Assessment should be conducted after implementation and evidence collected to ensure that the safety of the system is assured – see ICAO Safety Management Manual, ICAO Doc 9859.

In addition, the flight and ATM efficiency should be reviewed to ensure that the objective targets have been met.

3. LESSONS LEARNED

As with any new concept, the introduction of PBN was not trouble free. It required a change of thinking and a change of approach, some of which was felt to be too new, too complicated and too convoluted – but, which over the last 12+ years, has made clear improvements in re-framing and clarifying the use of RNAV and RNP. Unsurprisingly, there have been many lessons learnt, both on the aircraft side and on the ATM side, and providers of ATM/ANS and Regulators have had their share of lessons as has industry. This list of lessons learned is not exhaustive. It is focussed mainly on aspects relevant to providers of ATM/ANS.

- High **certification costs** have increasingly become a pretext for operators seeking to operate on procedures without their aircraft being certified for the appropriate navigation specification. Providers of ATM/ANS have sometimes become complicit in that they design procedures which they know to require a particular navigation specification to operate on the procedure, but they do not make the navigation specification a requirement. This should be guarded against as safety could be compromised and legal liability ensue.

- **Delayed availability of certification material** can result in providers of ATM/ANS authorising the use of certain RNP specific functions with RNAV specifications which the PBN Manual prohibits. An example is the use of RF with RNAV 1 which had several implementations due to the absence of appropriate RF certification material. This problem has been overcome: Certification material exists in the form of EASA's CS-ACNS.

- There is **neither longitudinal nor vertical RNP** as RNP is almost exclusively lateral with a small element of longitudinal precision where an RNP certified aircraft is required to be within 1 NM longitudinally of a WPT when operating on an RNP 1 route. The emphasis on lateral RNP is frustrating to some providers of ATM/ANS who increasingly want to utilise longitudinal precision for sequencing and merging. Furthermore, confidence in vertical performance along a path (outside the FAS) will provide a higher level of confidence when strategic separation is designed at aircraft crossing points.

- The **original strategy for PBN was to migrate from RNAV to RNP and then to 4D**. Unfortunately, the major financial crisis of 2008 and the COVID-19 pandemic have slowed progress and may delay the progress of PBN's evolution.

- **PBN Education and Training**: A PBN Workshop held with operational staff revealed that when a generic PBN course provides too much depth, it can contaminate one part of the PBN community with information (and complex vocabulary) that it is unlikely to encounter or need.

- **Radar vectoring** has been the bread and butter of controllers for many decades. There is a marked reluctance amongst controllers to hand over navigation of the aircraft to the flight management system and thereby reduce controller workload. This reluctance is due to the fact that controllers retain responsibility for separation and spacing. In addition, controllers are anxious not to become deskilled. Nevertheless, the preference for radar vectoring risks being a tangible limitation to the efficiency that PBN can deliver.

- PBN's evolution relies controller involvement in the development of (technical and operational) requirements for flight management systems (FMS). Unfortunately, **ATM experts seldom become involved in 'technical or research work'** which is why most technology is sealed and unchangeable by the time controllers get to complain about it!

- **Complex regulatory language** and cross-referencing makes it very difficult for operational staff to wade their way through the morass of PBN related regulation. There is considerable difficulty also in understanding the relationship between EASA and ICAO material.

- **En Route and Terminal PBN connectivity must be assured:** This was a critical lesson learned from the B-RNAV implementation in Europe. A switch to RNAV or RNP in the en route airspace must be accompanied by a switch to RNAV or RNP in the terminal airspace otherwise the en route PBN aircraft are left with conventional procedures following PBN use. This is also highly inefficient as regards route placements which would require that all en route ATS routes terminate either at a VOR or at a VOR/DME fix. Furthermore, if there is a (residual) NDB network intended for use, the airspace design team should confirm that it can be used as an increasing number of aircraft being produced do not have an ADF.

- **Turn Anticipation and Performance:** A generation of controllers has been surprised that with the implementation of RNAV in en route airspace, all aircraft did not turn in exactly the same way. In fact, a spread of turn performance became more visible to the controllers; in some cases with alarming consequences. Airspace planners had also overlooked the need to widen the route spacing on the turn when designing the en route ATS route network. This had to be, and was, corrected. (See Route Spacing Handbook for spacing between aircraft on parallel routes on the turn).

- In an unregulated environment, if there is **no mandate**, there is **no incentive** for aircraft to equip. This was the case with P-RNAV in 2000 which will only be fully mandated EU wide as RNAV 1 in 2030! As such, mixed mode will be the order of the day, and this is known to render operations more complex and cause unnecessary workload.

- **Database storage:** One of the offshoots of PBN implementation has been the excessive publication of SIDs/STARs by some providers of ATM/ANS. This has highlighted an issue related to the lack of data storage space in some FMS databases (one airport had some 118 SIDs/STARs which left little space for much else). It is highly recommended as new procedures are put in place older, less efficient ones are withdrawn.

- **AIRAC Cycle Dates:** Publication must become effective on an AIRAC cycle date and not at any other chosen date. In addition, do not 'pull' (withdraw at short notice) an implementation close to the publication date as the aircraft databases will already be updated with the new procedures in preparation for the AIRAC turn over date.

- **PBN ATC Simulations:** In real- and fast-time simulations, aircraft navigation accuracy is shown as being excellent and turns are exactly the same and always executed at the same point because the tracks are computer generated. To make ATC simulation realistic, particularly those for route spacing, it is necessary to script in navigation errors including shallow and sharp deviations from track. Such errors would need to reflect the current error rate e.g. two errors in ten hours. Variation of turn performance can also be scripted into a simulation where neither RF nor FRT are included as part of the navigation specification performance requirements. If the simulation is looking to introduce consistent, highly repeatable turn performance (delivered by RF and FRT) then it is imperative to script turn performance variation in current operations so controllers observe the change in turn performance in the future concept.

ATTACHMENTS

ATTACHMENT 1:

SAMPLE PROJECT PLANNING ESTIMATION

Sample Project Planning with sample timings
Activities 1 to 17 *with critical milestones.*

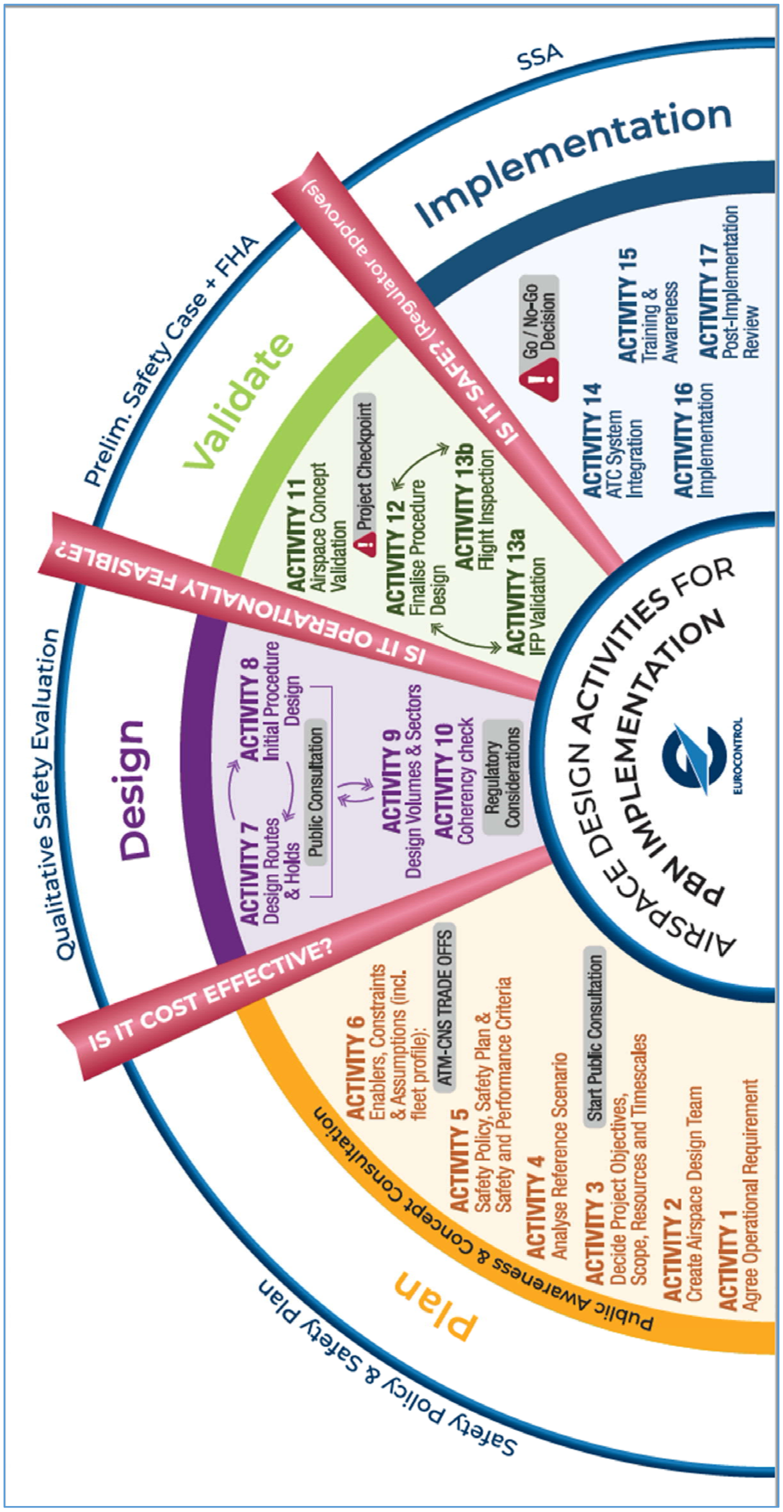
ACT	*(to be read from bottom-up)*	No of Days	Key Dates dd/mm/yy (Actual)	
17	Post Implementation Review (e.g. 6 months after project implementation)		**5-08-2014**	
16	Implementation of Airspace Change (Match AIRAC Cycle date)		**6-02-2014**	**<<Enter INTENDED Implementation Date here (Must match AIRAC Cycle Date)**
	Additional working day buffer to allow for unforeseen delays (±10% of total)	56	**12-12-2013**	
14-15	ATC System Integration - Write up LoAs - Awareness and Training	56	**6-12-2013**	
	GO : No-Go Decision	10	**26-11-2013**	Notes
12+13 a+13b	Procedure Design, Ground & Flight and Validation & Flight Inspection + 56 day AIRAC cycle - ATC Training † & ‡	90	**13-09-2013**	*† Assumes availability of FTS and/or RTS simulator slots, and required specialists & ATCos/pseudo pilots available*
11	Airspace Concept Validation by Real-Time Simulation † (Preparation and Runs)	100	**5-06-2013**	*‡ Separate no. of days not calculated for ATC Training: Above shows that this would occur at the same time as PANS-OPS procedure design or during 2 final AIRAC cycles (56 days)*
11	Airspace Concept Validation by Fast-Time Simulation † (Preparation and Runs)	70	**27-03-2013**	
10	Confirmation of ICAO Navigation Specification	2	**25-03-2013**	
6-9	Finalise Airspace Design & CBA - iteration	5	**20-03-2013**	
9	Airspace Design: Volumes and Sectors	5	**15-03-2013**	
7	*2nd Iteration:* Airspace Design - Routes and Holds	5	**10-03-2013**	
	Public Consultation with Airspace Users and other stakeholders & Comment Review	90	**10-12-2012**	
	Environmental Impact Assessment	50	**21-10-2012**	
8	Initial Procedure Design	50	**19-01-2013**	
7	*1st Iteration:* Airspace Design - Routes and Holds	10	**9-01-2013**	
6	*Cost Benefit Analysis - fleet, infrastructure etc*	25	**15-12-2012**	
6	Data collection and agreement on CNS/ATM assumptions incl. Fleet capability; traffic sample etc.	5	**4-01-2013**	
5	Select Safety Criteria; Determine Performance Criteria and understand Safety Policy Considerations	10	**25-12-2012**	
4	Analyse Reference Scenario (incl. Data collection of full ATM operations and critical review of current opertions)	20	**5-12-2012**	
1-3	Agree Operational Requirement; Project Planning; Create Airspace Design Team; Agree Project Objectives and Scope	10	**25-11-2012**	**<<This is the latest project start date**
	*Total number of **working** days required for the PBN Implementation Project*	**669**		
Pre-Start	Public Awareness and Concept Consultation with preliminary Environmental Impact Assessment and Benefits Case	180	**29-05-2012**	This start date for formal consultation would be decided outside the project, but would influence the project start date in green, above.
	Total number of working days needed including public consultation	849	*includes the number of days needed for public consultation, if appropriate*	

AIRAC effective dates 2020-2030

AIRAC cycle id	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
01	02 Jan	28 Jan	27 Jan	26 Jan	25 Jan	23 Jan	22 Jan	21 Jan	20 Jan	18 Jan	17 Jan
02	30 Jan	25 Feb	24 Feb	23 Feb	22 Feb	20 Feb	19 Feb	18 Feb	17 Feb	15 Feb	14 Feb
03	27 Feb	25 Mar	24 Mar	23 Mar	21 Mar	20 Mar	19 Mar	18 Mar	16 Mar	15 Mar	14 Mar
04	26 Mar	22 Apr	21 Apr	20 Apr	18 Apr	17 Apr	16 Apr	15 Apr	13 Apr	12 Apr	11 Apr
05	23 Apr	20 May	19 May	18 May	16 May	15 May	14 May	13 May	11 May	10 May	09 May
06	21 May	17 Jun	16 Jun	15 Jun	13 Jun	12 Jun	11 Jun	10 Jun	08 Jun	07 Jun	06 Jun
07	18 Jun	15 Jul	14 Jul	13 Jul	11 Jul	10 Jul	09 Jul	08 Jul	06 Jul	05 Jul	04 Jul
08	16 Jul	12 Aug	11 Aug	10 Aug	08 Aug	07 Aug	06 Aug	05 Aug	03 Aug	02 Aug	01 Aug
09	13 Aug	09 Sep	08 Sep	07 Sep	05 Sep	04 Sep	03 Sep	02 Sep	31 Aug	30 Aug	29 Aug
10	10 Sep	07 Oct	06 Oct	05 Oct	03 Oct	02 Oct	01 Oct	30 Sep	28 Sep	27 Sep	26 Sep
11	08 Oct	04 Nov	03 Nov	02 Nov	31 Oct	30 Oct	29 Oct	28 Oct	26 Oct	25 Oct	24 Oct
12	05 Nov	02 Dec	01 Dec	30 Nov	28 Nov	27 Nov	26 Nov	25 Nov	23 Nov	22 Nov	21 Nov
13	03 Dec	30 Dec	29 Dec	28 Dec	26 Dec	25 Dec	24 Dec	23 Dec	21 Dec	20 Dec	19 Dec
14	31 Dec										

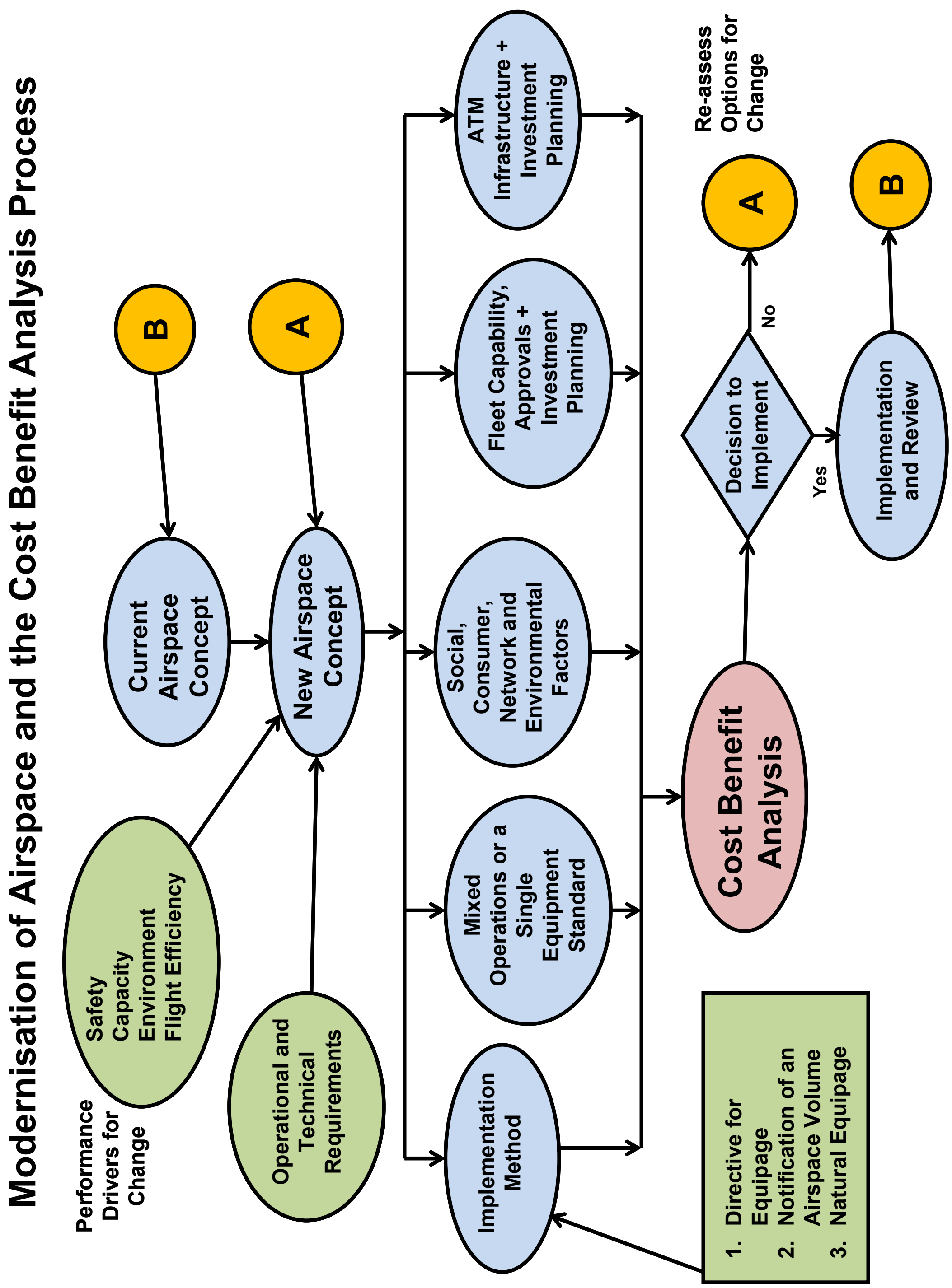
A web-based interactive version of this planning tool is available in the Tools section of the PBN Portal (https://pbnportal.eu).

ATTACHMENT 2:
AIRSPACE ACTIVITIES FOR PBN



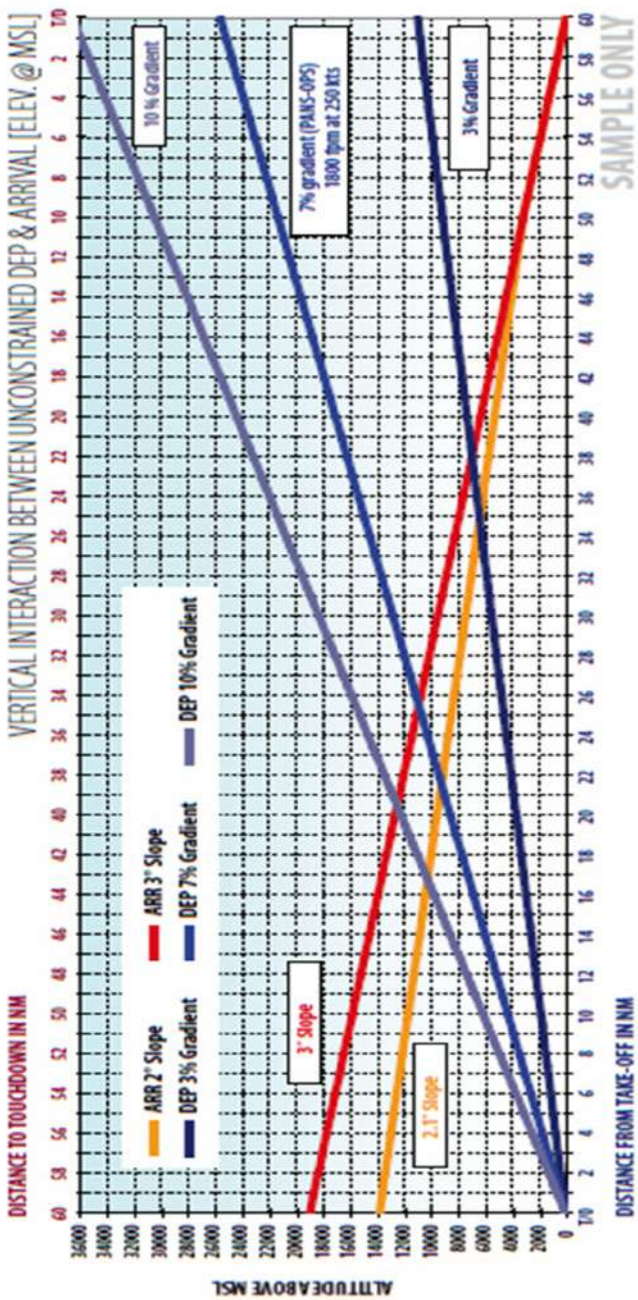
ATTACHMENT 2a:

AN EXAMPLE OF AIRSPACE CHANGE PROCESS



ATTACHMENT 3:

SAMPLE CLIMB AND DESCENT PROFILES



— This sample graph is intended as a simplistic illustration of the vertical interaction between arrivals and departures. The **top** horizontal axis at shows nautical miles reducing from left to right as the aircraft descends and gets closer in track miles to the runway, the **lower** horizontal axis shows nautical miles increasing from left to right as the aircraft increases its track miles after departure from the runway. The purpose of such a graph is to determine whether the selected crossing point between SIDs and STARs is appropriate or whether the point selected is one where both aircraft on their 'natural' profiles would seek to be at the same level, thereby needing to level them off which is not flight efficient.

— When undertaking an airspace design particularly in the terminal area, it is important for the design team to create their own graphs which can be based on input from flight crews, or, better still, on radar data showing actual vertical performance.

— The correct selection of the crossing point greatly alleviates flight inefficiency that PBN so capably delivers.

— A web-based, interactive version of this graph is available in the 'Tools' section of the PBN Portal (https://pbnportal.eu).

ATTACHMENT 4:
PBN IN EN ROUTE AIRSPACE CONCEPTS

INTRODUCTION

European Airspace Concepts are varied and some are complex. At the highest level, they can broadly be split into those whose airspace 'architecture' is based on a fixed ATS Route network, and others which are predicated on routes or flight paths that are not reliant on a fixed ATS route network. But this simplistic dividing line is inaccurate because ATS Routes and alternative flight paths can co-exist in an airspace made up either predominantly of ATS Routes or within airspace primarily using other flight path options (see below). Trying to 'group' the various kinds of flight path options in other ways e.g. which are ICAO and which are not, or which are published, and which are not, can be unhelpful as regional airspace concept evolutions have created scenarios which defy categorisation.

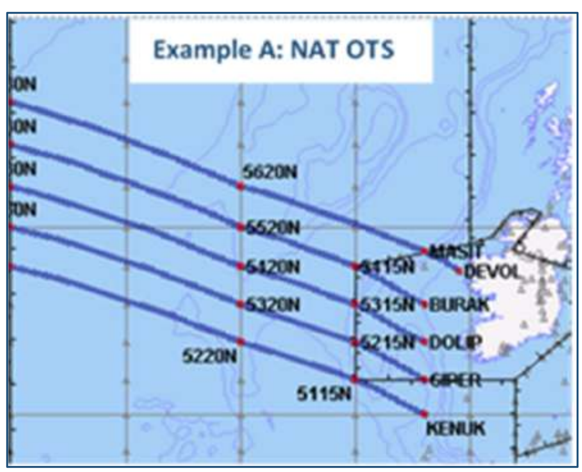
This attachment aims to enable the target audience, the European airspace planner, to understand the interplay between PBN's performance and flight path options. The Attachment takes a 'generic' high level view of the different flight path options and then narrows in to focus on European en route operations, and makes the connection to PBN for those airspace planners.

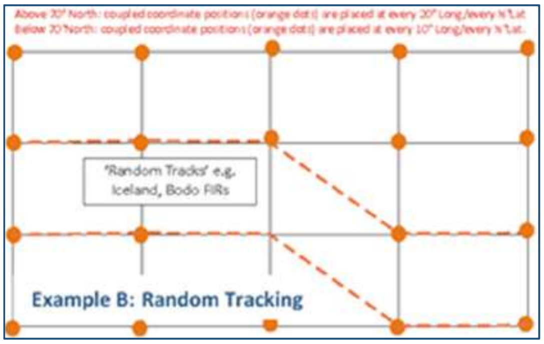
FLIGHT PATH OPTIONS SUPPORTING THE AIRSPACE CONCEPT

ICAO's PANS-ATM describes ATS Routes as including airways, advisory routes, controlled and uncontrolled routes as well as arrival and departure routes (which if designated, are referred to as SIDs and STARs). ICAO Annex 11 sets requirements for the designation of ATS Routes. Appendix 1 to Annex 11 provides the convention for designating 'en route' ATS routes whilst Appendix 3 of the Annex covers the designation of SIDs/STARs and PANS-OPS, Doc 8168 Vol II and ICAO Circular 353 explain the designation of instrument approach procedures and PBN IAPs respectively.

In reality, however, aircraft operating in many of the world's airspace often do not follow an ATS Route. There are multiple airspace concepts using alternative PBN flight path options which are not based on ATS Routes.

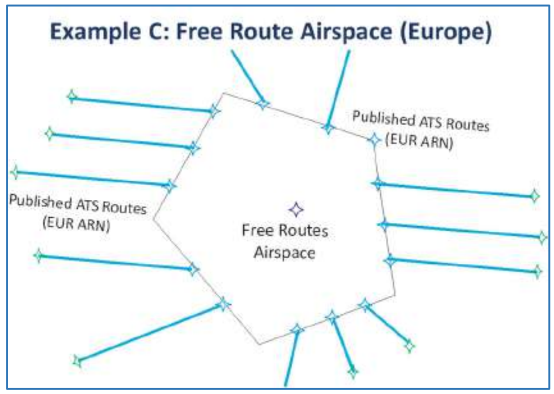
Example A, shows the **North Atlantic organised track system (NAT OTS)**. The NAT OTS has a system of (*movable*) PBN *Routes published as a set,* and when seeking to cross the North Atlantic, one of these Routes must be selected. But the routes forming part of the NAT OTS are **not 'ATS Routes'**, in the strict sense of the term, because even though the Routes *are* published, they are not designated as per ICAO Annex 11, Appendix 1. The absence of this standard designation is because the OTS Routes are not fixed *absolutely* (or geographically) but rather *relatively,* i.e. in relation to the other routes forming part of the 'set' of the NAT OTS. This entire 'set of tracks' moves North or South on a given day to obtain the greatest benefit of upper winds.



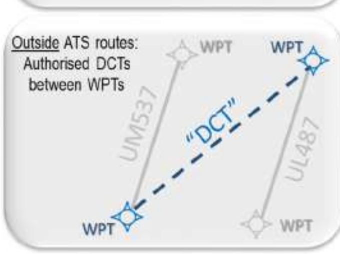
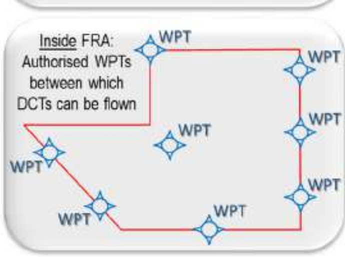


Example B, shows an example of ***Oceanic/Remote Continental routeing*** requiring PBN, used at high latitudes (in this case, off the coast of Northern Norway).

Example C, shows Free Route Airspace (FRA) in Europe. The European Route Network Improvement Plan (ERNIP) - Part 1 European Airspace Design Methodology - Guidelines (First Edition June 2012) explains the European 'Free Routes' Airspace Concept as follows: *"A specified airspace within which users may freely plan a route between a defined entry point and a defined exit point, with the possibility to route via intermediate (published or unpublished) waypoints, without reference to the ATS Route network, subject to airspace availability. Within this airspace, flights remain subject to air traffic control."* Airspace regulated by the European Commission's CP 1 IR ((EU) 2021/116) is required to operate as Free Route Airspace in a two-stepped approach with December 2022 and December 2025 milestones. Importantly, the FRA is designated, and users select their flight path between any of the WPT's published as entry/exit points to the FRA.



The airspace concepts in the above Examples A, B and C either connect to another similar concept (e.g. Example A connects to Example B) or more typically, aircraft operating in one of these airspace concepts will then join a fixed ATS route network which could be comprised of en route ATS Routes, SIDs/STARs or even directly to an instrument approach procedure. (Examples of ways in which connectivity is achieved with terminal airspace are shown in the Terminal discussion with Free Routes Airspace, below).

	USE & DESIGNATION	PUBLICATION
	EUR ARN or, exceptionally also in FRA. Route designation as per Annex 11, Appendix 1	**ATS Routes** published in States' AIP *(as per Doc 10066, PANS-AIM).*
	Between EUR ARN, direct (shortcut) flight paths permitted using WPTs that anchor PBN ATS Routes. These direct paths are designated as a DCT.	**WPTs** published in AIP for ATS Routes *(as per Doc 10066, PANS-AIM).* Authorised ***DCTs*** between WPTs *that do not form part of an ATS route* are *published in the Eurocontrol RAD Appendix 4 (on behalf of the Network Manager).*
	Designated FRA devoid of routes. No routes/tracks designated between published WPTs, except ATS Routes which may exceptionally be embedded.	**WPTs** usable for direct routeing within the FRA are published in State AIP *(as per ERNIP Part 1).* No 'routes/tracks' are published as routing at the discretion of airspace user.

Global as well as European en route operations are not limited to the use of ATS routes. Indeed, three kinds of flight paths characterise the airspace, and two of these originate in ICAO, whilst the third has its origins in the Eurocontrol concept of operations for free route airspace (FRA).

The absence of an ICAO definition for Free Route Airspace (or indeed a 'free route') can lead to the mistaken belief that operation on any track that is not a published fixed ATS route equates to free route operations. This is not the case, and three points can be clarified regarding the above Examples and Free Routes.

1. Although the expression 'free route' [or its alternatives such as random route/routeing, or free routeing, or user defined route] is not defined in ICAO, these terms sometimes appear in ICAO and other documents. Despite the absence of a definition, operators continue to define their own flight paths particularly in oceanic and remote continental airspace as they have done for decades based on area navigation techniques. Nowadays, as the use of area navigation techniques must match a PBN application, these operations are included in PBN operations and require a navigation specification to be prescribed for the airspace.

2. Typically, where no ATS Routes or NAT OTS exist (Example A), or restrictions on path choice (Example B), the flight crew use the FMS to define a flight path using the area navigation computer/techniques. For the same reason as above, PBN is a pre-requisite. The flight crew decides how to get from A to B, with cost typically being the over-riding factor. [The 'freedom' or 'randomness' of the flight path chosen explains the invention of these non-ICAO expressions].

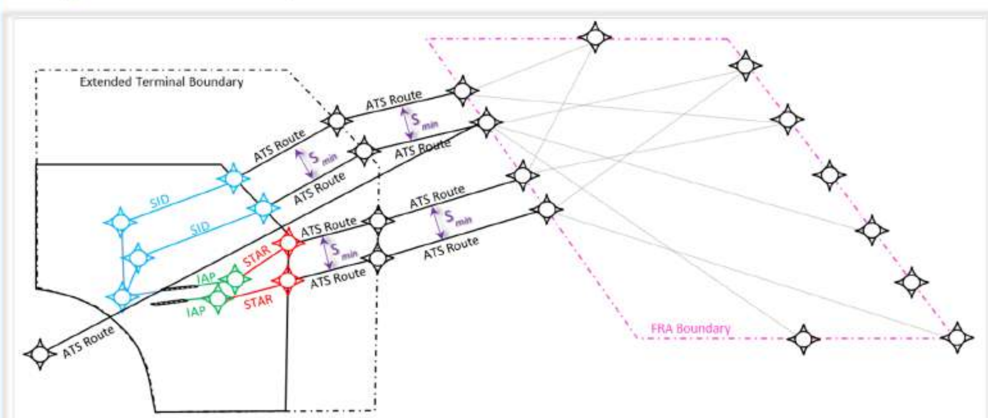
3. If there are no published ATS Routes, and the environment requires the flight crew to create/define its own flight path, this does not mean that the resultant path is a free route or that the airspace is Free Route Airspace. The European FRA concept of operations is described at Example C and delimited.

Examples of how routes used for terminal operations can be connected to FRA

Example 1:

Full structuring of ATS Routes in congested areas to/from major TMAs with their SIDs/STARs/ATS Routes. Above and beyond can be FRA for which only waypoints (not tracks) are published.

Note – SIDs/STARs would be RNAV 1 as a minimum and ATS routes would be RNAV 5 to ensure strategic de-confliction in compliance with PBN IR.



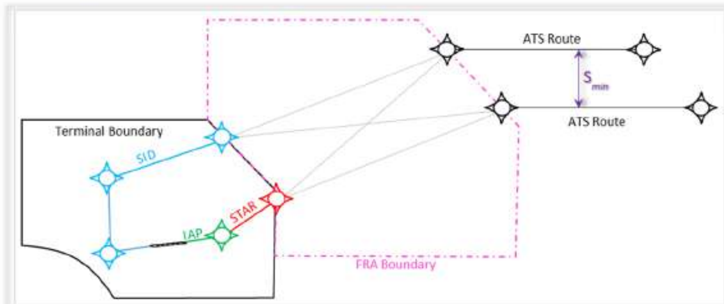
Note: Waypoint naming. 5 letter name codes (5LNC) or Alphanumeric codes may be used on SID/STAR and IAPs although the final waypoint on the SID and first waypoint of a STAR are to be a pronounceable 5LNCs. En route ATS routes are to use pronounceable 5LNCs. If any waypoint is associated with a ground-based NAVAID, then the three letter identification code of the NAVAID is to be used.

Care has to be taken in the airspace design to ensure that all free routes do not join at the same entry waypoint on the STAR or on the fixed ATS routes. A system of entry gates could be used with parallel entry WPTs to alleviate the threat of congestion at a single point.

Example 2:

After last point on SID the aircraft enters FRA and the flight crew have the option to select desired routeing which is subject to ATC acceptance. Conflict resolution is done tactically by the ATCO. On leaving the FRA, the aircraft rejoins an ATS Route network.

Note – SIDs/STARs would be RNAV 1 as a minimum and ATS routes would be RNAV 5 to ensure strategic de-confliction in compliance with PBN IR.



ATS Routes vs. other flight paths (excluding the NAT OTS)

Area navigation ATS Routes tend to be designed where there is a need to systemise a network of routes and to strategically deconflict the traffic flows. This is enabled because it is possible, in the on-board area navigation computer, to associate a required lateral navigation performance with an ATS route that has been designated and published as per ICAO Annex 11, Appendix 1 [Lateral navigation performance pertaining to SIDs/STARs and IAPs, is detailed in Attachment 5]. This possibility of ascribing performance stems from the fact that the process of designing (using PANS-OPS Criteria) and publishing (using Annex 15 standards and Doc 10066 processes) means that 'matching' ARINC 424 coding norms can be used to load these ATS routes in the on-board navigation database as either an 'airway' or 'airport' record. Once a data record exists, particular navigation performance and functionality attributes are associated with each leg of these 'airway records' such as the navigation accuracy required along a flight segment e.g. RNP 1, or a particular way of executing a turn at a waypoint along the route (e.g. using a Fly By, Fly Over or Fixed Radius Transition – see Attachment 5).

Although the NAT OTS is not comprised of ATS Routes, it is a highly systemised network of tracks which though not designated as per Annex 11, are spaced at set distances and rely on prescribed PBN performance (RNP 4) with a comprehensive set of procedures to meet the target level of safety (TLS). Enabling requirements include manual entry of waypoints, separated by ½ degree of longitude as well as comprehensive procedures for flight crew mean that the systemised deconfliction of tracks is possible.

Other flight paths, such as the direct tracks in the European context, enable an airspace concept which does *not* seek to ensure systemisation of tracks or their strategic deconfliction. The procedural burden for flight crews is not comparable to the NAT, and the onus is on the ATC to tactically deconflict any aircraft where conflict resolution is required. In these contexts, the extent to which navigation performance attributes can be ascribed to a DCT 'track' or other alternative flight path options is unclear. Current indications are that 'default' navigation performance against a defined path that is not an ATS Route is not standardised. In such a context, such as the European Free Route Airspace, the prescribed PBN specification is RNAV 5, which provides a mesh of navigation performance permitting the operations in the airspace. However, the ultimate responsibility for separation of aircraft remains with the controller.

ATTACHMENT 5:

ON-BOARD NAVIGATION SYSTEMS: PERFORMANCE & FUNCTIONS ON SIDS/STARS & IAPS

The PBN Concept relies on the use of area navigation techniques and defines the Navigation Specification (performance requirements for aircraft's RNAV/RNP Systems and the air crew), the Navigation Infrastructure, and the Navigation Application (SIDs/STARs, IAPs, ATS Routes, FRA etc). The overall objective is the efficient contribution of the navigation application to the strategic objectives of the airspace concept.

At its most basic level, PBN provides a level of assurance of aircraft performance to adhere to a path in space, in different dimensions for a vast majority of the time. This is why, each of the ICAO Navigation Specifications contain performance and navigation functional requirements for the RNAV or RNP system to support the intended operation.

But what is 'performance' in the context of PBN? And how is it achieved? Which functions enable it?

Whilst an Area Navigation 'tutorial' is provided in Attachment A of the *EUROCONTROL Route Spacing Handbook, No 3,* this Attachment contextualises performance and functionality for airspace planners who will be required to develop airspace concepts using PBN. To this end, easy-to-understand answers to the above questions are provided so that the airspace designers acquire sufficient understanding of the PBN 'tools' that exist, and what they can (and cannot) do with it.

This Attachment addresses navigation performance generically and some key lateral navigation functions enabling this performance.

1. Navigation Performance

PBN reflects two different approaches to implementation. One, embodied in RNAV specifications, is based upon generic performance derived from the navigation infrastructure that aids airspace improvement. The other, reflected in RNP specifications, is based upon a level of navigation performance that must be achieved by the aircraft to address airspace and operational needs.

- For RNAV systems and operations, PBN uses the generic performance solution i.e. the level of lateral navigation accuracy is derived from the available Navigation Infrastructure that is associated within an airspace. The aircraft RNAV system simply performs its point-to-point area navigation by estimating the aircraft's position and comparing that to the defined path: the direct implication is that its performance satisfies the operational requirement because that's all the referenced infrastructure allows. In the RNAV framework, the performance is reverse engineered based upon what the infrastructure provides and what the aircraft RNAV system achieves as a result. In this case, the RNAV system provides a lateral navigation **accuracy** that is within the specified performance 95% of the flight time.
- For RNP systems and operations, PBN spells out the required performance solution. It starts with what operation needs to be performed and what navigation accuracy is needed to enable it. The lateral navigation **accuracy** must be supported by the navigation infrastructure but it may differ from the minimum or maximum of navigation accuracies possible. This expectation of specific performance leads to a need for operational confidence in the RNP system performance. The result is that the aircraft's RNP system or RNP system in combination with the flight crew, provides the assurance that the aircraft is within the lateral navigation accuracy 95% of the flight time and will alert when it fails to achieve that accuracy. Additionally, the RNP system provides confidence in the performance it achieves through an integrity check ensuring that the probability of the aircraft position being outside of 2x the lateral navigation accuracy does not exceed 1×10^{-5}. (A detailed explanation of on-board-performance-monitoring and alerting is provided in the ICAO PBN Manual (Doc 9613) Volume II, Part A, Chapter 2). Each navigation specification includes

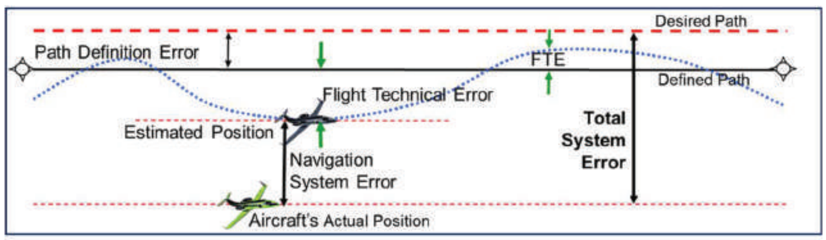
specific requirements for accuracy, integrity, continuity and, for specifications ***requiring*** GNSS, requirements related to the Signal-in-Space.

— *Note: Most aircraft in Europe on a PBN route or procedure will be GNSS equipped, but only those operating on an **RNP** route or **RNP** procedure are **required** to be GNSS equipped and certified.*

1.1. Lateral Navigation Performance for airspace planners

The *Eurocontrol Route Spacing Handbook, No 3,* explains the role played by PBN's lateral navigation accuracy in the systemisation and strategic de-confliction of routes. Essentially, PBN's specifications provide a level of 'guarantee' that the aircraft will adhere to its route, with RNP specifications being required to provide a greater level of confidence. This permits the airspace planner to rely on this navigation performance and layout ATS Routes, SIDs, STARs and IAPs in an optimum manner and have a high level of confidence that the aircraft will adhere to the centreline of the defined flight path published in the AIP.

These 'guarantees' do not suggest that navigation is error free; it is not. As is shown in the diagram on the right, there are different kinds of errors irrespective of the navigation specification.



Lateral navigation errors occur whether aircraft operate on ATS Routes, SIDs, STARs, IAPs and whether this operation is on straight routes/tracks or when executing a turn. (The different ways in which an aircraft turns is discussed under Navigation Functions).

An ATS Route, a STAR (or IAP) or a SID?

In theory, airspace designers instinctively know what is meant by an ATS Route, SID, STAR and IAP. What can be surprising however, is to discover **ATS routes** that are not SIDs/STARs may transit a terminal airspace; that some **STARs** begin at high altitude and 'end' at a terminal area boundary, whilst others begin at a terminal area boundary and end at the intermediate approach fix; and that some ATS Routes link directly to an **instrument approach procedure**. Differently put, one may not just find ATS routes above a certain altitude, and only STARs below another altitude, etc. Instrument approach procedures can also begin at some distance from the airport, at quite high levels.

Traditionally, instrument approach procedures were divided into precision or non-precision approaches. With the increased number of available technologies available to fly the final approach segment with vertical guidance, ICAO split approaches into Type A and Type B with the longer term goal of abandoning the precision/non-precision approach distinction.

— Type **A** approaches can be 2D or 3D and may have a MDA/MDH (2D) or DA/DH (3D) as appropriate, of **250 feet or *above***. Type A approaches encompass traditional conventional NPAs and RNP APCH (LNAV, LNAV/VNAV or LPV)

— Type **B** approaches are 3D only, and accommodate the traditional precision approach operations with a **DA/DH *below* 250 feet**. Today, Type B approaches include ILS, GLS, SBAS CAT I (see ICAO EUR Doc 025).

Note: The Aerodrome Operating Minima identifies MDA/MDH (D=Descent) as associated with 2D approaches where no vertical guidance is provided; pilots will not continue the approach after the Missed Approach Point (MAPt) unless visual contact with the runway is established.

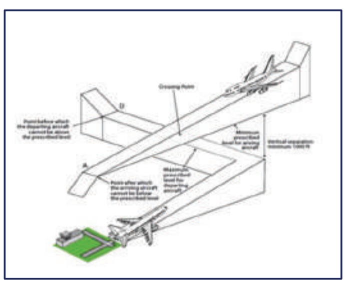
*In contrast, DA/DH (D=Decision) is associated with 3D approaches where vertical guidance is provided; it is the altitude/height at which a **decision** is made to execute the approach or to execute a mixed approach.*

Activity 8 explains that where the RNAV 1 or RNP 1 STAR begins at terminal airspace entry, it would normally connect to an IAP. The STAR would normally end at either the initial approach fix (IAF) or intermediate fix (IF) after which it is possible to design an instrument approach procedure. [A STAR cannot terminate beyond the intermediate fix (IF)]. In addition, an instrument approach procedure cannot start earlier than the initial approach fix (IAF). There are several ways in which RNAV 1 or RNP 1 STARs can be connected to an IAP:

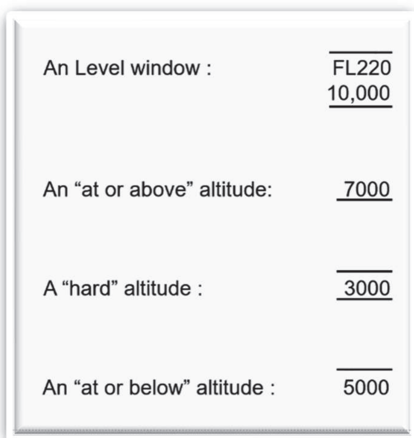
- An RNP APCH instrument approach procedure could start from the initial approach or intermediate fix and continue through the final and missed approach; or
- The RNAV 1 STAR could terminate downwind requiring radar vectors from ATC to join the extended runway centreline prior to the final approach fix, for the cleared RNP APCH IAP.
- Alternatively, an RNP 1 STAR could also end at the initial approach fix of a T or Y shaped IAP (where the Intermediate Fix (IF) forms the stem of the T or Y RNP APCH and the stem is typically aligned with the extended runway centreline).

When an RNAV or RNP STAR is to connect to an instrument approach procedure, the kind of technology used for the intermediate/final approach segment determines the level of flight crew workload. For example, a transition from RNAV 1 to RNP APCH may be seamless and almost invisible in terms of avionic management. In contrast, a transition from an RNAV 1 STAR to an ILS may require a different level of avionic management and therefore increased crew workload for the pilots. This avionic management workload is not only determined by the kind of IAP connected to the PBN STAR, but also by the aircraft type.

1.2. Vertical navigation performance for airspace planners



The vertical aspect of navigation often seems to cause confusion in a PBN context. For purposes of this handbook, which is focused on airspace planning of ATS routes and SIDs/STARs before the Final Approach Fix i.e. outside the final approach segment (FAS), the airspace planner needs to understand the vertical profile is typically managed in one of two ways:



- By ‘vertical constraints’ where a WPT in a procedure includes a requirement to cross that WPT ‘at or above’, or ‘at or below’ , or ‘at’ a certain level or finally between two specified levels which is sometimes referred to as a ‘window’ constraint.
- By a minimum climb gradient prescribed by the SID or an optimum descent profile managed by the flight crew.

2. Navigation Functions

Although there are numerous navigation functions across aircraft avionics, this Attachment focuses on two navigation functions related specifically to path adherence on straight and turning segments.

Note: Functions not discussed in this Attachment include ways in which the vertical profile can be managed (mentioned above), the holding function, the parallel offset function and the vector to final (VTF) function. The VTF is of particular importance to procedure designers and pilots – for more information, see RAISG19_IP4_Analysis of Course Intercept Functions in the ECAC fleet (EUROCONTROL).

The aircraft system's computed flight path is typically the result of information contained in the navigation system's database. The system uses this information to construct a flight path that, for the sake of simplicity, is a varied sequence of connected straight and curved path segments. The path segments, called legs, are defined in one of two ways depending on the phase of flight, primarily for the efficiency in specifying data in a manner so it can be used by a computer-based system:

- For procedures such as ATS Routes, the flight path is basically the specification of a series of fixes (called waypoints) that the navigation system connects together with a geodesic (great circle) path segment. Additionally, the navigation system can calculate a curved path that it uses to smoothly transition (turn) from one leg to the next. This type of transition, called a fly-by transition, will differ from aircraft to aircraft even if the same navigation system is used. A series of factors influence the performance of a fly by turn including aircraft speed, altitude and Angle of Bank (AOB) as well as angle to turn, wind speed and other flight conditions. One solution to eliminate this variability is to define as part of the ATS Route a transition with a fixed radius (FRT).

- For instrument flight procedures such as those in SIDs, STARs and Approaches, for each leg of the IFP the aircraft flight path is defined in terms of two elements denoted as a Path Terminator. The first (Path) can be viewed as an 'action' and the second (Terminator) viewed as the 'end point'. For example, a *course* to a *fix* means that the aircraft is expected to perform the action to *fly a course* in order to reach the end point, the fix; so Course to a Fix is denoted as **CF**. Differently put, a path terminator defines a specified type of path for the aircraft to fly and when that action is to be terminated; examples are a Track to Fix (TF), Fix to Altitude (FA) and Radius to Fix (RF). This allows for much more variability in the definition of a flight path, which coincidentally matches many of the types of clearances and procedures issued by ATC.

2.1. Consistent Turn Performance

Fixed Radius Transition (FRT) is a leg transition associated with a waypoint on ATS Routes in en route operations. A path terminator, termed **Radius to Fix (RF)**, is associated with Terminal Instrument Flight Procedures (SIDs/STARs/IAPs). Although both functions differ in their definitions and intended use, they both enable a consistent, repeatable and predictable path to be flown by an aircraft during a ***turn***.

2.1.1. Fixed Radius Transition (FRT)

FRT as defined in the MASPS DO-236C/ED-75D can be enabled in aircraft with FRT capability by coding a turn radius at the desired waypoint in the airway record of the navigation database, as defined by the aircraft database coding specification, ARINC 424.

Note.— Guidance on how to employ FRT is still being developed and once it is mature, it is expected that design criteria for FRT will be included in PANS-OPS.

For such a transition from in- to outbound leg to be executed as an FRT, the waypoint and the turn radius must have been defined as part of a Route in the airway record of the navigation database. The Route must have been enabled in the navigation system by calling it from the database using the appropriate Route identifier e.g. UL611.

Because navigation functions have been defined but implementations in aircraft FMS are not always standardised, it is not possible to make absolute statements regarding the operational implications of an FRT implementation. In general however, it could be expected that in current implementations:

a) Where a "DCT TO" clearance has been given to a waypoint, depending on the aircraft type, an FRT may not be executed at that waypoint (even if the waypoint was initially inserted using the airway identifier). This is because the active leg in the flight plan will become a direct track between current position and the DIRECT-TO waypoint, after which the Route that was originally programmed will continue.

b) Where a Route has been constructed wholly or partly by pilot inserted fixes (e.g. by name, place/bearing/distance or Lat/Long in a FRA or published Route environment – see Examples in Attachment 4) a FRT cannot be executed at the manually inserted fixes.

c) The FRT requires careful design: the preceding and succeeding waypoints must provide enough distance between them to ensure that the FRT will be executed.

The leg transition at the fixes forming the junction of SIDs or STARs with ATS Routes can usually not be executed as a FRT. This could be overcome though by suitable design of the procedure, connecting it to the en route airway structure. One solution could be realised by the procedure designer creating an RF leg (the terminal equivalent of an FRT) at the end of the SID or the beginning of the STAR. For a SID, the last point of the RF leg could then be connected to the first point of the en route ATS Route in order to ensure appropriate Route spacing during the turn. For a STAR the connection would be from the last point of the en route ATS Route to the first point of the RF leg in the STAR.

Two key points are added: the first is that FRT can only be associated with an ATS Route which is ***not*** a SID or STAR. The second is that an FRT **can only** be associated with an RNP specification defined for use in the en route phase of flight.

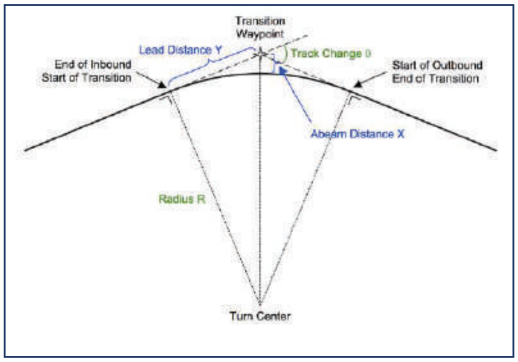
2.1.2. Radius to Fix (RF)

RF is defined as an arc with specified arc centre and radius between two defined waypoints in a procedure (SID/STAR or IAP). It is an ARINC 424 path terminator with the leg starting at a waypoint, the aircraft maintaining the radius distance around a defined arc centre and terminating at the next waypoint. Because of the way the RF is defined, implications of manual waypoint entry and DIRECT TO operations in a flight plan are different, as for the FRT. As long as the start and end points of the RF are not affected by these flight plan modifications, the RF will remain intact. It can be expected however that, where an aircraft routes directly to the start point of an RF (as depicted by the dotted line in the right hand diagram, below), the aircraft may deviate from the defined track because of the fact that the direct inbound track is not tangential to the beginning of the arc at the start point of the RF.

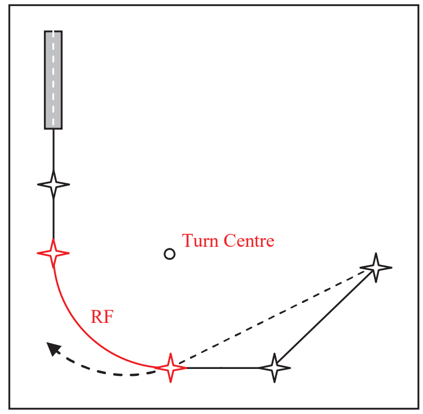
2.1.3. Differences between FRT and RF

The FRT is defined as a transition from one track to another at a waypoint along an en route ATS Route. There is no start or end waypoint to define an FRT, which is a main characteristic of RFs. The FRT starts and ends where an arc with the specified radius is tangential to the inbound and outbound track of the transition waypoint.

Fixed Radius Transition (FRT)



Radius to Fix



Note: Further details on RF and FRT can be found in the PBN Portal and PANS-ATM, Doc 4444

3. Navigation Data Records

ARINC 424 is the industry standard used to define the coding of data in the navigation database. This data is used by the navigation system to calculate the desired flight path, be that a straight path or a turning path.

Most RNAV and all RNP systems have a navigation database which contains many different types of navigation data records. The kinds of navigation data records include ones for ground-based Navigation Aids, records for published and designated en route ATS Routes (known as 'Airway records') and, records for airports including published and designated SIDs/STARs/Instrument approach procedures (known collectively as 'Airport SID/STAR/Approach Procedures records').

Key terms relating to navigation data records in the navigation data base

(in the context of this Attachment):

- An **Airway record** refers to a data record for a published and designated **en route ATS Route**
- An **Airport SID/STAR/Approach Procedure record** refers to data recorded for a published and designated **SID** or **STAR** (which are classified as ATS routes) or **IAP**.

*Note: Here, the term 'Route' (used generically) or 'ATS Route' or 'SID/STAR/IAP' refer to Route(s) which have been **published** by the appropriate authority in the AIP **and designated in the AIP** in accordance with ICAO Annex 11 Appendices 1 and 3 (designation of ATS Routes and SIDs/STARs respectively) or PANS-OPS, Doc 8168 Vol II for IAPs. This publication ensures that the trajectory to be flown over the surface of the earth is known.*

Note 1: The Airport SID/STAR/Approach Procedures record may contain SID, STAR or Approach Procedures data for a defined runway. For convenience, the collective term Airport SID/STAR/Approach Procedures in the section below is referred to as Procedures record.

Note 2: The airport data also contains a specific airport record which contains the aerodrome reference point (ARP) and other specific airport data

Airway/Procedure records can include the navigation performance requirements for each leg making up the complete Route. The construction of a Route contains a series of fixes, possibly including path transitions for ATS Routes and a series of path terminators for SIDs/STARs/IAPs. In designing the Route, the procedure designer uses the performance capability and any combination of functionalities that are included in the navigation specification against which the aircraft must be qualified to operate along the ATS Route, SID/STAR or IAP. As each published ATS Route or SID/STAR/IAP has its own airway or procedure record, respectively, the navigation database can include thousands of such records. From the 'published' ATS Routes and SIDs/STARs/IAPs information, navigation data providers [DAT providers] (who are the suppliers of navigation databases and other related services/products), build 'airway/procedure records', optimise the data for the records, and use this data along with other aeronautical information (e.g. navaids, runways, etc) to create navigation databases which are used by specific aircraft operators/airlines and navigation systems, etc.

This link between airway or procedure record, published Routes and navigation performance/functionality are currently the only means that an RNP system has to determine navigation performance requirements. This results in the fact that navigation performance cannot currently be ascribed 'generically' to 'RNP airspace', because navigation performance specification and associated functionality is embedded in the airway or procedure record enabling an intended operation. Although the notion of 'area RNP' has long been established, the technical preparatory work for its implementation is still outstanding. For these reasons, ATC can only be assured that ATC clearances (voice or data) to an RNP certified aircraft operating in an airspace will meet the performance and functional requirements of an RNP specification (e.g. RNP 1) if the clearances are based upon the use of designated and published ATS Routes or SIDs/STARs/Approaches along with specified navigation performance requirements (i.e. RNP 1) that are contained in the airborne navigation database airway/procedure records. If ATC clearances are issued to fixes and procedures which are not contained in the database, on-board performance monitoring and alerting (i.e. RNP 1) by the RNP 1 aircraft cannot be expected.

For an RNAV system, the issue with the match between the aircraft capability and the navigation performance requirements for Routes, procedures, airspace and clearances does not exist. This is because of the generic and fixed navigation performance relationship of the aircraft's RNAV system, navigation infrastructure and procedures/Route. For example, where the navigation infrastructure for operations is predicated on VOR/DME, the density of the infrastructure supports a consistent level of aircraft flight accuracy such as ±5 NM (e.g. RNAV 5), and the placement of the Routes/procedures are based upon the VOR/DME locations, ATC can be assured that the nominal level of aircraft performance in the airspace will meet RNAV 5 whether it's for a published Route/procedure contained in the navigation database or for an ATC clearance containing fixes and procedures not contained in the database (this could be viewed as a notion of 'area' RNAV). However, lacking assurance that the aircraft will always meet the operational performance expectation because of the lack of on-board performance monitoring and alerting, other means of assurance such as surveillance may be needed. What this suggests is that RNAV does have some advantages if the operationally needed performance matches the RNAV system's generic performance. But this also requires the State/regulator to take more responsibility for the infrastructure and accept the aircraft/systems with basic compliance assessments; the latter is becoming more and more difficult.

*Note: From 2024 all aircraft operating in ECAC will effectively have to be GPS equipped due to the PBN IR requiring RNP APCH to become the norm. This means that even aircraft complying with an RNAV specification, such as RNAV 1, will have GPS as a means of position determination. The difference between RNAV 1 and RNP 1 will then be exceeding subtle: in the former case, OBPMA (provided by RAIM) is **not required**, and in the latter case, it **is required**, but in reality it is available in both RNAV 1 and RNP 1 but credit cannot be taken for OBPMA without RNP 1 certification. An RNP APCH certification does not automatically equate to an RNP 1 certification; the RNP 1 formalities must be complied with to obtain the RNP 1 certification status and it must be reflected in the Aircraft Flight Manual (AFM).*

From airspace concept to *airway or procedure record*:

1) ***Airspace Concept***: Using an example cited in the Route Spacing Handbook, No 3, an airspace concept could be comprised of parallel straight and turning tracks. To this end, a set of RNP 1 SID/STAR procedures with straight parallel legs and turning segments predicated on RF could enable the tracks to remain 5 NM apart on both straight and turning segments.
2) RNP 1 with RF becomes the prescribed requirement for operation on these SIDs/STARs.
3) When the DAT providers compile the *airway or procedure record*s of the RNP 1 SIDs and STARs, the navigation data suppliers include into the *procedure record*s the performance and functional

requirements of RNP 1 with RF. These records are a part of the navigation database that is loaded into the RNP system.

4) To operate along these SIDs/STARs, airspace users (AUs) must have operational approval and aircraft qualified against the appropriate regulatory standards comparable to the RNP 1 with RF specification. Consequently -

   a) ATM procedures and acceptable intervention rates to control deviations are based on RNP 1 with RF Route spacing, for example, allowing reliance on aircraft performing controlled turns, see RF, above.

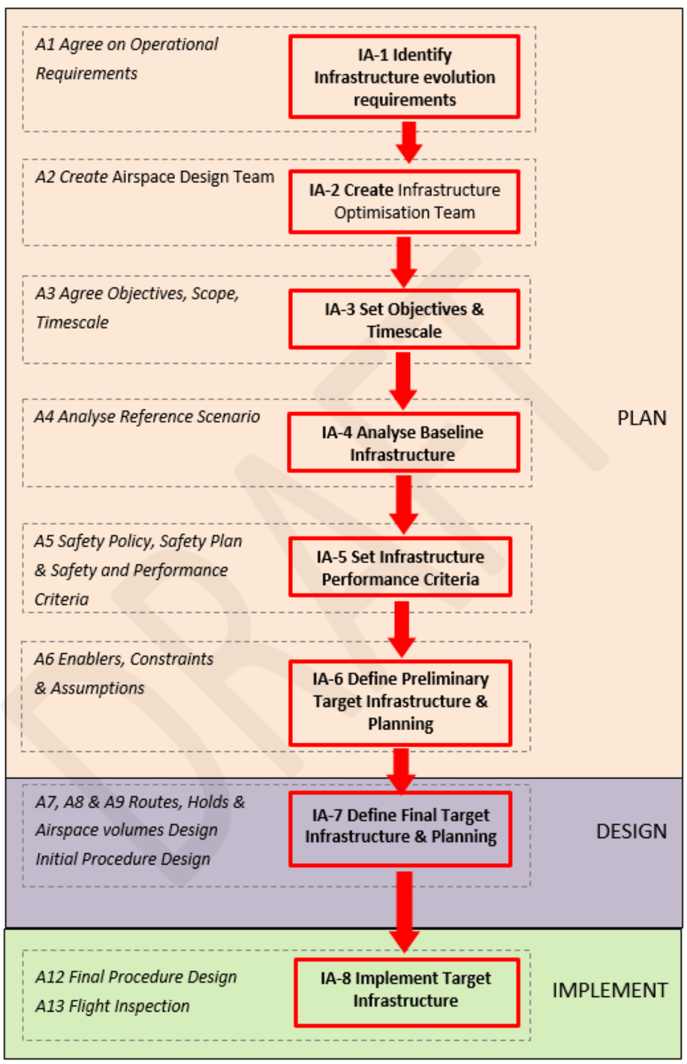
   b) Operators use instrument flight procedures which are separated from obstacles based on RNP 1 performance and functional criteria. This would include reliance on aircraft performing controlled turns using RF outside the final approach segment.

ATTACHMENT 6:

NAVIGATION INFRASTRUCTURE ASSESSMENT FOR AIRSPACE PLANNING

Typically, airspace planners are not directly involved in infrastructure assessment, but the operational requirements provided by airspace planners and ATM more generally play a significant role in infrastructure evolution. The need for ATCOs and Infrastructure Managers to work together is emphasised several times in this Handbook. More particularly, this cooperation intensifies when dealing with GNSS Contingency/Reversion which is the subject of Handbook No 6. In this handbook, the vocabulary differences of the two communities is addressed to facilitate mutual understanding.

The navigation infrastructure assessment process in support of airspace planning is described in Handbook No 4, the *European Navigation Infrastructure Planning Handbook including Minimum Operational Network (MON).* This contains a methodology with a sequence of Activities for navigation infrastructure planning. This methodology mirrors the methodology described in this Handbook No. 1, the European Airspace Concept Handbook for PBN Implementation. The two methodologies permit the mapping between their respective activities and this may enable the seamless integration of infrastructure planning within the development of an airspace concept.



In the infrastructure methodology (shown left), the activities specific to Infrastructure Planning are referenced to the corresponding Airspace Concept Development activities. However, as Navigation Infrastructure planning & implementation activities (**IA-**) are sometimes related to more than one Airspace Concept Activity (**A**); there is not a direct one-to-one relationship between the two methodologies' numbered activities and the timelines of these activities will seldom occur at the same time. Whilst some INFRA activities may take place prior to the associated Airspace activity, some will naturally take place after the associated Airspace activity. In some instances, the INFRA activities can occur when there is no airspace change in progress, in other cases, the two methodologies may be applied in similar time-frames. Nevertheless, in most instances, the final phase of the airspace concept development (i.e. implementation) can only occur once the relevant Navaid Infrastructure is available i.e. it has been agreed, deployed, flight inspected and is fully operational.

The *Infrastructure Planning Handbook* also describes two possible approaches to infrastructure planning: a **top-down** and **bottom-up** approach. The **top-down** approach is one where infrastructure evolution is driven almost exclusively by ATM operational requirements thus placing the infrastructure manager in a 'reactive' role. The **bottom-up** approach has the infrastructure manager playing a pro-active role: here the infrastructure manager aims to influence the airspace concept with the objective of infrastructure optimisation and realising cost-efficiencies. In this approach, infrastructure optimisation acts as a catalyst for airspace change by avoiding the need to renew the infrastructure at the end of equipment lifecycle.

In reality, the infrastructure manager is often required to manage the **top-down** and **bottom-up** approaches simultaneously. This is due to pressure coming from both ATM and technological evolutions (driven by cost) and the two processes are used in tandem to complement each other and often provide the optimum outcome. An example of combined approach may be that in a certain FIR the **top-down** approach is applied as a general strategy, but in particular airspaces (e.g. a certain TMA) the PBN implementation is planned and implemented based on a **bottom-up** approach, considering the priorities of the infrastructure.

The future operational roles of different navigation infrastructure that have to be considered in the assessment process are also detailed in the *Infrastructure Planning Handbook.* High-level considerations are provided below:

GNSS

As explained in Activity 6 in *this* Handbook, providers of ATM/ANS planning for PBN implementation needs to consider both acceptance and recognition of GNSS as an available navigation infrastructure and consider mitigation measures should GNSS fail. Failure can have various causes such as constellation failures (these can be service failures or failures of one or more space vehicles); interference originating from user segments outside of aviation or space weather. While future GNSS developments are expected to greatly increase GNSS service robustness, some form of non-GNSS mitigation will remain necessary. The challenge when providing mitigation measures for GNSS non-availability is that the probability of its non-availability is unknown but expected to be low. As such, reversion to alternative positioning sources may not necessarily need to be designed to maintain 100% capacity and in the evolution of the contingency airspace concept may be deemed acceptable to handle lower traffic levels. However, GNSS is a geo-strategic asset which can be affected by conflict, so national strategies can often be beneficial when deciding mitigation measures.

A-PNT

Alternative Position, Navigation and Timing (A-PNT) is a commonly accepted term used to refer to what *alternatives* to GNSS are available when GNSS cannot be used to provide positioning for PBN or timing for other applications. Thus, one alternative to GNSS for RNAV 1 or RNAV 5 is typically DME/DME, and for RNAV 5 only, VOR/DME is possible (Strictly speaking, these alternatives are not A-PNT because no *timing* is provided, however, the P-N-T tend to be used as alternatives not as requirements together).

The *European GNSS Contingency/Reversion Handbook, No 6*, deals extensively with the topic of A-PNT and the ways in which to select mitigation measures for reversion.

In the future, A-PNT seeks to find new technologies to support GNSS mitigation for the domains of Communication, Navigation *and* Surveillance. The rest of this attachment briefly discusses DME/DME and VOR/DME for PBN applications.

DME/DME

Currently, the only authorised A-PNT in the event of GNSS non-availability for RNAV 1 (or RNP 1 reversion), is DME/DME. To enable RNAV based on DME, multiple DMEs (at least a pair) need to be available with a sufficient relative geometry. Due to terrain restrictions and limitations in siting options, it may be difficult to achieve DME/DME coverage to low altitudes. For STARs, the goal should be to provide coverage down to all intermediate fixes (IFs) or waypoints. For SIDs, it is generally necessary to fly the initial portion based on conventional navigation, until the aircraft reaches the DME/DME coverage region. To close the gap between take-off and the RNAV portion of the SID, it may be necessary to require aircraft carriage of an IRU/IRS (Inertial Reference Unit/System).

Unfortunately, due to geometry requirements, DMEs (co-located with VORs) lying directly beneath a route centreline are not ideally placed to support RNAV 1 (or RNP 1 reversion) operations. However, when there is no need to co-locate the VOR/DME, a stand-alone DMEs has significant installation flexibility. For example, a stand-alone DME can be placed with existing surveillance or communications ground infrastructure. Three to four DMEs located in ideal positions should generally be sufficient to cover terminal airspaces, but the actual number would depend on the airspace volume in question.

The DME infrastructure assessment in support of RNAV 1 (formerly P-RNAV) is described in the Eurocontrol RNAV 1 Infrastructure Assessment Guidelines (Eurocontrol – GUID – ER114). This assessment must be undertaken and appropriate tools are available to help infrastructure planning for RNAV 1, for example: Eurocontrol DEMETER Software.

Some aircraft avionics are capable of providing RNP based on DME/DME – these are mainly commercial air transport aircraft. However, to enable all equipped aircraft to demonstrate RNP 1 capability based on DME/DME (/IRU), considerably more work is needed. Furthermore, current research suggests that with DME/DME positioning, a lateral accuracy supporting a performance of less than 1 NM could be possible.

Some airspace users are not equipped with DME/DME RNAV capability, in particular general aviation (GA) aircraft. Typically, these aircraft would rely exclusively on GNSS for positioning. When providing DME/DME as a reversion infrastructure for air transport operators (to ensure business continuity), general aviation aircraft (GNSS only) must also be catered for. For GA, mitigation measures such as radar vectors to an ILS/to a visual approach or conventional procedures can be provided. The airspace concept developed and the over-riding (reversion) strategy drive the choices made. For non-equipped DME/DME aircraft, the Contingency/Reversion measures in the Airspace concept could consider holding aircraft on the ground to ensure safety and/or minimise controller workload.

VOR/DME

VOR/DME only enables RNAV 5, which is an en route navigation specification and is permitted for use for the initial part of an arrival procedure outside 30 NM from the ARP and above MSA. From the infrastructure assessment perspective, it is relatively easy to achieve low-altitude coverage with a relatively small number of facilities e.g. to support low level en-route traffic. However, while most modern multi-sensor FMS and even older RNAV systems provide a VOR/DME mode of operation, this is the least preferred position estimation option as it is the most inaccurate. Furthermore, to minimise the impact on the position estimation accuracy, some RNAV or RNP systems limit the usable range of VOR's to 40NM (or even in some FMS systems to 25NM). However, VOR/DME can also enable conventional procedures as an alternative means of reversion during a GNSS outage, e.g., for aircraft non-equipped with DME/DME and in areas with insufficient DME infrastructure. Given this secondary role of VOR providing a PBN reversion capability (RNAV 5 only), the rationalization opportunity arises, leading to the maintenance of only a Minimum Operational Network (MON) of VOR's (preferably collocated with DMEs) for conventional use.

Summary

The navigation infrastructure assessment process needs to have the coverage requirements from airspace planners (desired navigation specification and sensor combination depending on user fleet analysis, as well as geographic extent of the planned operations). An initial feasibility assessment is possible using software tools.

The infrastructure assessment should always consider the least equipped user taking into account avionics constraints relative to PBN. If facility changes are required, more detailed assessments, including all operational factors and economic considerations, will be conducted. The opportunities for the optimization of the navigation infrastructure should be taken into account in the airspace planning process. This should be done on the basis of an analysis aimed at identifying rationalization opportunities, evaluating the necessary route changes and ascertaining whether a prioritised PBN implementation on the affected routes would be more cost effective than the replacement of the facilities. The planning should be continuously refined by the Navaid engineering department in cooperation with airspace experts, procedure designers and any other relevant party.

The infrastructure assumptions are then formally confirmed during the validation process. The infrastructure assessment may also lead to changes in how facilities are operated (maintenance practices).

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