

# **Performance-Based Navigation**

**Best Practice Guide for ANSPs**



|                                                   |         |
|---------------------------------------------------|---------|
| <b>Executive Summary</b>                          | page 4  |
| <b>Foreword</b>                                   | page 7  |
| <b>Acknowledgements</b>                           | page 7  |
| <b>1 Introduction to PBN</b>                      | page 8  |
| <b>2 Performance Metrics</b>                      | page 12 |
| <b>3 Aim of PBN Implementation</b>                | page 13 |
| <b>4 Limitations to Resolve</b>                   | page 19 |
| <b>5 Design Process</b>                           | page 24 |
| <b>6 Knowledge and Training</b>                   | page 27 |
| <b>7 Vertical Profile Optimisation</b>            | page 29 |
| <b>8 Rules and Regulations</b>                    | page 31 |
| <b>9 Fleet Equipage</b>                           | page 35 |
| <b>10 Resources</b>                               | page 40 |
| <b>11 Change Management</b>                       | page 44 |
| <b>Appendix A PBN Stakeholders</b>                | page 47 |
| <b>Appendix B ICAO Resolution A37-11</b>          | page 48 |
| <b>Appendix C ICAO Doc 8168, Path Terminators</b> | page 50 |
| <b>Abbreviations and References</b>               | page 54 |

# Performance-Based Navigation Best Practice Guide for ANSPs

## Executive Summary

Performance-based navigation (PBN) is the highest air navigation priority of the International Civil Aviation Organization (ICAO) and is an important element of the ICAO Aviation System Block Upgrades (ASBUs). The implementation of PBN is equally a high priority for the Civil Air Navigation Services Organisation (CANSO) and its Members. CANSO provides practical information on implementing PBN to States and air navigation service providers (ANSPs), including seminars and workshops on PBN. CANSO has developed this Best Practice Guide as another practical and useful tool to assist in the implementation of PBN.

PBN has a number of benefits including:

- flexible route structures which allow for more efficient flight paths and result in reduced fuel burn and emissions
- access to airspace and runways that are limited or not achievable by conventional navigation aid (NAVAID) infrastructure
- improved safety through more straight-in instrument approaches with vertical guidance
- increased airspace capacity
- increased airport accessibility
- more efficient operations
- reduced infrastructure costs (for example the reduction of sensor-specific (e.g. VOR or non-directional radio beacon (NDB)) conventional procedures and routes enables a reduction in legacy infrastructure)
- and reduced environmental impact

In order to take advantage of these benefits, ANSPs must address a wide range of issues before a successful implementation can occur. This Guide provides useful tips that will prove invaluable to those ANSPs that are embarking on the implementation of PBN. It draws on the lessons learned from those with previous PBN implementation experience and provides PBN

guidance that specifically addresses the five key issues that have been highlighted by CANSO Members:

- knowledge
- regulations
- fleet equipage
- resources
- and training

This document provides guidance on PBN implementation as it applies primarily to the terminal and approach environments. The key learnings are as follows:

### **Preparing your PBN implementation plan**

- Knowing the appropriate navigation specification for a given phase of flight (i.e., arrival, departure, approach, en-route) will save valuable time in the initial development process
- Understanding the interaction between aircraft systems and procedure design will reduce surprises during the simulation and implementation process
- Understanding the differences in path terminators will enable ANSPs to design a more predictable flight path, resulting in a reduction in design modifications
- Performance metrics can be used
  - to help build a business case for PBN implementation, and to justify the provision of appropriate resourcing
  - to determine the viability of a PBN concept, and to assess the success of an implementation
  - to define key performance indicators (KPIs):
    - Airspace/aerodrome capacity
    - Safety
    - Efficiency
    - Environmental

### **Understanding the existing issues and potential benefits will help when determining appropriate aims for a PBN implementation.**

- Airports – improved access, potential for reduced infrastructure costs, community economic benefits, environmental benefits
- ANSPs – improvements in safety, reduced service costs, service improvements
- Airlines – enhanced safety, improvements in efficiency, better schedule reliability, opportunities for broad cost reductions, reductions in CO<sub>2</sub> footprint
- Communities – environmental benefits such as reduced impact from aviation operations via CO<sub>2</sub> emissions and noise exposure; also reduced passenger airfares, flight times, and flight diversion disruptions

### **It is important to understand the full range of variables that need to be addressed**

- Changes need to be broken down to identify the items within the direct control of the ANSP, their magnitude, interdependencies and influence on the identified outcomes.
- Critical path items which may be within the ANSP's control include:
  - Business case development
  - Fleet capabilities and mixed capability environment
  - ATC procedures and training
  - Airspace and procedure design including continuous descent operations/continuous climb operations (CDO/CCO) considerations
  - Terminal control area (TMA) redesign with potential re-sectorisation
  - Navigation service monitoring and potential vulnerabilities

- Critical path items that are typically outside of the ANSP's control include:
  - Regulatory changes
  - Environmental impacts
  - Avionics impacts/considerations
  - Navigation database considerations

### **The importance of a clear and concise set of design requirements**

- Design considerations must be addressed as individual variables, as well as how they contribute to the overall result for the airspace and/or procedure implementation
- Procedure design criteria contain limits related to anticipated aircraft performance and ANSPs need to beware of the dangers of over-complex designs
- An iterative construction process between air traffic control (ATC) and its flying customers is necessary in all but the simplest of designs

### **Sharing PBN knowledge is vital**

- Begin knowledge-sharing with key decision-makers
- Make use of existing PBN resources (ICAO etc.)
- Use a range of media to inform and educate
- Provide pilot / ATC cross-training if possible

### **Understanding the benefits and constraints of CCO/CDO in a PBN environment**

- CCO/CDO benefits include reduced fuel burn, CO<sub>2</sub> emissions, and environmental noise
- Complex terminal areas and high traffic levels may prevent continuous CCO/CDO usage

### How to develop a PBN implementation plan and dealing with regulations

- To ensure the civil aviation authority's (CAA's) plans are complementary to the ANSP and industry plans, they should begin with a shared broad strategic direction. This could start in the form of a CAA policy that evolves into a State PBN implementation plan
- Cooperative consultation is critical between the regulatory authority, the service provider, other stakeholders, and the users of the air navigation service
- Knowledge of the equipment proposed for a given operation, the structure of the air navigation service, and the operating procedures of the stakeholders, is paramount to the effective development of PBN regulations

### The application of fleet equipage in the planning process will save time

- To ensure the appropriate selection of a navigation specification will be utilised in a given airspace concept, the ANSP must secure the requisite expertise on the design team
- The challenge to understanding aircraft equipage can be accurately determined by having the operators pilots and/or their respective avionics engineers as members on the design team
- The fact that an operator has PBN capable aircraft does not necessarily mean that their aircraft have been operationally approved. The operator may not have received authorisation from the regulator to fly a designated navigation specification

### How to best source and allocate resources and utilise subject matter experts

- Having a dedicated resource from each area of domain expertise within an ANSP

or stakeholder is not always required. However, it will require a minimum level of participation from subject matter experts (SMEs) to ensure continuity in meeting the PBN airspace objectives

- Expertise in financial analysis, ATC simulation, aeronautical information and procedure design services, policy and standards, safety management, and the ANSP's customer expertise will be necessary during certain stages of the process
- Resources allocated to education and communication will be essential in establishing a non-threatening environment to enable acceptance of PBN initiatives

### How best to manage the changes that PBN implementation requires

- Managing expectations is a key challenge in managing change
- Understanding the various environments (i.e., political, social, community) surrounding the designated airspace coupled with a clear and consistent messaging will enable ANSPs to effectively manage change
- Post implementation activities should include a continuous improvement process

It will be clear from the experiences shared and the guidance provided that PBN implementation can be an enormous job, requiring input from a wide range of stakeholders, and involving a large number of technical complexities. As ANSPs gain experience through the PBN implementation process – particularly with respect to the five key areas of knowledge, regulations, fleet equipage, resource, and training – this Best Practice Guide will be updated regularly. CANSO Members are invited to continue to contribute their own implementation experience to help ensure the its future value and relevance.

## Foreword

CANSO provides this *Performance-Based Navigation Best Practice Guide for ANSPs* to support Member ANSPs as they prepare for, or continue with, PBN implementation.

While acknowledging that a wide range of PBN material and training is available publicly, particularly from the International Civil Aviation Organization (ICAO), International Air Transport Association (IATA) and Airports Council International (ACI), feedback from CANSO ANSPs has highlighted the need for greater support to address ANSP-specific PBN implementation issues.

A PBN Sub Group (PBN SG) was formed in 2012 to assist CANSO Members with PBN implementation. The PBN SG contributes to the Optimised ATM Systems Workgroup (OAS WG), under the CANSO Operations Standing Committee (OSC). One of the first tasks completed by the CANSO PBN SG was to conduct a survey of Members to identify the primary concerns of ANSPs with respect to PBN implementation. Five key areas were highlighted: *knowledge, regulations, fleet equipage, resource, and training*.

This document explains the five key PBN implementation issues that relate to ANSPs, and provides an overview of lessons learned from those ANSPs that have already implemented PBN.

This information is intended to be reviewed and updated at regular intervals, to capture developments in PBN as well as the growing body of expertise of CANSO Members. And it is intended to supplement, not replace, the excellent guidance material that is already provided by CANSO partner organisations—ICAO, IATA, and ACI.

This document is designed to be accessed online. Hyperlinks have been included to provide quick and easy access to relevant PBN information.

## Acknowledgements

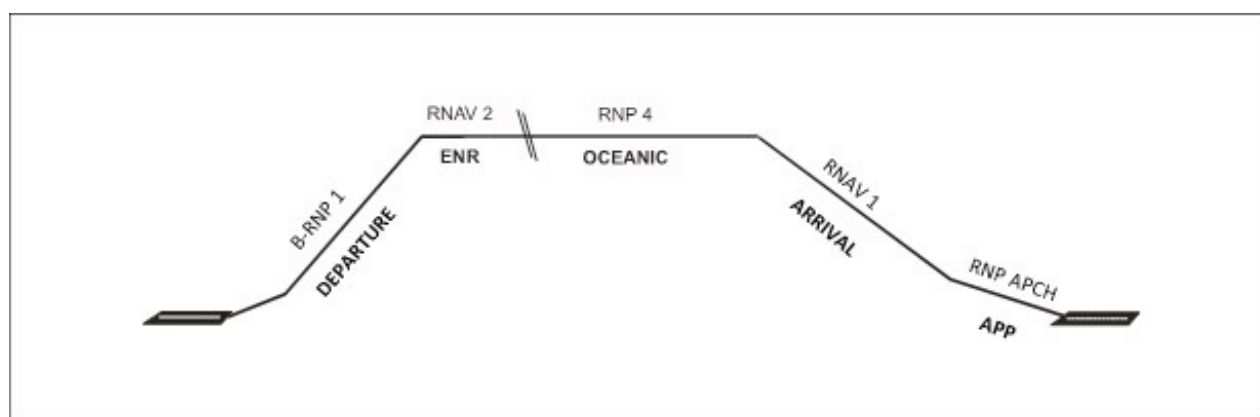
CANSO would like to thank Tetra Tech AMT, Airways New Zealand, and NAV CANADA for their leadership in producing the *CANSO Performance-Based Navigation Best Practice Guide for ANSPs*.

We also acknowledge the valuable input provided by AENA, Airservices Australia, ATNS, ENAV, Federal Aviation Administration, Jeppesen, Metron Aviation, Saab and the many other contributing CANSO Members.

Sources for the information used in this publication have been referenced where possible, but some of the guidance material provided originates from CANSO Member organisations and so may not be publicly available. Every effort has been made to acknowledge the original author and to confirm the validity of the content of this document.

## 1

### Introduction to PBN



Example of an application of RNAV Phase of Flight<sup>1</sup>

PBN is a global set of area navigation standards, based on performance requirements for aircraft navigating on departure, arrival, approach or en route segments of flight. These performance requirements are expressed as navigation specifications in terms of accuracy, integrity, continuity, availability and functionality required for a particular airspace or airport. PBN does not exist in isolation but rather as an integral component of an airspace concept.

The PBN concept is defined in the ICAO Document 9613, Performance-Based Navigation Manual. This encompasses two types of navigation specifications: area navigation (RNAV); and required navigation performance (RNP).

**RNAV specification** is a navigation specification based on area navigation that does not include the requirement for on-board performance monitoring and alerting. Two common RNAV specifications are:

RNAV 1 which requires a total system error of not more than 1 nautical mile (NM) for

95 percent of the total flight time. RNAV1 is typically used in the terminal environment.

RNAV 2 which requires a total system error of not more than 2 NM for 95 percent of the total flight time. RNAV2 is typically used in the en route environment.

RNAV provides the potential for increasing airspace capacity both en-route and in the terminal area in two ways:

First, by enabling flexible route structures which do not have to over fly ground-based NAVAIDS, allowing for more efficient use of airspace

Second, by enabling the reduction in lateral separation between aircraft, airspace and obstacles

**Total System Error:** The inability to achieve the required lateral navigation accuracy may be due to navigation errors related to aircraft tracking and positioning. The three main errors are path

<sup>1</sup> ICAO DOC 9613 Performance-Based Navigation Manual Volume II Implementing RNAV and RNP Operations. Reproduced with the permission of ICAO.



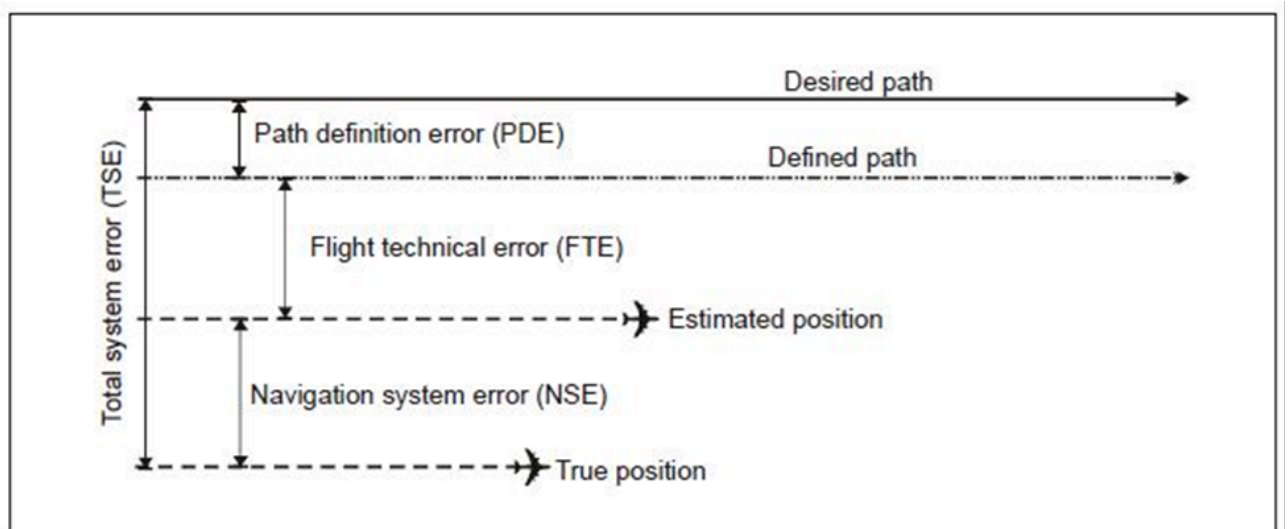
definition error (PDE), flight technical error (FTE) and navigation system error (NSE).

PDE occurs when the path defined in the RNAV system does not correspond to the desired path, i.e. the path expected to be flown over the ground.

FTE relates to the air crew or autopilot's ability to follow the defined path or track,

including any display error. FTE can be monitored by the autopilot or air crew and the extent to which these procedures need to be supported by other means depends on the phase and type of operations. Such monitoring support could be provided by a map display.

NSE refers to the difference between the aircraft's estimated position and actual position.

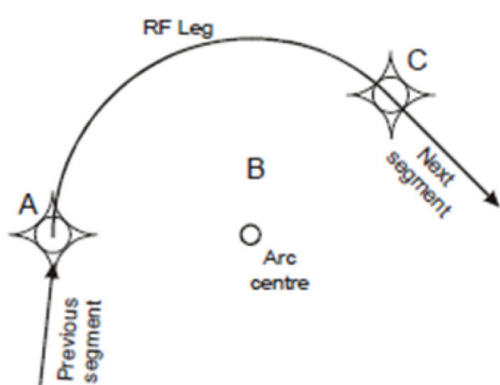


Example of PDE, FTE and NSE<sup>2</sup>

<sup>2</sup> ICAO DOC 9613 Performance-Based Navigation Manual Volume I Concept and Implementation Guidance and Volume II Implementing RNAV and RNP Operations. Reproduced with the permission of ICAO.

**RNP specification** is navigation specification based on area navigation that includes the requirement for on-board performance monitoring and alerting; aircraft equipage; and pilot training and qualifications. RNP navigation specification values also refer to 95 percent accuracy values designated by an RNP prefix (e.g. RNP 0.3). These procedures can include vertical system accuracy as well. Another key advantage of RNP is that fixed radius paths (FRP) can be flown. FRPs can take two forms:

The constant radius to a fix (RF) leg is one of the leg types that should be used when there is a requirement for a specific curved path radius in a terminal or approach procedure. The RF leg is defined by radius, arc length and fix. RNP systems supporting this leg type provide the same ability to conform to the track-keeping accuracy during the turn as in straight line segments.



Radius to Fix Leg Type<sup>3</sup>

The fixed radius transition (FRT) is intended to be used in en-route procedures. These turns have two possible radii, 22.5 NM for high altitude routes (above flight level (FL)195) and 15 NM for low altitude routes. Using such path elements in a RNAV route enables improvement in airspace usage through closely spaced parallel routes.

Under PBN, operational requirements are defined as those that drive the airspace concept. These requirements may be as simple as the establishment of a new runway or as complex as

the introduction of a communications, navigation and surveillance / air traffic management (CNS/ATM) infrastructure. Civil aviation authorities then evaluate options that lead to the selection of a navigation specification. A chosen navigation specification may be based on airspace configuration, traffic density, equipage and types of users, etc. Technology can evolve over time without requiring the operation itself to be revisited as long as the requisite performance is provided by the RNAV or RNP system. A thorough explanation of the process can be found in ICAO Doc 9992, *PBN Airspace Design Manual*.

PBN procedures are commonly built to be flown by aircraft equipped with Global Navigation Satellite System (GNSS) only or can use ground-based distance measuring equipment and/or inertial reference system (DME/DME/IRS) and are in most cases developed to be flown by either type of equipage.

PBN procedures may allow for closely spaced tracks and routes allowing easier airspace design standards since the route always remains the same width and is not dependent upon electronic signals from ground-based NAVAIDs with wavering signals. This applies to DME/DME/IRS flight as well as GPS (global positioning system) flight. DME/DME/IRS flight would apply to legacy aircraft that have not been retrofitted to allow for GNSS operations and must use ground-based DME stations. Aircraft and crews capable of GNSS flight can utilise RNP and RNAV procedures allowing for a mixed environment with DME/DME/IRS to better utilise the tightly spaced routes and various airspace configurations which can be developed to enhance ATC functions.

Use of PBN procedures can reduce environmental constraints over conventional procedures by reducing greenhouse gases (GHGs) through increased efficiencies in the lateral and vertical paths, as well as improving the opportunity to constrain flight paths over less noise sensitive

<sup>3</sup> ICAO Doc 8168 Vol II Part 3, Section 2, Chapter 5, para 5.2. Reproduced with the permission of ICAO.

areas. The lateral and vertical accuracy of PBN also allows for the potential reduction of noise in urban environments at lower altitudes.

**Coding of Procedures** – an instrument flight procedure (IFP) will be coded and included in the database loaded on the aircraft flight management computer (FMC). If the procedure is selected by the pilot, the FMC will then provide appropriate flight guidance. Each portion or leg of the IFP will be coded with a specific path-terminator.

**Paths and Terminators**<sup>4</sup> – a path-terminator is a two-letter code specifying a leg type on a procedure, explaining how a leg is to be flown.

**First Letter (path):** V = heading, C = course/track, F = course from a fix, H = hold, D = direct, P = procedure turn, T = track, I = initial, A = arc, R = radius.

**Second Letter (terminator):** A = altitude, D = DME distance, I = intercept (next leg), R = radial, F = to fix/at fix, M = manual termination, C = distance from fix.

Path-terminators that may be used for PBN procedures:

- VA = Heading to an altitude (often used off parallel runways)[ICAO RNAV]
- VI = Heading to intercept next leg (used to intercept ILS Localizer) [ICAO RNAV]
- VM = Heading to a manual termination (e.g. end of STAR for radar vectors)[ICAO RNAV]
- CA = Course to an altitude (more accurate groundpath than VA) [ICAO RNAV]

- CF = Course to a fix (the original path/terminator). [ICAO RNAV and RNP]
- TF = Track between two fixes (most accurate leg type [ICAO RNAV and Primary RNP]
- IF = Initial fix (begins a series of path-terminators, used for some SIDs, and for all STARs/APCHs) [ICAO RNAV and Primary RNP]
- DF = Track from present position direct to a fix [ICAO RNAV and RNP]
- RF = Constant radius to a [ICAO RNAV and Primary RNP]
- HM = Hold to a manual termination [ICAO RNAV and Primary RNP]
- HA = Hold to an altitude (climb in the holding pattern) [ICAO RNAV and Primary RNP]
- HF = Hold to a fix (one circuit in hold then continue; can cause issues if only intended for reversal turn, not straight-in) [ICAO RNAV and Primary RNP]

#### Why this is important for ANSPs.

To enable ANSPs to successfully implement PBN, a basic understanding of the PBN concept, benefits and terminology, including procedure coding, is necessary. With this knowledge, ANSPs are able to assess their respective operational requirements and select an appropriate PBN specification. This introduction should also provide a basis to understanding facets of ICAO Doc 9613, *Performance-based Navigation Manual* and ICAO Doc 9992, *Manual on the use of PBN in Airspace Design*.

#### Key Points:

- Knowing the appropriate navigation specification for a given phase of flight (i.e., arrival, departure, approach, en route) will save valuable time in the initial development process
- Understanding the interaction between aircraft systems and procedure design will reduce surprises during the simulation and implementation process
- Understanding the differences in path terminators will enable ANSPs to design a more predictable flight path, resulting in a reduction in design modifications

<sup>4</sup> Doc 8168 Vol 2 III-2-5-App-1 (p 677).

## 2

### Performance Metrics

ANSPs are run on business models that have them investing and spending on behalf of their customers. Having metrics that support capital investment for project initiation and performance indicators that demonstrate value throughout are essential.

Performance metrics provide value to the PBN implementation process in a number of ways:

- Pre-implementation metrics are used to develop a business case justifying expenditure on PBN, and help to prioritise the order of locations and procedures to implement
- During concept development, metrics may show how effective an implementation is likely to be, and metrics may provide guidance to help finalise a concept
- Post-implementation metrics show how effective the PBN implementation has been, and may point to areas that can be refined for further performance gains

A PBN implementation may target access to an airfield, capacity, or track-mile efficiencies. Appropriate performance metrics will help to

determine potential and achieved benefits, including: the impact of minima reductions; inbuilt procedure separations; and flight-path efficiencies. Measurement criteria used may include: diversion rates; flight time; fuel burn; CO<sub>2</sub> emissions; operating costs; and the impact of noise on the community.

CANSO Operational Performance Workgroup (OPS WG) and PBN SG plan on producing more detailed guidance to assist States in developing their own PBN performance metrics and key performance indicators. This section will be expanded and references to relevant OPS WG-developed documents will be provided in future editions.

### **Key Points:**

- Performance metrics can be used to help build a business case for PBN implementation, and to justify the provision of appropriate resourcing
- Performance metrics may be used to determine the viability of a PBN concept, and to assess the success of an implementation
- PBN implementation objectives may be associated with key performance indicators (KPIs) which are based on performance metrics:
  - **Airspace/aerodrome capacity** - measured by the number of aircraft movements over time
  - **Safety** - a reduction in operating irregularities and flight safety incidents
  - **Efficiency** - reduced customer track miles, reduced aircraft time in the system, or a reduction in the number of ATCOs required to support an operation
  - **Environmental** - with benefits measured in reduced emissions and/ or reductions in noise exposure

### **3**

#### **Aim of PBN Implementation**

PBN has been identified by the International Civil Aviation Organization as the critical path to achieving many of the objectives identified in the Global Air Navigation Plan<sup>5</sup>. PBN provides an opportunity for each ANSP to work in a globally harmonised and collaborative framework with their customers, regulators and stakeholders to enable operations that will result in mutual benefits. This belief has been reinforced by a broad industry declaration of support for PBN<sup>6</sup>.

Why an ANSP should implement PBN procedures and processes. In the modern commercial era, a satisfactory business case with benefits outweighing costs is almost always a prerequisite to implement a new process. The benefits gained may not be financial, as enhanced safety is the priority in many aviation-related programmes. Many benefits associated with implementing PBN are well documented and differ depending on the stakeholder—airports, ANSPs, airlines, and surrounding communities. Some of the benefits may seem irrelevant to an ANSP, but if a cross-industry business case is being developed, it is prudent to include all the benefits.

First and foremost, ANSPs should be aware that PBN has been accepted as the main building block of all future airspace systems, particularly where the emphasis is on three-dimensional (3D) and four-dimensional (4D) trajectories. PBN will also be enhanced in the future by new generation multi-constellation multi-frequency avionics and will thus support additional performance and robustness for ANSP applications. Both the European Union's SESAR (Single European Sky ATM Research) and the United States (U.S.)

Federal Aviation Administration's NextGen (Next Generation Air Transportation System) programmes view PBN as central to enhancing safety, efficiency, and capacity targets facing the aviation industry.

ICAO, IATA, CANSO and ACI give guidance to their members on the direction in which they should progress with regard to PBN.

PBN is an integral part of ICAO Doc 9750, Global Air Navigation Plan. PBN implementation fits into the ICAO strategic objectives of safety, environmental protection, and sustainable development of air transport.<sup>7</sup>

PBN complied with earlier ICAO Global Plan Initiatives:

- GPI-5** RNAV and RNP (performance-based navigation)
- GPI-7** Dynamic and flexible ATS route management
- GPI-10** Terminal area design and management
- GPI-11** RNP and RNAV SIDs and STARs
- GPI-12** Functional integration of ground systems with airborne systems
- GPI-21** Navigation systems<sup>8</sup>

PBN is also a vital part of the ICAO Aviation Safety Block Upgrades (ASBU)<sup>9</sup>:

- Performance Improvement Area 1: Airport Operations
- Performance Improvement Area 4: Efficient Flight Paths – Through Trajectory-based Operations

<sup>5</sup> Global Air Navigation Plan <http://www.icao.int/sustainability/pages/GANP.aspx>

<sup>6</sup> Refer to Figure 1 in this section

<sup>7</sup> ICAO Doc 9750-AN/963 2013 – 2028 Global Air Navigation Plan Fourth Edition - 2013.

<sup>8</sup> ICAO Doc 9750-AN/963 Third Edition 2007.

<sup>9</sup> Loc cit GANP Fourth Edition, and Aviation System Block Upgrades issued 28 March 2013

- Block 0 with initial deployment target fixed for 2013:
  - B0-APTA: Optimisation of approach procedures including vertical guidance
  - B0-CDO: Improved Flexibility and Efficiency in Descent Profiles using Continuous Descent Operations (CDOs)
  - B0-CCO: Improved Flexibility and Efficiency Departure Profiles – Continuous Climb Operations (CCO)
- Block 1 with initial deployment target fixed for 2018:
  - B1-APTA: Optimised airport accessibility (APTA)
  - B1-FRTO: Improved Operations through Optimised ATS Routing
  - B1-CDO: Improved Flexibility and Efficiency in Descent Profiles (CDOs) using vertical navigation (VNAV)
- Block 2 with initial deployment target fixed for 2023:
  - B2-CDO: Improved Flexibility and Efficiency in Descent Profiles (CDOs) Using VNAV, Required Speed and Time at Arrival

The table below shows the correlation between some of the PBN Toolsets proposed for use and the ICAO Aviation System Block Upgrades (ASBUs).

ICAO Resolution A37-11 (Appendix B): – The Assembly resolved that States complete a PBN implementation plan as a matter of urgency to achieve:

1. Implementation of RNAV and RNP operations (where required) for en-route and terminal areas according to established timelines and intermediate milestones;
2. Implementation of approach procedures with vertical guidance (APV), either barometric vertical navigation (BARO-VNAV) and/or augmented GNSS. This includes lateral navigation (LNAV) only minima for all instrument runway ends, either as the primary approach or as a backup for precision approaches by 2016 (with 30 percent by 2010 and 70 percent by 2014);
3. Implementation of straight-in LNAV only procedures (as an exception to 2. above) where the fleet is not APV capable.

| En Route                                                                                            | Terminal                                               | Approach                                             |
|-----------------------------------------------------------------------------------------------------|--------------------------------------------------------|------------------------------------------------------|
| Airspace defined by ICAO Navigation Specification performance<br>B0-FRTO                            | RNAV/RNP SIDs and STARs<br>B0-APTA<br>B0-CDO<br>B0-CCO | RNAV (GNSS) approach procedures<br>B0-APTA<br>B0-CDO |
| Static and dynamic waypoints for point to point preferred routes<br>B0-FRTO<br>B0-OPFL              | Lateral terminal corridors<br>B0-FRTO<br>B0-OPFL       |                                                      |
| RNAV fixed route structures (Q, T and L routes)<br>B0-FRTO                                          | Vertical terminal corridors<br>B0-FRTO<br>B0-OPFL      | RNP AR approach procedures<br>B0-APTA<br>B0-CDO      |
| Closely spaced parallel routes to enhance en-route climb, descent and overtake scenarios<br>B0-OPFL |                                                        |                                                      |

Finally, on 1 April 2009 (see Figure 1 to the right) in conjunction with the 4th annual Aviation & Environment Summit in Geneva, PBN was recognised across the aviation industry as the catalyst for improving air traffic operations.

PBN is recommended as the future path by the aviation industry, but what benefits will stakeholders gain by implementing these processes?

### Airports

**Improved access** – More than 5,000 PBN RNP approaches have now been published within several States. Statistics show a significant improvement of operational minima (decision height and required visibility) delivered to airspace users, in a vast majority of cases, with respect to VOR, NDB and circling/visual approaches. Even when an instrument landing system (ILS) is delivering the main approach and landing service, RNP approaches (APCH) are found to be the second best approach technology, and have been deployed by ANSPs to support periods of ILS outages. In areas where a satellite-based augmentation system (SBAS) with at least APV I performance is available, approach minima close or similar to ILS Cat I may be available, improving very significantly the accessibility at runway ends not already served by an ILS. PBN also offers specific solutions to deal with specific configurations (obstacle rich areas, etc.). In Queenstown, New Zealand, prior to the establishment of PBN approach procedures, the existing approach minima of approximately 2,630 feet resulted in frequent weather diversions. Approach minima have been reduced to approximately 250 feet under RNP AR APCH with RNP 0.1 procedures, vastly improving access. Higher payloads and fewer diversions



Figure 1 – Cross Industry Declaration in Support of PBN<sup>10</sup>

have resulted (14 percent down to one percent) at Queenstown<sup>11</sup>. Similarly at the Gold Coast Airport in Australia, the establishment of RNP AR approach procedures saw equipped airlines taking advantage of approximately 250 feet minima while other airlines were still flying VOR/DME or NDB approaches with minima of around 750 feet. The number of aircraft diversions due to weather has declined significantly.

**Economic advantage** – The introduction of PBN procedures can help ANSPs reduce

<sup>10</sup> ICAO News Release PIO 04/09

<sup>11</sup> Information Paper presented by New Zealand at The Tenth Meeting of the ICAO Asia/Pacific Performance-Based Navigation Task Force (PBN/TF/10)



their investment costs in ground-based NAVAIDS, and could even mean the difference between an airport going into bankruptcy, or that same airport surviving and thriving to serve its community. Several ANSPs are evaluating and planning for the reduction of ILS Cat I infrastructure. As an example, France's ANSP, DSNA, is now taking advantage of PBN to cut its ILS Cat I infrastructure investments within a set of 50 small and medium sized, selected airports. Within this plan, airport owners are free to take on their own the ILS ownership, maintenance and flight inspection costs to sustain the ILS service, or alternatively decide to shift to using DSNA provided PBN RNP APCH. Most of the target airports have now made the choice to shift to PBN, rather than supporting ILS Cat I costs. Pietermaritzburg airport is an excellent example<sup>12</sup>.

Pietermaritzburg airport, 80km west of Durban in Kwazulu Natal, South Africa frequently has overcast conditions with cloud base 500-800 above ground level (AGL). It had two NDBs that are more than 50 years old, and two NDB procedures. Airport operations were not cost effective due to the large number of weather diversions occurring, which resulted in a loss of passenger numbers and a declining number of aircraft movements. This decline directly and negatively impacted the local economy. To rectify the situation the airport implemented two RNP APCH procedures and installed a simple approach lighting system (SALS) on Runway 16. The lowered RNP approach minima and new lighting resulted in an 83 percent decrease in weather diversions. This enabled a 53 percent reduction in one-way airfares and a 23 percent reduction on return airfares between Pietermaritzburg and Johannesburg and lead to a 56 percent increase in passenger numbers through the airport.

**Environmental advantage** – PBN procedures can facilitate environmental benefits with fewer track miles flown and CCO/CDO operations helping

to reduce aircraft fuel-burn, reduce CO<sub>2</sub> emissions, and to avoid noise-sensitive areas.

### **ANSPs/Controllers**

Safety enhancements – PBN reduces controller workload due to:

- Decreased dependency on tactical radar control
- Potential introduction of flight path monitoring/alerting tools for controllers
- Reduction in complexity and variability of procedural approach control
- Lower dependency on radiotelephony (RTF) with decline in incidents caused by read-back/hear-back issues

**Reduced service cost** – The transition to a PBN environment is linked to a GNSS-based service and a move away from traditional ground-based NAVAIDS. This allows for a rationalisation of infrastructure and subsequent savings in capital investment and maintenance, with savings passed onto the operators through reduced navigation services charges and a requirement to carry less equipment. As an example, the DSNA ILS Cat I investment costs reduction programme mentioned above, contributed to a plan to reduce the landing taxes for all airspace users.

**Service** – Improvement in the quality of the service to meet new airspace user requirements.

### **Airlines**

**Enhanced safety** – Controlled flight into terrain (CFIT) on an approach is the cause of many fatal accidents. ICAO CFIT studies have shown that 'runway-aligned approaches (LNAV only) are some 25 times safer than circling approaches, and that once some form of vertical guidance is added to these approaches the safety margin is increased again by a factor of eight<sup>13</sup>.' RNP on-board monitoring and alerting requirements also benefit safety.

<sup>12</sup> Pietermaritzburg: PBN Opening New Doors to Economic Success' Brief to PBN Symposium Montreal 16 October 2012, Gary Newman, Manager Procedure Design & Cartography South African Civil Aviation Authority

<sup>13</sup> A37-WP/148 Performance-Based Navigation – The Implementation Challenge: [http://www.icao.int/Meetings/AMC/Assembly37/Working%20Papers%20by%20Number/wp148\\_en.pdf](http://www.icao.int/Meetings/AMC/Assembly37/Working%20Papers%20by%20Number/wp148_en.pdf)



**Enhanced reliability, repeatability, and predictability of operations in all weather conditions** – PBN procedures based on the RNP APCH down to localizer performance with vertical guidance (LPV) minima, as well as RNP AR APCH navigation specifications are designed to meet higher standards of navigation accuracy. The supporting avionics are shown to deliver a high degree of availability and thus improve ATC predictability of operations<sup>14</sup>. RNP AR APCH may be used to further reduce track miles flown as well as address environmental issues (noise, reduced carbon emissions, reduced fuel burn, etc.), when additional tracks to an airport are proved to be manageable by ATC.

**Improved airspace capacity** – PBN can be used to better manage and define shorter, more efficient routings in complex airspace. One of the greatest advantages of PBN is that air traffic service (ATS) routes, standard instrument departures (SIDs)/standard terminal arrival routes (STARs), and instrument approach procedures (IAPs) no longer have to pass directly over ground-based NAVAIDs. As a result, routes can be placed where they give flight efficiency benefits by avoiding conflicts between flows of traffic. It also means that parallel routes can be designed to avoid having bi-directional traffic on the same route, and to provide various options between same origin and destination airports. Most significantly, this placement benefit provided by PBN can ensure efficient connectivity between en-route and terminal routes to provide a seamless (vertical) continuum of routes.

**Payload benefits** - Flexibility in PBN procedure design can grant significant payload benefits to airlines. As part of the original Australian RNP-AR procedures trial, airlines increased payloads at some terrain-challenged airports by up to five tonnes by using a PBN procedure that takes advantage of tighter obstacle clearance criteria.

**Utilise aircraft capability** - Some airlines maintain that although they invest significant sums of money in cutting-edge technology for new aircraft, an air traffic management (ATM) system that uses conventional navigation procedures does not allow modern flight-deck technology to be fully utilised. The PBN environment allows the airlines to harness more of their fleet's navigation capabilities, and can offer significant airspace capacity and environmental benefits. The concept of 'service priority' may add pressure on less well-equipped airlines to upgrade, or be faced with exclusion from certain routes or procedures. Smaller operators that choose to upgrade may also benefit from improved access and reduced delays, and with improved safety.

**Operating efficiency** – PBN procedures have been used to reduce track miles, fuel burn, flight time, voice communication, and pilot workload, as a result of the benefits outlined above.

### **Communities**

**Reduction in CO<sub>2</sub> Emissions** - The ability of PBN to provide shorter route length or vertical windows supporting CDO/CCO allows more fuel-efficient profiles to be flown. The flexibility of PBN procedure design allows aircraft to fly similar profiles in instrument meteorological conditions (IMC) as they have done previously only in visual conditions. Between 2007 and 2009, Qantas Boeing 737-800s flew approximately 20,000 RNP AR approaches across Australia. During this period, they saved 59,000 track miles (up to 17.3 NM per flight), 737,000 kg of fuel; and 2.36 million kg of CO<sub>2</sub><sup>15</sup>

**Reduced impact of aircraft noise** – Continuous descent allows aircraft to keep engines near flight idle and to deploy flaps and landing gear later, reducing the noise impact. Curved 'RF' legs also allow noise sensitive areas to be avoided by placing flight paths over areas such as motorways and industrial parks, which can significantly reduce the number of people exposed to aircraft noise.

<sup>14</sup> ANSPs should take account of availability of RNP APCH down to LNAV or LNAV/VNAV minima.

<sup>15</sup> Airservices Australia RNP Project Brisbane Green Report March 2008

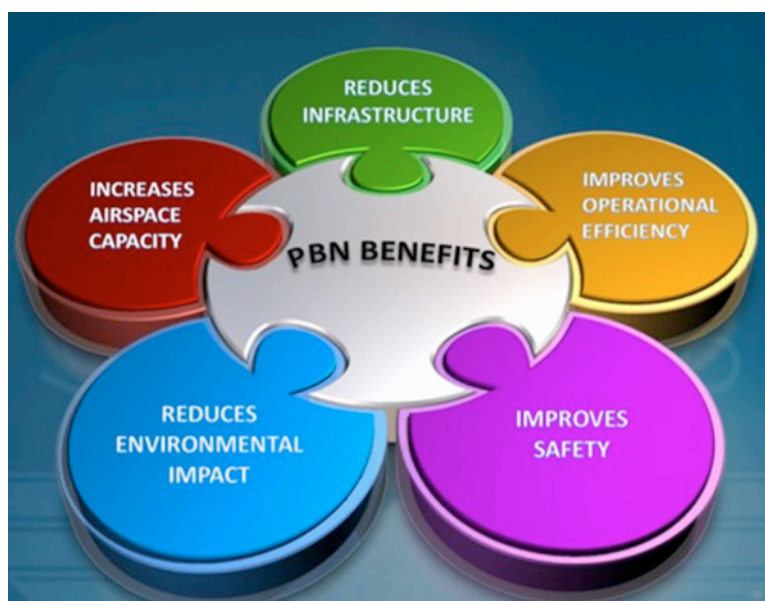
#### Reduced airfares and diversion disruptions

– New PBN procedures and the potential for lower minima improve accessibility and the reliability of airline schedules, particularly in winter months. This enables airlines to reduce airfares and encourages passengers to place greater reliance on the time savings and efficiencies that air travel can generate.

#### Why this is important for ANSPs.

Understanding the ultimate goal of any PBN implementation is essential if resources are to be applied efficiently, concepts developed and assessed appropriately, and for the success of the implementation to be measured.

ICAO summarises the benefits of PBN in the PBN iKit<sup>16</sup>:



#### Key Points:

Understanding the existing issues and potential benefits will help when determining appropriate aims for a PBN implementation. Consider:

- Airports – Improved access, potential for reduced infrastructure costs, community economic benefits, environmental benefits
- ANSPs – Improvements in safety, reduced service costs, service improvements
- Airlines – Enhanced safety, improvements in efficiency, better schedule reliability, opportunities for broad cost reductions, reductions in CO<sub>2</sub> footprint
- Communities – environmental benefits such as reduced impact from aviation operations via CO<sub>2</sub> emissions and noise exposure; also reduced passenger airfares, flight times, and flight diversion disruptions

<sup>16</sup> ICAO PBN iKit - <http://www.icao.int/safety/pbn/SitePages/PBN%20ikit.aspx>. Reproduced with the permission of ICAO.

## 4

### Limitations to Resolve

Although the implementation of PBN can clearly benefit all sectors of the aviation industry, it seldom occurs without imposing significant challenges and/or limitations. Multiple challenges are inherent in any change management. Understanding the full range of variables that need to be addressed will allow the ANSP to better plan where competing interests may arise, the opportunities for compromise and the tasks and timelines that will be outside the ANSP's direct control. PBN implementation reaches across all domains of the aviation sector and demands an appreciation of all areas for successful execution.

**Business Case** – Before deciding to commence PBN implementation, the ANSP, as part of its business case, must confirm what benefits can be achieved. The first step should be to analyse the navigation capability of the domestic and international aircraft fleet to make sure that benefits will outweigh cost, noting that some benefits will be hard to quantify (safety, noise reduction etc.) but should also be included. What percentage of the fleet will only be capable of conventional terrestrial navigation? All stakeholders must realise that increased capability results in increased cost. In Canada for example, although RNAV-based STARs have been in use since the early 1990s, the business case for developing more advanced RNP AR procedures could not be justified until a sufficient percentage of the traffic had completed aircraft upgrades and fleet certification. This was despite one airline having been an early adopter of PBN procedures. The business case for developing procedures for four major airports could only be met when a percentage contribution of traffic from qualified aircraft was defined. Further ANSP benefits may be anticipated if PBN implementation facilitates a reduction in the need for terrestrial-based NAVAIDs.

**Fleet Capability** - The manner in which PBN is introduced is important in identifying limitations. Will it be a phased process or will it be mandated at a certain time or at certain airports? Both paths have their issues, but a common approach is for a phased introduction leading to mixed-mode operations, where both PBN and conventional procedures exist side by side. For RNP APCH approaches, experience has shown that the PBN fleet capability may not be the main issue, given the underlying operational concept which is usually easy to integrate within an existing conventional approach system where, in mixed-mode operations, ATC may switch smoothly from clearing users from a conventional procedure to a PBN procedure. RNP AR APCH requires additional investments at ANSP and airline levels and may require a significant enough number of equipped users. Also, RNP AR approach paths, while offering benefits, often significantly deviate from conventional based routes, and studies should assess how ATC will handle mixed-mode operations with two or more different paths to the airport. For en-route or terminal area operations, experience indicates that in some areas when approximately 70 percent (location dependent) of aircraft operating in any area have upgraded to PBN-capable navigation equipment, then PBN should be used as the primary method of operation. If an airfield is operating at a lower level of capacity or traffic density, it may be appropriate to bring in PBN procedures earlier. In the interim, while mixed-mode operations are required for early benefits, they will introduce complexities and challenges. Mixed-mode operations refer also to fleet capability to use a certain navigation sensor(s), i.e. mixed PBN environment versus mixed PBN and conventional environment such as navigation equipment capable of using GNSS and/or DME/DME within terminal airspace operations. PBN is heavily driven by a specific approval process; therefore attention should be paid to

ensure that, for example, an RNAV 1 capable aircraft is not confused with an RNAV 1 approved aircraft. In the first situation the aircraft is capable of being certified and acquiring operational approval but has not yet done so, while in the latter case, the aircraft and crew are formally approved by the regulator. Understanding the fleet composition is of paramount importance as this is one of the fundamental assumptions that drive the design of SIDs/STARs and approaches.

**Costs** - Implementation involves an investment from the service provider (airport and/or ANSP) but it is the airspace user that often receives the largest benefits. Additionally, mixed-mode operations generate further costs through the need to maintain the ground infrastructure (navigation aids), which in turn could limit the pace of transitioning towards a GNSS environment as recommended by the ICAO Global ATM Concept. Additional considerations include operators' concerns about upgrade costs, savings for ANSPs as NAVAIDS are retired, and airport benefits from additional passengers. A business case based on market-driven demand makes the investment decision simple but safety-driven provision of PBN is not as clear-cut, and will likely be led by the regulatory authority.

**ATC procedures** – If PBN-capable aircraft remain in the minority, controllers may need to develop a means to quickly recognise aircraft that are approved to fly PBN procedures. In a more complex environment this may involve the flight data processor being able to extract the relevant information from the ATC flight plan and displaying this capability in the aircraft label.

**ATC training** - ANSPs must ensure that controllers receive sufficient training and guidance material on handling mixed traffic. Such material will include: airspace design considerations; allocation of the appropriate clearances; and the percentage of approved aircraft needed for the

PBN operation. Following implementation, PBN training should be incorporated into initial ATC training.

**Mixed navigation environments** – These can increase ATC workload, particularly in dense terminal area operations that use differing approach and departure paths. In some cases, ATC has only been able to accept a mixed environment where between 70 and 95 percent of the traffic is approved to the required navigation specification. However, ATC has been able to accept a significantly lower percentage where traffic density and complexity allowed. Also note that a mixed traffic scenario may lead to a reduction in capacity and so may not be appropriate during periods of airspace congestion. For these reasons, it is crucial that operations in a mixed navigation environment are properly assessed in order to determine their viability. Consideration should be given to aligning conventional flight paths as much as practical to new PBN flight paths to reduce the impact of mixed equipage operations.

**Change management** – As with the introduction of all new technologies and procedures, the implementation of PBN must be supported by the controller workforce. If PBN capable aircraft remain in the minority, integrating both PBN and conventional procedures will be challenging. The experience in some countries has been for ATC to revert to more familiar conventional procedures when a sequence gets too busy. Similarly, persuading controllers to leave aircraft untouched to fly full procedures rather than be radar vectored to 'improve' capacity can be challenging. Controllers need to be educated on the benefits that the industry as a whole will accrue from these procedures. Early consultation should be carried out with all PBN stakeholders, outlining the broad range of costs and benefits. An agreement on the benefits and a commitment to PBN may be obtained during consultation.

**Airport capacity** – In capacity-constrained environments, integrating different approaches into a single sequence is not only challenging for ATC, but may also decrease the capacity of an airport. One solution is to consider the traffic management advisor or flow manager as having two modes: a capacity mode for use when mixed PBN/conventional is troublesome and interaction needs to be mitigated to ensure maximum capacity is delivered; and an efficiency mode where the mix can be accommodated and best flight efficiency can be delivered. Consider two modes as an intermediate step during the transition period, with a long-term goal being pure PBN. Night operations, noise curfews, low visibility operations, and high-capacity operations should also be considered.

**Regulatory** – Some States will need to assess the performance of GNSS constellations before deciding to approve usage in their airspace. Because approval and usage depends on measured performance, some States may also decide to monitor signals from GNSS constellations continuously. Sometimes the regulator or CAA has limited resources and infrastructure, so this task is delegated to the ANSP. In other regions, such as Europe, issues arise when GNSS core constellation service providers are not certified as navigation service providers (in accordance with the Single European Sky framework) and so mitigations and/or solutions have to be determined. Similarly, the extension of SBAS over adjacent regions may generate a need for the establishment of formal bilateral agreements.

**Irrespective of the mode of implementation, other challenges must be addressed:**

**Environment** – The accuracy of PBN compared to conventional visual or instrument approaches and the consequent concentration of noise footprints can be a major issue at

many airports. Lateral accuracy of GNSS-based systems provides very precise performance with repeatable ground paths, eliminating the natural variation associated with conventional ground-based NAVAIDs. Community concerns may be mitigated through consultation and, where possible, procedure design that either shares the noise (using differing paths), or provides flight paths that avoid residential areas. Noise-sharing has had mixed results, and can bring about flow management issues without a modern and relatively complex arrivals manager, and a fleet that is able to handle multiple paths. The design flexibility that PBN offers could result in the concentration of noise over specific areas. If the community is not involved early, noise resolution could become a political issue and severely lengthen the approval processes.

**Airspace and Procedure Design** – A State can choose to implement a range of navigation specifications, referenced in ICAO Doc 9613, Performance-Based Navigation Manual. The ANSP and regulatory authority should jointly select the navigation specifications that best satisfy the navigation functional requirements. It is important to take the time to determine the level of sophistication and precision required for a particular airspace or operation before selecting the navigation specifications; the target should be to introduce as few (and as appropriate) navigation specifications as possible. Some countries do not have procedural design resourcing and/or training available (see Resources), or have the regulatory resource and/or subject matter expertise needed to approve PBN procedures.

**Avionics** – From an aircraft operator's viewpoint, there are some avionics systems that are not capable of loading approach procedure identification suffixes, resulting in only a single procedure being available in the system.

With respect to coding, some design choices may not be practicable given existing avionics constraints (e.g. missed approach point (MAPT) positioning in a LNAV approach may create VNAV coding issues for some avionics equipment).

**Implementing Approach Procedure with Vertical Guidance** – Implementing approach procedure with vertical guidance at all aerodromes, as recommended by ICAO, is a substantial task for all States. For example, of Australia’s 300 aerodromes only around 10 percent are currently fitted with ILS approaches providing vertical guidance. From a procedure design perspective, to design APVs for all these aerodromes so as to comply with ICAO’s timelines presents a challenge. Consideration should be given to the aircraft capabilities that will use the published procedures, i.e. barometric vertical navigation (BARO-VNAV) requires an aircraft air data computer, and LPV requires a useable SBAS signal.

APVs require BARO-VNAV or SBAS to provide vertical guidance, but the introduction of BARO-VNAV procedures alone will not solve all of the problems. By implementing BARO-VNAV in Australia to provide APV, the Civil Aviation Safety Authority estimates that 97 percent<sup>17</sup> of fare paying passengers will benefit from the added safety of vertical guidance, but that this will count for only 15 percent of aircraft. To add APV capability for the other 85 percent of aircraft, SBAS would need to be available and the aircraft equipped and authorised for RNP APCH operations to LPV minima based on SBAS.

Note that RNP APCH based on SBAS provides 3D geometric approach profiles, and allows flight down to decision altitudes lower than those associated with RNP APCH based on BARO-VNAV.

**TMA re-design** – TMA re-design may be required to accommodate PBN procedures. Airspace volumes and ATC sectors may need changing to permit optimisation of PBN procedures, and to receive the full benefits of PBN.

**Navigation Database Management** – Most of the PBN navigation specifications have requirements in respect of on-board navigation database, the integrity of which is supposed to be demonstrated as being in compliance with an established data quality assurance process, as specified in DO200/EUROCAE ED 76. This demonstration may be documented with an LOA or other equivalent means.

**Navigation Service Monitoring** – If GNSS becomes an essential navigation service, clear requirements and guidelines must be developed in order to ensure both adequate GNSS service monitoring and the proper allocation of monitoring responsibilities between ATC and aircrew, as well as the aircraft equipment and operator approvals to be used.

**Operating Procedures** – Some States face problems implementing PBN due to the lack of adequate tools available to provide suitable information on NAVAID infrastructure status for the period of an intended operation.

**GNSS Vulnerabilities** – ANSPs must clearly understand GNSS vulnerabilities in relation to GNSS elements system design (e.g. local or wider environmental and ionospheric interferences) and put in place commensurate mitigations/contingency procedures. Usually these aspects are studied within the local safety study conducted before introducing the PBN procedure in service. Contingency operations must be

<sup>17</sup> Civil Aviation Safety Authority Australia – Australian PBN Implementation Plan: [http://www.casa.gov.au/wcmswr/\\_assets/main/media/pbn-plan.pdf](http://www.casa.gov.au/wcmswr/_assets/main/media/pbn-plan.pdf)



considered utilising ground-based NAVAIDs, ATC surveillance, or other means. Note that GNSS also provides benefits such as being less sensitive to local structures or aircraft close to an ILS.

**Obstacles** – Obstacles must be assessed precisely and included within the PBN procedure design study. Depending on the national regulations, obstacles will need to be reassessed periodically (a current recommended practice in Europe is a five year maximum validity period for obstacle surveys). This represents the main maintenance cost of PBN procedures, and should be taken into account during the PBN decision phase. Also, in some areas the proximity of obstacles will not allow the development of basic RNP APCH procedures and may require implementation of RNP AR APCH, pending user acceptability of associated costs.

#### **Why this is important for ANSPs.**

An understanding of the limitations and constraints applicable to a given PBN implementation will be essential if appropriate PBN procedures and navigation specifications are to be selected.

#### **Key Points:**

- Changes need to be broken down to identify the items within the direct control of the ANSP, their magnitude, interdependencies and influence on the identified outcomes.
- Critical path items which may be within the ANSP's control include:
  - Business case development
  - Fleet capabilities and mixed capability environment
  - ATC procedures and training
  - Airspace and procedure design including CDO/CCO considerations
  - TMA redesign with potential re-sectorisation
  - Navigation service monitoring and potential vulnerabilities
- Critical path items that are typically outside of the ANSP's control include:
  - Regulatory changes
  - Environmental impacts
  - Avionics impacts / considerations
  - Navigation database considerations

## 5

### Design Process

A clear and concise set of design requirements, developed in consultation with the affected stakeholders sets the stage for preliminary designs. It is highly likely that the first design prototype will go through refinements, making it imperative that all of the contributing parties are familiar with the considerations in this chapter.

#### **PBN Design involves a number of steps:**

**Scope the task** – Consider what accuracy level of PBN is required – use the least restrictive navigation specification appropriate. Based on traffic types, volumes, equipment levels, terrain and other constraints determine whether it is more appropriate to provide PBN procedures with just tracking guidance; or include some speed and level constraints for ATM; or provide fully separated arrival/approach and departure procedures. A high level of consultation will be required to ensure that all user needs are identified and, where appropriate, accommodated. Refer to Appendix A for a typical PBN stakeholder list. RNP APCH<sup>18</sup> or A-RNP approach specification may provide a better solution than RNP AR.

RNP AR approaches are a useful design solution for terrain-challenged airports, taking advantage of curved path RF legs (for a capable fleet) within the final segment. The RNP AR operational approval process is highly demanding for all (operators, airport, ATC, and regulator). RNP ARs are defined as an LNAV/VNAV level of operation (BARO-VNAV navigation sensor), compared to RNP APCH operation which may permit LPV mode if a regional SBAS signal is provided.

A-RNP (Advanced RNP) approach specification allows for RF legs, but doesn't require as demanding navigation performance (e.g. Inertial Reference Systems).

RNP approach design is less complex, and in its simplest form it can be one straight leg.

**Confirm the Concept of Operations**, including an appropriate navigation specification. This may be subject to surveillance coverage, traffic volume, fleet capability, adjacent regional navigation specifications, regulator-approved safety case, capability of reversion in case of GNSS loss, etc. For example, for terminal airspace operations both RNP 1 and RNAV 1 specifications are used to support area navigation on SIDs and STARs, and on approach transitions up to the initial approach fix (IAF). However, GNSS is the primary navigation sensor to support RNP 1, either as stand-alone or as part of multi-sensor systems, while RNAV 1 also supports an equivalent DME/DME mode; therefore RNP 1 should not be used in areas where signal GNSS interference will significantly impact the airport operations.

**Develop Instrument Flight Procedures** – While the en-route portion must be considered, the focus of this document is on PBN implementation in the terminal environment. Phases to consider here include:

- Approach and missed approach (APCH) Design to the primary runway first, and consider traffic types and equipment to determine which type or types of approach are appropriate.
- Arrival (STAR) Based on anticipated traffic, determine an appropriate number and location of commencement and convergence points. Whether a single three-degree glide path is appropriate will depend on terrain, airspace, and other restrictions such as ATM requirements.
- Departure (SID) If there are significant performance

<sup>18</sup> RNP APCH navigation specification may be referred to as RNAV(GNSS) on approach plates.



variations between aircraft types (e.g. jets, turboprops, general aviation) consider designing high as well as low performance departure paths using different climb gradients.

Outcomes can incorporate air traffic management procedures such as speeds and levels, which would otherwise be applied tactically by ATC. RNAV and RNP flight paths may simply overlay existing VOR/DME procedures, although they will not be constrained by the same limitations as conventional procedures.

The best practice design process should consider:

- **Taking a 'Clean Sheet'** approach to PBN procedure design – and then re-design VOR/DME procedures (for conventional/contingency use) to align with PBN
- **Minimising the number of feeder fixes** into, and departure gates out of, the terminal environment. Note that an aircraft's avionics limitation of 30NM may apply to SIDs and STARs, i.e., basic GNSS procedure design for arrivals assumes that the transition between en-route and terminal phases of flight occurs at 30NM from the arrival ARP (aerodrome reference point)
- **Minimise number of legs** on a procedure, while providing sufficient detail to allow for an efficient hands-off procedure
- **Leg descriptors** – understand the path and terminator code options (Appendix C), e.g. TF (track to a fix), RF (constant radius arc), CF (course to a fix), and CA (course to an altitude). Note that RF leg capability is not available to all flight management systems (FMSs) or stand-alone navigation avionics. The A-RNP navigation specification allows a wider range of aircraft to fly RF legs
- **Leg Distance** – ICAO recommends 5 NM optimum lengths for initial approach segments which ensures that the minimum segment length for aircraft indicated airspeed (IAS) up to 210 knots (KT) below 10,000ft will be accommodated. In New Zealand a minimum of 4.15 NM is used, e.g. for a T-bar procedure with short initial approach fix (IAF) to intermediate approach fix (IF) legs. The minimum segment length for legs of less than 5 NM shall be not less than the distance required by the highest initial approach speed for the fastest category of aircraft for which the approach is designed. This distance is the sum of the minimum stabilisation distances required at the IAF and IF. Lowering the procedure limit speeds may be required.
- **Turns** – For the offset initial approach segments, the shortest possible track distance will occur when a 110 degree turn is made at the IAF and a 70 degree turn is made at the IF for a Y-bar procedure and when a 90 degree turn is made at either the IAF or the IF for a T-bar procedure. Bank angle limitations should be considered. Boeing and Airbus have different bank angles permitted within their autopilot functions. Turn radius will be driven by operational design considerations and limited by bank angle, speed, and atmospheric conditions
- **Speed Requirements** for either procedure design (e.g. airspace containment, obstacle clearance.) or for ATM. A speed restriction may be used to limit lateral dispersion on departure or arrival and the waypoints where speed restrictions apply/cease must be established
- **Level Requirements** – At or above / at or below levels may be used to facilitate separation of SIDs and STARs.

Appropriate levels may be determined through the use of climb/descent gradient tables or graphs, and following consultation with operators. The waypoints where the altitude restrictions apply/cease must be established

Be wary of trying to satisfy everyone – accommodate individual stakeholders where possible, but overall system efficiency is the goal. Keep it simple to avoid over-taxiing either ATC or the pilot.

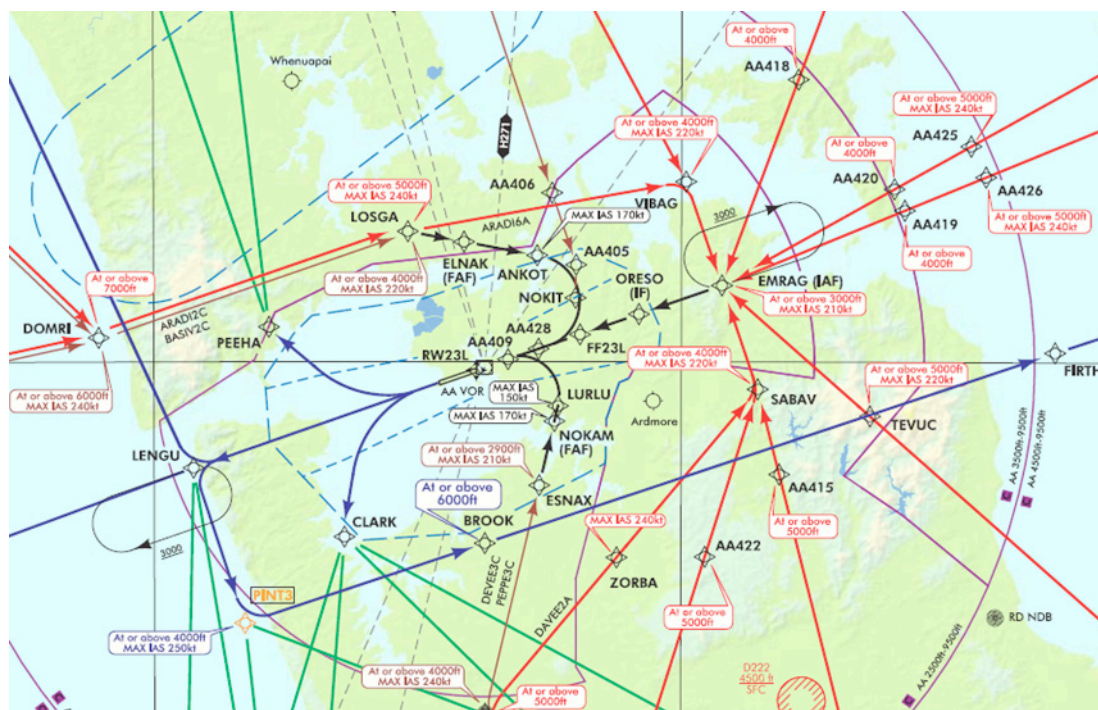
The design process will require input and feedback from all stakeholders, and is an iterative process – it may take several revisions before a firm

concept can be established. The recommended core design team membership can be found in ICAO Doc 9992, Manual On The Use of Performance Based Navigation (PBN) in Airspace Design, Section 2.2.2.2.

The diagram below is an example of a PBN concept that includes ATM speed and level restrictions, as well as catering for short and long approaches.

### Why this is important for ANSPs.

Insights to the design processes used by other ANSPs, including some of the issues and potential solutions, will help ensure that the complex process of developing a PBN implementation runs more smoothly.



PBN concept that includes ATM speed and level restrictions, and caters for short and long approaches

### Key Points:

- Design considerations must be addressed both as individual variables, as well as how they contribute to the overall result for the airspace and/or procedure implementation
- Procedure design criteria contains limits related to anticipated aircraft performance; however while adhering to criteria it is still possible to create a design that is unsuitable for ATC or flight crew due to its complexity
- An iterative construction process between ATC and its flying customers is necessary in all but the simplest of designs

## 6

### **Knowledge and Training**

All stakeholders in the PBN process are experts in their respective domains. Knowledge sharing and collaboration among stakeholders is essential.

Knowledge sharing should begin with key decision-makers to facilitate the required organisational direction and guidance. Key decision-makers include executive managers, operational managers, ATC training centres and team leader groups.

A PBN presentation can be used as an education tool for these leaders and will also prove valuable for scoping and consultation meetings. In addition, it will provide all stakeholders with a common vision.

#### **Promulgating PBN Knowledge**

While the ICAO framework has harmonised and simplified many of the navigation specifications and definitions associated with PBN, it remains a complex subject that is not always easy to explain to those who are not immersed in the field.

PBN knowledge is gained and shared through publications such as this CANSO PBN Best Practice Guide for ANSPs, as shared experiences promulgated through CANSO / ICAO-type forums (e.g. PBN symposia), via initiatives like ICAO/IATA Go-Team visits, and through online training resources. The training messages must continue to be updated and reinforced. Messaging needs to be presented at a level that is appropriate for the target audience: more technical detail for procedure designers, PBN subject matter experts, pilots and controllers; less so for managers and non-technical audiences; outcome-focused for the general public.

Education is enhanced if the target audience can be reached in a range of media, so that many different learning styles are catered for. It is important that the products provide a broad reach, are user-friendly, inviting and informative. Involving training and/or communication specialists is recommended. Consideration should be given to the use of computer-based training (CBT); an informational website; printed material such as a newsletter, pamphlet or brochure; and initial and recurrent training.

CBT can be an effective medium for training controllers, ANSPs, airlines, pilots, airport companies, environmental specialists, and regulators, and allows the staff to log in remotely to complete and review the PBN CBT as needed.

An organisation's internal website could provide PBN background, benefits, implementation plans, and links to the CBT and other educational and technical PBN resources. An external website can provide the ANSP's stance on PBN, educate users<sup>19</sup>, outline benefits for customers, raise the profile of PBN, and provide an overview of the PBN implementation plan.

Newsletters, pamphlets and brochures, can be used to target internal as well as external customers. Newsletters are a means to provide regular communication with graphics and feature articles on such topics as PBN basics, mixed-mode operations (PBN and conventional), and benefits to concerned stakeholders. Brochures and pamphlets are a way to target and inform both internal and external sources.

Initial and recurring training is a critical step in ensuring new knowledge is incorporated

<sup>19</sup> Fundamentals of PBN – RNAV Stars <http://www.navcanada.ca/EN/products-and-services/Pages/on-board-operational-initiatives-pbn-rnav-video.aspx>

and existing knowledge is current and retained. Initial and recurring PBN training should cover theory as well as practical requirements for PBN, and can take many forms. A classroom would be suitable for PBN history, benefits, design process, and concept of operations; a flight-deck video of a PBN flight from start to finish; or a presentation from a senior pilot with significant PBN experience. A simulator would be a good option for training and reinforcing routine PBN, mixed-mode operations, and contingencies including runway changes, NAVAID/GNSS failure or interference, and emergencies.

Another form of initial and recurring training that should be considered is cross-familiarisation. In this scenario, the ATCs spend time on the flight-deck observing pilot PBN operations, and the pilots spend time in the radar centre and/or the approach tower.

PBN SME development – Building knowledge among PBN professionals can be facilitated through participation in workshops such as the Australasian PBN Users Group, ICAO European PBN Task Force, or involvement in ICAO forums, visiting neighbouring ANSPs, and even through short-term staff exchange programmes. Building relationships with PBN experts who have learned from experience can be one of the best

ways to avoid repeating mistakes that have been made by others.

An appropriate level of education is required for managers, avionics technicians, procedure designers and for non-ANSP stakeholders, but it is the pilots and controllers who will apply PBN operationally. It makes sense for pilots and controllers to learn together and/or cross-train when possible, as this will provide efficiency of training time as well as depth of understanding that will not otherwise be achieved. For instance, Airways New Zealand provided introductory support for Mount Cook Airlines PBN training, and Air New Zealand provided flight simulator video support to Airways New Zealand. However there will be elements of job-specific training which must remain targeted. Start early to encourage interest in PBN by highlighting the benefits to both controller and pilot. PBN implementation procedures and certification require extended training time and include CBT, classroom, tower-simulator, and competency checks.

#### **Why this is important for ANSPs.**

Appropriate knowledge-sharing and training, from senior managers down to the end-users, is necessary to ensure a successful PBN implementation.

#### **Key Points:**

- Begin knowledge-sharing with key decision-makers
- Make use of existing PBN resources (ICAO etc.)
- Use a range of media to inform and educate
- Provide pilot / ATC cross-training if possible

## 7

### Vertical Profile Optimisation

#### **Continuous Climb Operations and Continuous Descent Operations in the PBN environment**

PBN capabilities should be considered as an enabler to enhance the vertical element of climbing and descending traffic. PBN eases the implementation of CDO and CCO, which help to deliver the improvements needed for flight efficiency and environmental benefits. Working together with PBN, CDO/CCO contributes to airspace optimisation and will assist future systems interoperability.

CDO and CCO are tools available to ANSPs that enhance safety, predictability and airspace capacity while impacting fuel burn, emissions and noise. For ANSPs and airport operators, it is important to understand the benefits and limitations of PBN capabilities when introducing continuous descent and continuous climb operations.

CDO is defined in ICAO Doc 9931 Continuous Descent Operations (CDO) Manual 'as an operation, enabled by airspace design, procedure design and ATC facilitation, in which an arriving aircraft descends continuously, to the greatest possible extent, by employing minimum engine thrust, ideally in a low drag configuration, prior to the final approach fix or final approach point.'

CCO is defined in ICAO Doc 9993 Continuous Climb Operations (CCO) Manual as 'an aircraft operating technique enabled by airspace design, procedure design and facilitation by ATC, allowing for the execution of a flight profile optimised to the performance of the aircraft. CCO enables the aircraft to attain initial cruise flight level at optimum air speed and engine thrust settings set throughout the climb, thereby reducing total fuel burn and emissions during the whole flight.'

#### **Benefits to ANSPs using enhanced vertical profiles**

CCO/CDO enabled by ANSPs, and supported by the collaboration between different stakeholders, make it possible to facilitate efficient terminal operations through optimisation of horizontal and vertical profiles and reduce the need for climb and descent intervention. CCO/CDO profile procedures increase efficiency, flight predictability and airspace capacity while minimising noise impact. When an ANSP is validating the implementation of these procedures, the air traffic control officer's workload should be considered.

#### **Constraints impacting on implementation of CCO/CDO operations**

The rationale behind CDO/CCO operations based on PBN design is to implement a procedure that allows the aircraft to fly the optimal climb/descent profile (close to ideal fuel efficiency), the so called 'pure' CDO/CCO. It is evident that in complex terminal areas, such as a multi-airport environment, CDO/CCO scenarios may be implemented with full benefits only during certain parts of the day. Nevertheless, in a single airport environment supported with an advanced PBN airspace structure, CDO/CCO operation will provide enhanced efficiency – fuel savings, reduced CO<sub>2</sub> emissions, and noise mitigation. A detailed data performance comparison can help highlight the benefits of CDO/CCO, after PBN implementation in terminal areas, compared with conventional SIDs/STARs. The implementation of arrival management tools and departure management tools at medium and high traffic airports will assist in facilitating CDO and CCO, enabling minimal holding and departure queuing in typical situations. RNP-capable aircraft have greater predictability of position, which helps enable continuous climb or descent operations. Validation initially performed by fast time



simulations and lately by real time simulations may be needed in order to check that the new airspace concept works.

#### Implementation for ANSPs and other stakeholders

CDO/CCO procedures may be implemented in conjunction with significant airspace changes in a high density traffic environment. Airspace changes are less likely to be required in a simpler area/environment. Extensive collaboration will be required in the early design stages involving the ANSP, airspace users, airport operator, regulators and environmental entities. Research and development input will be required to assess and refine concepts.

Surveillance data and flight data recordings (FDR) will help if flight trials are performed. RADAR data will provide information about the tracks flown and will help to assess the level of predictability achieved. FDR is a detailed and valuable source of information and could provide relevant information such as fuel consumption etc. The design group will require some expertise in FMS. The path generated on-board should be easily modified by the flight crew, using standard procedures to perform any required tactical modifications.

#### Why CDOs and CCOs are important for ANSPs

The enhanced management of vertical profiles on climbs or descents, together with the use of PBN, provides safer, more cost-effective operations in terminal areas. PBN procedures facilitate the increased use of CCO/CDO, which

improves flight efficiency and reduces fuel burn, emissions and noise. There may also be workload reductions for pilots and ATC.

In order to implement continuous descent and/or climb operations it is important to bring together an appropriate group of stakeholders, providing the opportunity to collaborate with experts in each field and enhance prospects of successful validation and implementation of CCO/CDO.

#### Key Points:

- CCO/CDO benefits include reduced fuel burn, CO<sub>2</sub> emissions, and environmental noise
- Complex terminal areas and high traffic levels may prevent continuous CCO/CDO usage

## 8

### Rules and Regulations

#### Background

In order to enable PBN operations, it is essential that all component pieces work together. Like the multiple gears on a watch, each contribution must be synchronised to allow the operation to succeed. The graphic below indicates some of the regulatory components that are needed to support a PBN operation.

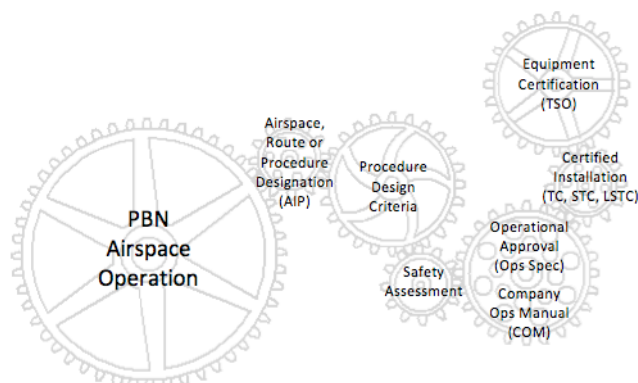
The rate of introduction of new technologies in aviation is straining CAAs to keep pace with the broad range of approvals for their use. Environmental and financial pressures in aviation demand that CAAs, airlines, and ANSPs have the ability to bring new technologies into operational use in a timely and efficient manner.

Early adopters (e.g. New Zealand and Australia) find themselves implementing prior to ICAO guidance being available and therefore may lack sufficient guidance from ICAO develop native solutions. While these solutions may end up being similar to the eventual ICAO product, it requires significant effort from SMEs to develop safety cases, procedures, and regulations.

Equipment installed in an aircraft must meet Minimum Aviation System Performance Standards (MASPS) and Minimum Operational Performance

Standards (MOPS) that are developed in consultation with regulators and industry. RTCA (Radio Technical Commission for Aeronautics) and European aviation standardisation body, Eurocae, facilitate this development. These standards (MASPS and MOPS) form the basis of certification documents and Technical Standards Orders (TSOs) against which CAAs will require aircraft registered in their States to demonstrate compliance.

Installation of equipment must be authorised through a Type Certificate, Supplemental Type Certificate, or Limited Supplemental Type Certificate. When required, a final stage would include an operational approval as to how these certified pieces of equipment, installed to an accepted standard, will be operated by the flight crew in the context of a specialised aviation operation. Operational approvals can be achieved in a number of ways, including; Operations Specifications (Ops Specs), Letter of Authority (LOA) and simply through approval of a Company Operations Manuals (COM). The approvals process should be kept uncomplicated, and use of deeming provisions should be considered to remove some of the process workload.



### Regulatory coordination

Just as airlines need to flight plan using aircraft with sufficient range and capacity to meet market demands, CAAs need to plan their resource application across the full scope of their initiatives. The best way to ensure that the CAA's plans are complementary to those of ANSPs and the industry is to begin with a shared broad strategic direction. This direction may start in the form of a CAA policy but must eventually result in a more specific State PBN implementation plan.

ICAO introduced the PBN concept in April 2007 through the issuance of State Letter AN 11/45-07/22, Guidance Material for the Issuance of Performance-Based Navigation (PBN) Operational Approvals, Volume II of Draft Doc 9613. The concept received endorsement at the 36th General Assembly, recorded in Resolution A36/23, and was again supported at the 37th General Assembly in Resolution A37/11. These resolutions call for each State to develop a PBN implementation plan based on the navigation specifications available in Doc 9613.

There is no set formula for a State PBN implementation plan; however, the plan's content and the manner in which it is coordinated are essential.

The Plan's general section should cover a few essential elements, including:

- The legal and regulatory framework within the State and/or region as to how air navigation services are provided
- The scope of responsibilities of each player in the provision of navigation services
- Support of, or differences filed against, applicable ICAO PBN standards and recommended practices (SARPS) and Resolutions
- Other supporting State documents

The plan should address the manner in which the CAA will develop, implement and/or enforce PBN regulations. This will include international harmonisation efforts and how other State's approvals will be recognised. The plan will also provide the reader with the consultation processes available for stakeholder involvement.

As a minimum, short, medium, and long term PBN milestones should be identified. These milestones may be further classified into phases of flight and/or geographic regions. The milestones should provide a clear indication of the expected performance levels and when they are required for all users of the air navigation system. Specifically in instances of planned airspace mandates or incentives, a benefits rationale should be provided.

Although the nature of the State PBN implementation plan is strategic, the contents of the plan must also be able to be tactically applied by its users. As an example, if the State plan includes a proposed performance mandate in an airspace segment, the affected customers may plan the retrofit or retirement of a segment of their fleet in advance of the mandate.

Aeronautical Information Circulars (AICs) are the CAA's and ANSP's primary means of official notification to the aviation community of impending changes. Since the State Aeronautical Information Package (AIP) will contain AIC references, it is the ideal forum for early notification of PBN navigation specification adoption and airspace requirements.

As planning progresses, where regulatory approval is needed, Advisory Circulars (AC) should be drafted with specific guidance related to equipment, installation, maintenance, operation, and training. Where special equipment, procedures, or training are involved, an additional approval may be required in the form of an Ops Spec or LOA related to the guidance provided in the AC. In less



complex PBN applications, CAA safety oversight of operational eligibility can be exercised through a combination of Instrument Flight Rules (IFR) licencing, equipment airworthiness certification, and COM approvals.

### ANSP specific considerations

The bulk of aviation regulation is focused on air operators; however, there are a number of PBN items that need to be addressed specifically by the ANSP.

The promulgation and adoption of procedure design criteria is a critical element. As new navigation specification (nav-specs) are published by ICAO, the corresponding procedure design criteria that can make use of the defined performance level must follow. ICAO Doc 8168, Procedures for Air Navigation Operations and United States Standard for Terminal Instrument Procedures (TERPs Doc 8260 series) provide ANSPs with defined criteria for application of the various nav-specs. Their use in the State must be approved by the CAA.

PBN nav-specs have opened the opportunity to re-examine ATC procedures and separation standards to improve efficiency. ICAO Doc 4444, Procedures for Air Navigation Air Traffic Management continues to be amended to reflect these advances, particularly in the application of procedural (non-surveillance) separation. ANSPs will also need to consider the regulatory impact of introducing new PBN procedures into surveillance terminal operations where procedures and separation are based on specific references to conventional procedures and NAVAIDs, such as ILS, and may not enable the full benefits of introduction of new PBN procedures.

Infrastructure assessment will be needed to ensure that an appropriate navigation

infrastructure is available to support PBN operations (e.g. DME coverage studies for DME/DME supporting RNAV1) and for backup purposes, in case of GNSS loss.

Airline and ANSP safety management systems (SMS) typically require a safety case and risk assessment to be prepared for any significant PBN implementation. Environmental assessments may also be required, in order to satisfy the airport and community that the impact of any implementation will be acceptable with respect to noise exposure and carbon emission levels.

Timely Publication – The standard Aeronautical Information Regulation And Control (AIRAC) schedule has lead-in times which must be met. Procedure designers, publishers, flight test/validation, and database coders all need time to thoroughly carry out their work, so planning activities must take all these stakeholders' time requirements into account. In order to accommodate publication activities, it is recommended to publish 56 days in advance of the effective date of the procedure. Flight test/validation involvement is required well in advance of the publication date.

### Consultation

The key to good PBN regulations is to ensure good knowledge of: the equipment proposed for a given operation; the structure of the air navigation system (ANS); and the operating procedures of the stakeholders. This will ensure that regulations are not overly prescriptive, but provide the required safety oversight while protecting the public interest in aviation operations. This work cannot be accomplished in isolation by either the CAA or the ANSP. Cooperative consultation is critical between the regulatory authority, the service provider, other stakeholders, and the users of the ANS. The CAA will contribute in-depth certification and approval expertise; the ANSP will provide expertise in air

traffic and service provision procedures; and the customer air operators will have the most detailed experience with the installed PBN equipment and their operation within the confines of applied standard operating procedures.

Owing to the fast pace of change desired to achieve environmental and financial results, countered by the relatively long lead times for regulatory changes, a regulatory component of the consultation process established in the very earliest stages of PBN implementation is essential. Consultation initiated in the form of a workshop that can facilitate brainstorming will bring all stakeholders to a common level of understanding of the current and proposed future PBN environment. Participants will be able to form the basis of a cooperative PBN implementation plan that balances the need for safety and efficiency.

Knowledge of the proposed regulatory framework is a prerequisite for the ANSP's concept of operations (ConOps). From the ConOps flows the ANSP's and their customers' complementary business plans. As the ConOps evolves into a specific implementation plan, on-going ANSP, CAA and customer consultation is needed to ensure that the plan execution continues to respond to the objectives identified in the original ConOps. Revisions may be required as variables change and opportunities are presented. Development is an iterative process – the ConOps can drive regulations and vice versa, but it is important that the regulations

are not allowed to develop in isolation. Good examples of collaborative development are Australian Civil Aviation Orders (CAOs) 20.18 and 20.91, which were negotiated over several years through a representative forum (ASTRA) involving stakeholders from all levels of the industry.

Airspace regulations protect the public interest and provide the framework for safe operations. Continuous open consultation between ANSPs and their customers with the State CAA is essential to ensure that regulatory instruments are developed that enable efficient operations while meeting the safety oversight requirements of the State.

#### **Why this is important for ANSPs.**

Regulatory issues are the number one impediment identified in the 2012 CANSO PBN SG survey of ANSPs to determine the reasons why an ANSP has not started PBN implementation. One quote from a responding ANSP captures the essence of the concern: "PBN arrival, departure and approach procedures are available for the whole of our FIR (Flight Information Region), but we do not have the necessary regulatory documentation that defines the criteria and conditions under which those can be utilized". To overcome this key inhibitor to PBN implementation, knowledge of the relationship between airspace operations, design criteria, aircraft operational approval and aircraft equipment certification is needed. This chapter will assist the ANSP in assessing, planning and developing a regulatory strategy.

#### **Key Points:**

- To ensure the CAA's plans are complementary to the ANSP and industry plans, they should begin with a shared broad strategic direction. This could start in the form of a CAA policy that evolves into a State PBN implementation plan
- Cooperative consultation is critical between the regulatory authority, the service provider, other stakeholders, and the users of the air navigation service
- Knowledge of the equipment proposed for a given operation, the structure of the air navigation service, and the operating procedures of the stakeholders, is paramount to the effective development of PBN regulations

## 9

### Fleet Equipage

#### Background

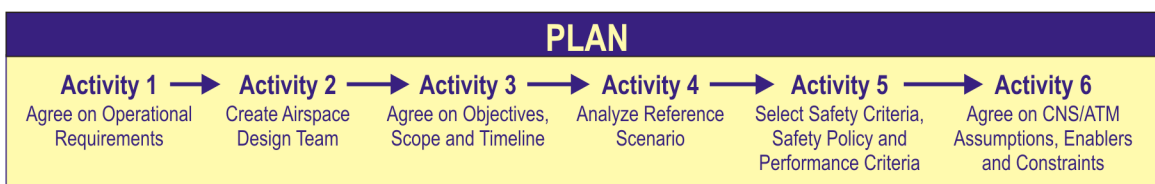
As documented in ICAO Doc 9613 PBN Manual and ICAO Doc 9992 *Manual on the Use of PBN in Airspace Design*, the development and implementation of the airspace concept involves four main phases: plan, design, validate, and implement. Planning activities generally take most time to ensure that all appropriate information is collected, analysed, and documented. Thorough planning successfully facilitates the design, validate, and implement phases. Within the planning phase, Activity 6 (see below) enables the ANSP to define and agree the CNS/ATM assumptions. One key assumption addresses the navigation capability of the aircraft.

#### Understanding the Application

To ensure appropriate selection of the navigation specification, GNSS performance and aircraft capabilities need to be fully understood by the design team. To understand these, the ANSP may rely on the operator(s) and/or its own avionics or operational experts participating in the design team. To fully understand equipage levels, the operators' respective 'technical pilots' and/or flight operations engineers should participate to bridge the gap between aircraft capability and operator approval (see Section 7). For example, the ANSP may find that several aircraft are equipped and capable to fly the navigation specification; however, the operator may not have undertaken the necessary approval requirements from the regulator to receive authorisation to fly

the intended navigation specification. To receive authorisation or approval from the regulator, the operator must apply and substantiate the appropriate training and validation of on-board navigation equipment to meet the requirements of the specification.

One of the challenges for the ANSP is to understand the various types of aircraft equipage that may operate in its airspace today and in the future. Multiple mixed-equipage types can exist. For example, different FMS and standalone navigation boxes may be resident within the same operator, as well as the same aircraft family (e.g. B737, B757, A319, A320, Q400). To exacerbate the issue, the operators may select different options within the same FMS or standalone navigation equipment. It is therefore imperative to have the operators present and fully engaged in the planning, design, validation and implementation processes. The flight-decks pictured on the next page provide an indication of various instrumentation layouts, FMS and standalone navigation boxes:



ICAO Doc 9992 - *Manual on the Use of PBN in Airspace Design*<sup>20</sup>

<sup>20</sup> Reproduced with the permission of ICAO.



Examples of instrumentation layouts, flight management systems and standalone navigation boxes



**A340**



**B737-800**



**Bombardier CL60**



**Embraer 145**



**Cirrus**



**Cessna 172 Skyhawk**

Careful planning and understanding of varying aircraft equipage will improve an ANSP's probability of success during the implementation phase.

ANSPs may consider several methods to accurately identify the aircraft navigation equipage capability operating in a given airspace.

#### *ICAO Flight Plan Information*

ICAO Flight Plan information provides detailed data on aircraft capabilities of the various operators. Although this information provides quantitative data, it does not address aircraft that may be capable but do not file the appropriate flight plan designator for other reasons (i.e. lack of operational approval, or no procedures developed or utilised by the ANSP). There is also a need to validate data reported in the flight plan that are correctly stating PBN capabilities before acting on the results of filed data (e.g. some operators are not filing a flight plan (FPL) in accordance with real aircraft capabilities).

In addition, not all of the current ICAO navigation specifications are defined in Flight Plan 2012 (e.g. Advanced RNP), and some issues regarding accuracy of Flight Plan information have already been identified in several countries.

#### *Industry Data*

Industry data provides a global, regional and facility snapshot of current and potential equipage data; however, the fidelity of the data may be skewed depending on parameters selected to develop the desired equipage levels.

#### *Operators*

As identified in both ICAO Doc 9613 and Doc 9992, technical pilots, flight operations engineers and similar personnel from airspace operators are key participants in the establishment of the 'Core Airspace Design Team.' They bring understanding and expertise

to the team in terms of operational and approved capabilities of the representative aircraft operators. This collective knowledge base is only as good as the representative sample of aircraft operators. As a result, this method is highly regarded as key to the successful determination of navigation equipage capability in the airspace. Conversely, limited or lack of participation of operators reduces the probability of successfully identifying the navigation capability, thus jeopardising the implementation phase through inappropriate selection of the navigation specification(s).

The methods described above should be considered most effective when used collectively to determine the navigation equipage. Depending on the complexity of the airspace design, one or all methods may be required. Regardless of which method(s) is chosen, having operators fully engaged in the process is highly recommended.

#### *Navigation (PBN) in airspace design*

The decision to proceed with PBN development with regard to equipage is a matter for each country or airspace. In some airspace regions, such as Australia, mandates exist for aircraft equipage. In other regions, such as the United States, equipage defines what procedures may be flown, but not necessarily right of entry into the airspace. Thus, airspace and procedure designers need to be familiar with their own State's requirements so as not to unduly limit the operations into the proposed PBN design area. However, designing to the lowest common denominator of equipage may result in fewer benefits for the airspace system. In particular, aircraft operators equip and train to realise a return on investment. If there is no benefit to be received from PBN because the ANSP has downgraded the design for legacy aircraft, then those aircraft operators that have equipped to gain efficiencies are in effect penalised for modernising. A balance must be sought between

providing maximum benefits for fully equipped PBN aircraft while still maintaining access for less equipped aircraft. Often this may take the form of developing several routes or navigation specifications, with the primary benefit going towards an efficient PBN airspace design, while still keeping some routes available to allow access for less capable aircraft.

In considering the development of PBN procedures in an airspace region, several fundamental questions must be considered to determine if an equipage capability should be considered:

- Will the new procedures result in the removal of non-PBN procedures?
- Will the new procedures result in airspace conflicts with legacy procedures, if legacy procedures are not removed?
- Does a flow management system, such as trajectory-based flow management, exist to help meter traffic?
- Is congestion a reason for the implementation of the PBN procedure?
- Do sufficient capably equipped aircraft exist to justify the time and expense for implementation at this time?

The following countries' experiences add depth to the equipage discussion:

#### New Zealand:

- The majority of the New Zealand fleet fly TSO-C129 receivers, with some TSO-C145 or TSO-C146s. CAA New Zealand has stated that TSO-C145/146 will become a requirement.
- As a general rule, jet operators were suitably equipped; however seven Boeing 737-300 aircraft were non-GNSS, necessitating DME/DME/IRS approvals and route operating limitations.

- Several different manufacturers, models and certifications exist so one single solution is not appropriate.
- The ANSP must provide a suite of procedures within a limited navigation-specification (nav-spec) provision:
  - ANSP/operators can refer to the State PBN Implementation Plan for nav-spec. However, if the standard has not been mandated, operators may delay upgrading (creating a PBN implementation mixed-mode issue).
  - The ANSP may need to cater for legacy equipped aircraft such as Boeing 190 with TSO—129 and no FMS or autopilot.
  - As a guideline, if 70 percent or more of flights are equipped for a given nav-spec, then the design should be to that nav-spec (ideally 70-90 percent, in line with ICAO Doc 9992 2.3.5.4 – Manual on the use of PBN in airspace design). Procedure Designers can then design to a limited number of nav-specs (e.g. ENR RNAV 2 and RNP 2, SID/STAR RNAV 1 and RNP 1, RNP APCH (RNP 1+0.3) (commonly referred to as 'RNAV(GNSS)'), and RNP AR, and perhaps A-RNP.
  - If or when the regulator mandates differing navigation specifications, instrument flight procedures might need to be modified.

#### Australia:

- Even in a mandated equipage environment like Australia there will be issues with mixed mode operations, but particularly during the transition period
- By its nature, PBN means there will never be a homogeneous equipage environment. However, in practical



terms, only a few combinations of avionics will likely give the required performance.

- Integrating approaches with different lateral paths into a single sequence is challenging for ATC, particularly in capacity constrained environments. The typical reaction experienced in Australia is to discontinue issuing the RNP AR approach (which is the exception in the current environment) when it looks challenging. Higher uptakes are expected to tip the balance and produce different results. The 70 percent figure quoted in the New Zealand context above is supported by the experience in Australia.
- To assist the air traffic controllers, decision support tools should be considered. Human factors and workload need to be addressed if the benefits of PBN approaches are to be preserved while maintaining capacity.
- States may consider localised equipage mandates in preference to a wholesale mandate like Australia, i.e., local to a particular airport, area, or airspace category. This should be justified on a safety, flight efficiency, community, or environmental basis.
- A consideration if moving toward mandated equipage is the capacity of the local support industry to deliver the required avionics equipage. Further, it

can be time consuming for engineers and aircraft maintenance engineers (and expensive for owners) where there is no Supplemental Type Certificate covering the navigation equipment for a particular aircraft type.

Thorough planning is the key to a successful PBN implementation. Understanding aircraft equipage in a given airspace allows the design team to accurately determine and execute the appropriate navigation specification for existing and future operations. Working with the operator is vital to ensure complete understanding of both aircraft capability and operator approval in support of the selected navigation specification.

#### **Why this is important for ANSPs.**

Fleet equipage issues are one of the top four impediments identified in the 2012 CANSO PBN SG survey of ANSPs to determine the reasons why an ANSP has not started PBN implementation. Accurate assessment of aircraft equipage operating in the airspace occurs during the discussion of the navigation capability assumption. A misunderstanding of this assumption can lead to serious flaws in the selection of the appropriate navigation specification and therefore jeopardise the total airspace concept and resulting implementation. Understanding the application of fleet equipage in the planning process will save ANSPs' valuable time and resources.

#### **Key Points:**

- To ensure the appropriate selection of a navigation specification will be utilised in a given airspace concept, the ANSP must secure the requisite expertise on the design team
- The challenge to understanding aircraft equipage can be accurately determined by having the operators pilots and/or their respective avionics engineers as members on the design team
- The fact that an operator has PBN capable aircraft does not necessarily mean that their aircraft have been operationally approved. The operator may not have received authorisation from the regulator to fly a designated navigation specification

## 10

### Resources

#### **Background**

PBN implementation requires the involvement of multiple disciplines across the ANSP and across a broad range of stakeholders (Appendix A). Participation does not always require a single dedicated resource from each area, but will require a minimum to ensure a continuity of involvement, with spikes in resource demands from SMEs at various stages.

The scope of PBN implementation by an ANSP is national, with requirements influenced by the desire for international harmonisation. The specific States' accountability for implementation may be further divided regionally. However the responsibility is distributed, it is essential that coordination takes place well in advance of the planned implementation. The lead time will depend on many factors, such as existing ANS and regulatory structures, complexity of the change, and the desire by all stakeholders for change. Coordination can never be started too early, since lead time can easily extend over several years. Stakeholders should understand the constraints of the AIRAC cycle and the lead-in times that it imposes on implementation (particularly if airspace changes are required).

Suitably skilled staff are scarce, expensive to train, and liable to being recruited by other ANSPs, airlines, regulatory authorities, etc. Human resource development and succession planning are important to build and maintain capability.

#### **Resource allocation – national, regional, or local?**

Irrespective of where the accountability to deliver PBN rests—national, regional, or local—the implementation resources will need to be drawn from a broad spectrum of expertise. Within each FIR, resources will be required to

gather data, coordinate activities, and act as the interface to front line air traffic controllers in the introduction of both new concepts and specific delivery of programmes. In addition to the mechanics of implementation in each area control centre (ACC) and at each airport, there should be a local resource to act as an 'agent for change' or 'PBN Champion' for the new way of providing services that PBN will bring. Direct management oversight and union involvement of the local PBN implementation activities is required owing to the potential changes to the way that controllers conduct services as well as allowing for changes in staffing distribution and work assignment levels that new PBN concepts may enable.

Some of the more regionally specific resources would include, but are not limited to:

**Data collection and analysis** – This involves gathering track files to identify current traffic flows, runway usage, and airspace 'choke' points; extraction of local knowledge from current air traffic personnel; participation in development of simulations for base and option cases; collection of survey data from local customers; participation in the development of business case analysis; and GNSS performance reports.

**Meeting organisation** – ANSPs should coordinate with the appropriate local personnel to complete required safety assessments; and consult with airport authorities, local stakeholders and customers.

**FIR coordination** – ANSPs must ensure that implementation activities have approved funding and personnel resources. They should coordinate with other business plan activities within the FIR to avoid conflicts; and should develop a concept of operations document.



**Implementation activities** – ANSPs should develop a FIR implementation plan; coordinate the development and delivery of training and education materials; analyse airspace and sector demands and workload; develop and coordinate procedure design concepts and a final Aeronautical Information Management (AIM) design submission package; and develop an airspace redesign that is coordinated with new procedures.

A local implementation manager, acting in a part time or full time capacity dependent on the scope of change, would oversee and coordinate these activities as well as interface with any regional or national authorities regarding the completion of activities identified within their accountability.

National and international management of PBN activities are best suited for centralised coordination. Coordination with the regulator is needed regarding navigation specifications approved for use in the State, or in development, and their planned application. These items require coordination between the regulator and the ANSP's customers to implement avionics certification processes and for customers to receive operational authority in response to the projected needs of the ANSP. Current and forecasted participation rates by customers may be determined based on survey data in conjunction with direct consultation sessions. International harmonisation is also critical to ensure the timely equipage and operational approval by customers while minimising costs involved in the transition. In addition, national oversight can facilitate inter-FIR coordination of PBN implementation activities.

The need to develop an appropriate level of subject matter expertise across all of the PBN domains while providing implementation continuity means that the best fit is a dedicated

PBN resource: a 'PBN architect,' capable of providing a strategic oversight, programme continuity, and international coordination.

Programme managers, project managers, project administrators, and SMEs for various components will be required at different stages of development and implementation. The expertise will include:

**Financial Analysis** – Financial Analysis supports the development of business cases. ANSPs will need to receive and track customer capabilities (survey and consultation data). In concert with ATC simulations, business case discrimination between a reference scenario and future PBN option cases can be conducted. Costs to train staff (PBN experts, procedure designers, and ATC), and the cost of maintaining procedures should also be considered. As with the ATC simulation, business case development is often an iterative process. A strongly positive business case, while not the only determining factor, is an important tool in facilitating the implementation both within the ANSP and in garnering customer support.

**ATC Simulation** – For implementation projects that involve airspace and procedure redesigns, there will be a need to conduct simulations of traffic flows. Depending on the complexity of the designs, the simulations may need to run through multiple iterations with parallel support from financial analysis to ensure a viable business case with appropriate sensitivity analysis.

**Aeronautical Information and Procedure Design Services** – These services are required to vet concepts as being within the general confines of existing or planned future design criteria. The services should be provided on a consultative basis throughout the development of airspace and procedure changes. The

introduction of new design criteria will involve additional training resources and time as well as design tool modifications. The design criteria will address aircraft to obstacle considerations and the ATC policy and standards SMEs will be able to address aircraft to aircraft separations. It should be the responsibility of the local or regional implementation managers to coordinate with AIM at the early stages of development and throughout the implementation to ensure that the proposed changes are practical in their construction. With complex design efforts, more than one iteration of the design will most likely be required. In these cases, planning for at least two full design cycles (procedure design, simulation, flight test/validation, database coding) is prudent. Close coordination between the ANSP and customer stakeholders is essential to limit the number and scope of changes. As the project progresses, the implementation manager should work with AIM to develop the submission documents defining all of the required parameters such that AIM can schedule and process the publication of all materials. The ability of AIM to meet the volume of work required for PBN prior to implementation will need to be identified.

**Policy and standards** – Policy and standards are required to assess and implement changes in flight procedures that impact airspace design. ANSP policy and standards SMEs can be responsible for administering any changes to the designated airspace required as a result of implementation. In addition, with the availability of new technology for navigation and containment of aircraft, changes in air traffic rules, standards, and procedures must be assessed and implemented. In particular, PBN provides additional opportunities for more efficient operations in non-surveillance or procedural separation applications.

**Safety Management** – Safety management is needed to facilitate risk identification and

mitigation measures in keeping with the ANSP's safety management system (SMS) processes. These may include environmental management and security management (particularly with respect to intentional GNSS interference). Safety case(s) and environmental impact statements will almost certainly need to be prepared and submitted to the regulator.

**ANSP customer's expertise** – The expertise of the ANSP's customer is important to complete the 'total system' evaluation in understanding the air operators; equipment capabilities and limitations, standard operating procedures, work environment limitations, and future operations plans; and assessment of GNSS performance. These SMEs will generally involve airline personnel, business and recreational users, airport environmental experts, and other stakeholders.

The development of new PBN concepts and implementation of new procedures requires interaction across a wide variety of expertise. Since the adoption of these new concepts will result in a paradigm shift, a great deal of preparatory work must be completed before implementation. In the early stages this will mean face-to-face meetings, brainstorming sessions, and demonstrations to build the confidence of the people that will receive and work with the new designs. Co-location of the SMEs involved to begin development is beneficial, although, internet-based meetings can be conducted using voice and computer desktop sharing to investigate solutions and reach consensus among the stakeholders. Project management software can also assist in allowing all parties involved to keep abreast of the pace of implementation and their specific responsibilities in keeping the implementation on track.

The implementation of PBN will be successful if it is done within a culture that is accepting of change. Acceptance will come

from a broad knowledge and understanding of what the changes are, what is expected, and how they will be achieved in a non-threatening environment. Resources allocated to education and frequent programme communication updates will create an atmosphere that is optimistic and accepting of the new technology. Through multiple small iterative steps, participants will be able to celebrate incremental successes that will help reduce potential resistance to change. With the implementation programme broken down into small manageable tasks, future plans can be readjusted if required. With PBN technology still developing, it is essential that the implementation process accounts for the resources needed for fine-tuning as work progresses. This implies that for complex implementations some steps may need to be repeated as new variables are introduced prior to moving to the next step.

The personnel charged with leading the implementation tasks will need to be persuasive speakers who project a positive attitude and can build consensus among their peers. Credibility

will come from a position of technical knowledge and experience. Owing to the complexity of component pieces that will be brought together, individuals will need to be well-organised.

#### **Why this is important for ANSPs.**

ANSPs invariably face challenging resource issues to maintain existing operations let alone introduce new airspace designs and procedures. “Unavailability of resources” is identified as the number two reason why ANSPs have not started PBN implementation. PBN implementation requires a broad range of disciplines across a given ANSP to ensure successful planning, design, coordination and execution of the desired PBN airspace concept. Understanding the commitment and expertise needed from the various subject matter experts and stakeholders, will enable ANSPs to properly access and determine the resource allocation required to initiate and implement a successful PBN airspace/ procedure design.

#### **Key Points:**

- Having a dedicated resource from each area of domain expertise within an ANSP or stakeholder is not always required. However, it will require a minimum level of participation from SMEs to ensure continuity in meeting the PBN airspace objectives
- Expertise in financial analysis, ATC simulation, aeronautical information and procedure design services, policy and standards, safety management, and the ANSP’s customer expertise will be necessary during certain stages of the process
- Resources allocated to education and communication will be essential in establishing a non-threatening environment to enable acceptance of PBN initiatives

## 11

### **Change Management**

Implementing PBN procedures may introduce several issues that ANSPs and stakeholders need to consider. To assist ANSPs in understanding and managing the diversity of areas introduced in the development, implementation, and post-implementation process, a comprehensive list of items is provided.

**Preparation** – In preparation for PBN implementation ANSPs should scope out the percentage of traffic that is PBN-capable (ideally 70-90 percent, according to ICAO Doc 9992 2.3.5.4 – *Manual on the use of PBN in airspace design*). ANSPs should plan for an integrated and fully connected PBN system.

### **Site Selection**

Implementation of PBN procedures at an airfield should not be undertaken without an understanding of exactly why this solution is preferred. The primary drivers can be characterised as terrain, minima, community outcomes and flight efficiency.

**Terrain** - Improving access to terrain challenged airfields is a major benefit offered by PBN procedures. The ability to tailor approaches, departures, and overshoots clear of obstacles with high precision and reliability offers improvements in safety, flight efficiency, and access.

**Minima** - Where only non-precision approaches are available, a PBN procedure may deliver more beneficial minima.

**Community Outcomes** - The obvious community outcome is to minimise the number of people exposed to the noise footprint associated with the procedure, although this can be contentious. Other outcomes sought may be visual amenity, avoidance of culturally or environmentally sensitive areas, and satisfying political agendas.

**Flight Efficiency** - The predictability, repeatability, and stability of PBN approaches can deliver flight efficiency benefits to operators.

**Stakeholder Engagement** - Development of a PBN procedure is arguably the simplest task required in implementing PBN at an airport. Accommodating the needs and wants of a disparate stakeholder group is a challenge. Consultation cannot begin too soon in the process.

**Understand the Operators' Drivers** - The same drivers that influence site selection will be at play in an operator's request for PBN procedures at a particular airport. A further consideration may be maximising take-off weight through a PBN departure procedure.

### **Consultation**

Early and frequent consultation with operators will help ensure that the focus of the design will remain on the appropriate areas.

**Understand Operations** - Any procedure must be considered in the context of the surrounding ATM environment. ATC will be able to identify any traffic management or ATM integration issues. Consultation will also help develop a sense of ownership in the change.

**Understand the Environment** - Changes to flight paths and patterns cannot be considered as just an aviation issue; they operate in a broader social environment. Consultation with community groups can be difficult and protracted. Before 'going public,' try to have a good understanding of the political, social, and community environment in which you are working. A documented stakeholder engagement plan or consultation protocol<sup>21</sup> can ensure consistent delivery of messaging and management of stakeholder expectations in this area.

<sup>21</sup> See for example Airservices Australia's Communication and Consultation Protocol: [http://www.airservicesaustralia.com/wp-content/uploads/13-089BKT\\_Communication-and-Consultation-Protocol\\_WEB.pdf](http://www.airservicesaustralia.com/wp-content/uploads/13-089BKT_Communication-and-Consultation-Protocol_WEB.pdf)

**Manage Expectations** - Too often the perceptions of the benefits of a change are too optimistic and the costs and risks disregarded to ensure support for the change. Stakeholders are entitled to expect delivery against these promises, particularly if they are asked to contribute to the costs of implementation.

### Procedure Characteristics

**How Many procedures should be implemented?** - The number of procedures implemented should be limited. It is suggested that no more than seven separate legs (IF/CF/TF etc.) on an individual SID or STAR should be implemented. Having a large number of procedures, besides being expensive to develop and maintain, adds to ATM complexity.

ATM flexibility is better maintained with multiple STARs or transitions linking to a small number of approaches.

**Length** - Maximum flexibility for ATC is maintained by keeping the procedure as short as possible. This allows sequence adjustments to be made before the aircraft begins the procedure.

**Begin with TF Leg** - Beginning a procedure with a TF leg of two or more miles allows ATC more flexibility in making sequence adjustments and vectors for intercept of the procedure.

**Duplicate Existing Paths** - Procedures which duplicate existing flight paths are more readily accepted by ATC and help overcome the 'mixed-mode' issues discussed below. It has been observed that procedures which replicate existing visual procedures offer a 'quick win' as the visual procedures are typically shorter, familiar to crews and ATC and proven to be both flyable and safe. However, duplicating existing paths may mean that some of the benefits of PBN may not be delivered, i.e. fuel burn, track mile reductions, noise and environmental constraints.

**Speeds** - Using coded speeds on the procedure can assist with integrating conventional and PBN procedures.

**Lateral Path Consistency** - Where PBN procedures are an overlay of the lateral paths associated with conventional approaches, the mixed-mode complexities are reduced. Similarly in a situation where multiple tailored approaches have been implemented by multiple operators, it is preferable that all retain substantially the same lateral path.

### Mixed-mode Operations

In an ideal environment all aircraft would be PBN capable, but this is unlikely to ever be the case. An issue for consideration in implementation is the bias of the traffic mix: capable versus non-capable aircraft movements. The focus here is the number of movements not the number of airframes.

A dominance of non-capable aircraft movements introduces complexities in traffic management particularly as demand at the airfield approaches capacity. A simple response that has been observed is for ATC to abandon PBN procedures and issue all operations conventional approaches, effectively denying the better equipped aircraft operational advantage and undermining the benefits available from PBN operations.

'Mixed-mode' operations have been observed as less efficient in a capacity sense as it can be difficult for ATC to accurately deliver a consistent spacing between arrivals on different lateral paths. It is reasonable to expect that at airfields without capacity challenges, a high uptake of procedures relative to the number of capable movements that may be realised.

It has been suggested that where PBN movements are in the order of 70 percent, PBN becomes the norm and the non-compliant operations are disadvantaged.

## Human Factors

**'Good Guy' Syndrome** - Historically, air traffic control officers (ATCOs) have understood that track shortening is of benefit to operators, and so there has been a preference to 'shortcut' and a resistance to 'extend' or slow down traffic. However PBN encourages minimal intervention – strategic controlling – and a primary benefit of PBN for operators is the stability, predictability, and repeatability of procedures. Taking an aircraft off an arrival to 'cut the corner' and save fractions or even whole track miles, impairs the benefits available. It can lead to pilots descending early in the hope of a short approach – but if most then level off, the shortcut may result in a greater fuel burn, and what was perceived as ATC/Pilot efficiency can actually lead to a net loss for the airlines. Leaving energy management to the crew and aircraft systems provides the best outcome for operators.

**Notifying Capability to ATC** - Early notification of approach expectation can be important to air crew in workload and energy management decisions. Notification of PBN capability to ATC can be achieved through ATM system automation based on the notified capability in the flight plan. This same automation may indicate the appropriate STAR/approach combination for the conditions.

**Perception when on Different Lateral Paths** - One of the difficulties experienced by approach and tower controllers is delivering consistent spacing between arrivals which are on different lateral paths and subject to different wind effects. In time it is reasonable to expect controllers to adapt based on their experience in dealing with this issue. However

a decision support tool would be a valuable aid to controllers in delivering consistent spacing between arrival aircraft.

**Education and Training** - Education and training are covered elsewhere but are key factors in a successful implementation.

**Partner with Airlines** - Some elements of PBN education are common to ATC and air crew. Partnering to deliver these elements can foster better understanding of each other's issues.

**Flying the 'Magenta Line'** - ATC education should include some appreciation of how the aircraft systems behave, in particular the 'Fly By', 'Direct To', and 'To To' nature of navigation in a PBN environment.

**Continuous Improvement** - Having implemented procedures, there should be a process of continuous improvement. Triggers for change may include:

- Post Implementation Review
- Incidents
- Procedure maintenance reviews
- Changes to aircraft fleet and performance
- Utilisation rates, consider discontinuing low usage procedures

## Why this is important for ANSPs.

One of the key issues ANSPs must consider during the PBN implementation process is the identification and coordination of multiple airspace and procedure changes. Becoming familiar with the various components an ANSP may encounter will assist in reducing surprises during implementation.

## Key Points:

- Managing expectations is a key challenge in managing change
- Understanding the various environments (i.e., political, social, community) surrounding the designated airspace coupled with a clear and consistent messaging will enable ANSPs to effectively manage change
- Post implementation activities should include a continuous improvement process

## **Appendix A**

### **PBN Stakeholders**

#### **Air Navigation Service Provider:**

1. Projects
2. Service Strategy
3. Safety and Risk
4. Policy and Standards
5. Aeronautical Design and Development
6. Tower ATC
7. Terminal ATC
8. En-route ATC
9. Oceanic
10. Air Traffic Support Services

#### **External:**

11. Civil Aviation Authority
12. Operators
  - a. Airlines
  - b. Training Centres
  - c. Charter Operators
  - d. Military
13. GA/Airspace Users
  - a. User Groups
  - b. Local Operators
  - c. Gliding
  - d. Para-gliders
14. Airport Company
15. Third-Party Navigation Service Providers
16. Government – including Federal, State and Local
17. Avionics Manufacturers, Suppliers, Fitters and Maintainers.



## Appendix B

### ICAO Resolution A37-11<sup>22</sup>

#### **Resolution A37-11: Performance-based navigation global goals**

*Whereas* a primary objective of ICAO is that of ensuring the safe and efficient performance of the global Air Navigation System;

*Whereas* the improvement of the performance of the air navigation system on a harmonized, worldwide basis requires the active collaboration of all stakeholders;

*Whereas* the 11th Air Navigation Conference recommended that ICAO, as a matter of urgency, address and progress the issues associated with the introduction of area navigation (RNAV) and required navigation performance (RNP);

*Whereas* the 11th Air Navigation Conference recommended that ICAO develop RNAV procedures supported by global navigation satellite system (GNSS) for fixed wing aircraft, providing high track and velocity-keeping accuracy to maintain separation through curves and enable flexible approach line-ups;

*Whereas* the 11th Air Navigation Conference recommended that ICAO develop RNAV procedures supported by GNSS for both fixed and rotary wing aircraft, enabling lower operating minima in obstacle rich or otherwise constrained environments;

*Whereas* Resolution A33-16 requested the Council to develop a programme to encourage States to implement approach procedures with vertical guidance (APV) utilizing such inputs as GNSS or distance measuring equipment (DME)/DME, in accordance with ICAO provisions;

*Recognizing* that not all airports have the infrastructure to support APV operations and not all aircraft are currently capable of APV;

*Recognizing* that many States already have the requisite infrastructure and aircraft capable of performing straight-in approaches with lateral guidance (LNAV approaches) based on the RNP specifications and that straight in approaches provide demonstrated and significant safety enhancements over circling approaches;

*Recognizing* that the Global Aviation Safety Plan has identified Global Safety Initiatives (GSIs) to concentrate on developing a safety strategy for the future that includes the effective use of technology to enhance safety, consistent adoption of industry best practices, alignment of global industry safety strategies and consistent regulatory oversight;

*Recognizing* that the Global Air Navigation Plan has identified Global Plan Initiatives (GPIs) to concentrate on the incorporation of advanced aircraft navigation capabilities into the air navigation system infrastructure, the optimization of the terminal control area through improved design and management techniques, the optimization of the terminal control area through implementation of RNP and RNAV SIDs and STARs and the optimization of terminal control area to provide for more fuel efficient aircraft operations through FMS-based arrival procedures; and

*Recognizing* that the continuing development of diverging navigation specifications would result in safety and efficiency impacts and penalties to States and industry;

*Noting with satisfaction* that planning and implementation regional groups (PIRGs) have completed regional PBN implementation plans;

*Recognizing* that not all States have developed a PBN implementation plan by the target date of 2009;

*The Assembly:*

1. *Urges* all States to implement RNAV and RNP air traffic services (ATS) routes and approach procedures in accordance with the ICAO PBN concept laid down in the *Performance-based Navigation (PBN) Manual*(Doc 9613);
2. *Resolves* that:
  - a) States complete a PBN implementation plan as a matter of urgency to achieve:
    - 1) implementation of RNAV and RNP operations (where required) for en route and terminal areas according to established timelines and intermediate milestones; and
    - 2) implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and/or augmented GNSS),for including LNAV-only minima, for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 with intermediate milestones as follows: 30 per cent by 2010, 70 per cent by 2014; and
    - 3) implementation of straight-in LNAV-only procedures, as an exception to 2) above, for instrument runways at aerodromes where there is no local altimeter setting available and where there are no aircraft suitably equipped for AOV operations with a maximum certificated take-off mass of 5700 kg or more;
  - b) ICAO develop a coordinated action plan to assist States in the implementation of PBN and to ensure development and/or maintenance of globally harmonized SARPs, Procedures for Air Navigation Services (PANS) and guidance material including a global harmonized safety assessment methodology to keep pace with operational demands;
3. *Urges* that States include in their PBN implementation plan provisions for implementation of approach procedures with vertical guidance (APV) to all runway end serving aircraft with a maximum certificated take-off mass of 5 700 kg or more, according to established timelines and intermediate milestones;
4. *Instructs* the Council to provide a progress report on PBN implementation to the next ordinary session of the Assembly, as necessary;
5. *Requests* the Planning and Implementation Regional Groups (PIRGs) to include in their work programme the review of status of implementation of PBN by States according to the defined implementation plans and report annually to ICAO any deficiencies that may occur; and
6. *Declares* that this resolution supersedes Resolution A36-23.

## Appendix C

### ICAO Doc 8168, Path Terminators<sup>23</sup>

#### 5.2 PATH TERMINATOR TYPES

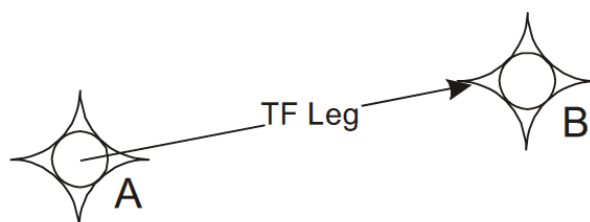
5.2.1 The definition for path and terminator (“Path terminator”) is provided in Part I, Section 1, Chapter 1. Currently there are 23 different path terminators defined in ARINC 424. However, only eleven of these path terminators are acceptable for RNAV procedure design use and an additional path terminator, IF, is used when coding the procedure in the database. A smaller sub-set of four path terminators should be used for RNP applications: IF, TF, RF, and HM. Descriptions of all the RNAV procedure design codes are provided below:

##### Initial fix (IF)

The coding of RNAV procedures starts at an IF. An IF does not define a desired track in and of itself, but is used in conjunction with another leg type (e.g. TF) in order to define the desired path. It is not used in the design process and need not be published with the procedure description.

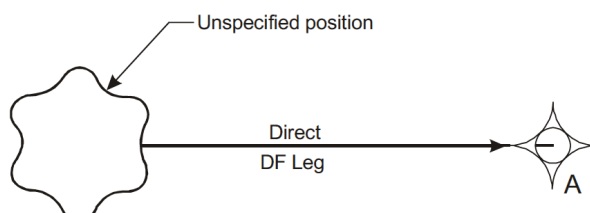
##### Track to a fix (TF)

The primary straight route segment for RNAV is a TF route. The TF route is defined by a geodesic path between two waypoints. The first of the two waypoints is either the termination waypoint of the previous segment or an initial fix (IF). The intermediate and final approach segments should always be TF routes. In cases where an FMS requires a CF for the final approach segment, the database coder may use CF in lieu of TF.



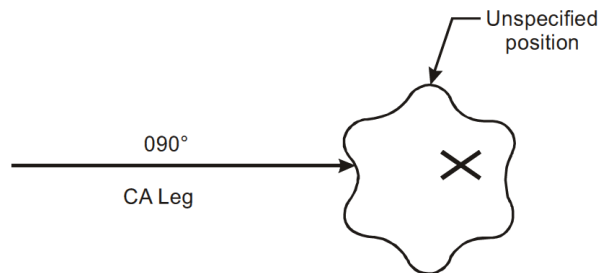
##### Direct to a fix (DF)

A DF is used to define a route segment from an unspecified position, on the aircraft’s present track, to a specified fix/waypoint. The DF path terminator does not provide a predictable, repeatable flight path and is highly variable in its application. When used after an FA, VA or CA the DF is effective in dispersing the tracks over the widest area and the CA/DF combination can be used to spread environmental impact on initial departures. The DF also ensures that the shortest track distance is flown from the turning point (fly-over waypoint) or from a turn altitude to the next waypoint. The use of DF is further constrained by a number of specific rules detailed in 5.3.



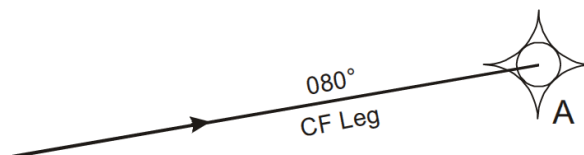
### Course to an altitude (CA)

A CA is used to define the course of an outbound route segment that terminates at an altitude with an unspecified position. The CA is used in preference to an FA as the initial path terminator in a SID, in order to guard against the effects of IRS drift.



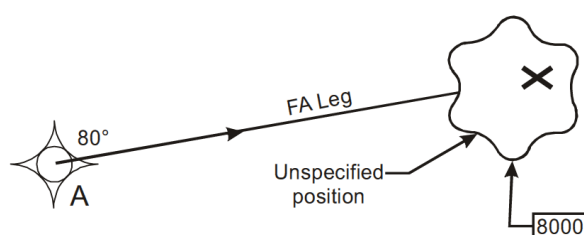
### Course to a fix (CF)

A CF is defined as a course that terminates at a fix/waypoint followed by a specific route segment. A CF was originally the only path terminator permitted to define the final segment of an approach and is currently used for this purpose by many RNAV systems. Normal use of the CF is after an FA or CA in a departure or missed approach where it is effective in constraining the track dispersion. The CA/CF combination can be effective in reducing environmental impact on initial departures. The use of CF is further constrained by a number of specific rules detailed in 5.3.



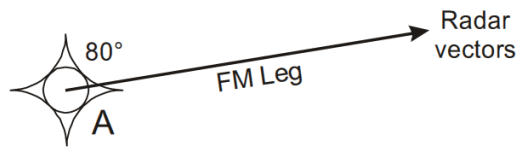
### Course from a fix to an altitude (FA)

An FA is used to define a route segment that begins at a fix/waypoint and terminates at a point where the aircraft altitude is at, or above, a specified altitude. No position is specified for the altitude point. The FA track does not provide a predictable, repeatable flight path, due to the unknown termination point, but is a useful path terminator in missed approach procedures.



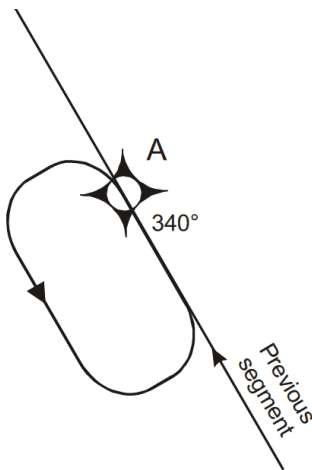
### Course from a fix to a manual termination (FM)

An FM is used when a route segment is terminated for radar vectors. It provides similar functionality to the VM. The aircraft continues on the prescribed heading until intervention by the pilot.



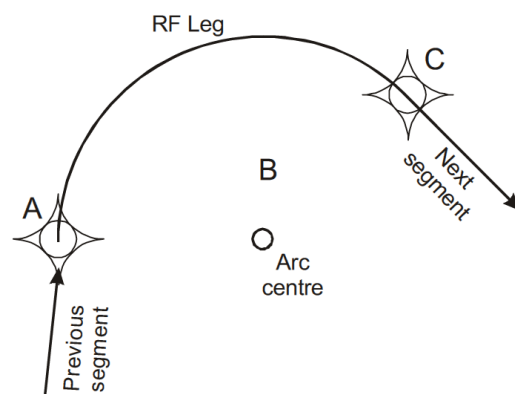
### Holding/Racetrack to a manual termination (HM)

An HM is used to define a holding pattern path that is manually terminated by the flight crew.



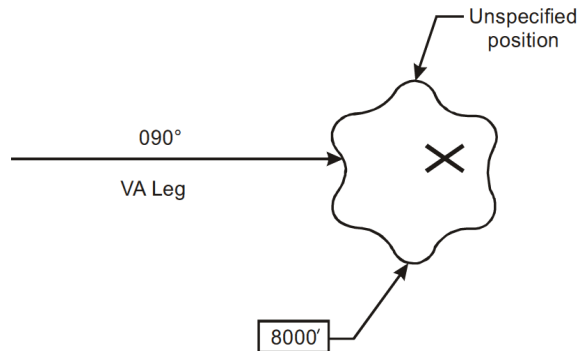
### Constant radius arc to a fix (RF)

The RF segment is a circular path about a defined turn centre that terminates at a waypoint. The beginning of the arc segment is defined by the terminating waypoint of the previous segment. The waypoint at the end of the arc segment, the turn direction of the segment and the turn centre are provided by the navigation database. The radius is computed by the RNAV system as the distance from the turn centre to the termination waypoint. A single arc may be defined for any turn between 2° and 300°. RF functionality is generally only available in systems designed to meet RNP-RNAV requirements such as those laid down in EUROCAE ED76()/RTCA DO 236().



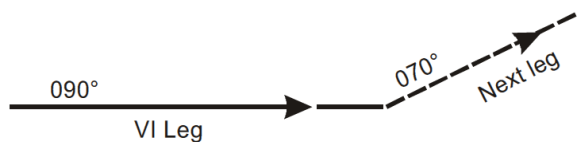
### Heading to an altitude (VA)

A VA is often used on departures where a heading rather than a track has been specified for climb-out. The segment terminates at a specified altitude without a terminating position. It is only used in RNAV design on parallel departures where initial heading legs are required.



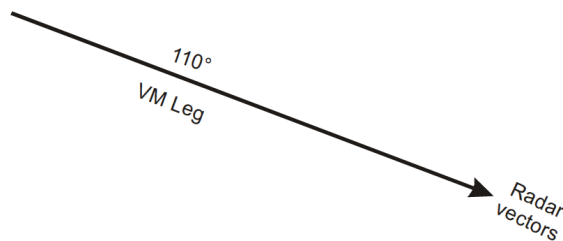
### Heading to an intercept (VI)

A VI segment is coded wherever a heading is assigned to an aircraft until it intercepts the next leg segment. The aircraft continues on the prescribed heading until the next leg is intercepted.



### Heading to a manual termination (VM)

A VM segment may be coded wherever radar vectoring is provided at the end of a procedure. It provides similar functionality to the FM. The aircraft continues on the prescribed heading until intervention by the pilot.



## Abbreviations and References

| Abbreviation | Definition                                                           |
|--------------|----------------------------------------------------------------------|
| AC           | Advisory circular                                                    |
| ACC          | Area control centre or area control                                  |
| ACI          | Airports Council International                                       |
| AGL          | Above ground level                                                   |
| AIC          | Aeronautical information circular                                    |
| AIM          | Aeronautical information management                                  |
| AIP          | Aeronautical Information Package                                     |
| AIRAC        | Aeronautical information regulation and control                      |
| ANS          | Air navigation system                                                |
| ANSP         | Air navigation service provider                                      |
| APCH         | Approach                                                             |
| APV          | Approach procedures with vertical guidance                           |
| A-RNP        | Advanced RNP (PBN navigation specification)                          |
| ARP          | Aerodrome reference point                                            |
| ASBU         | Aviation System Block Upgrades                                       |
| ATC          | Air traffic control                                                  |
| ATCO         | Air traffic control officer                                          |
| ATM          | Air traffic management                                               |
| ATS          | Air traffic services                                                 |
| BARO-VNAV    | Barometric vertical navigation                                       |
| CA           | Course to altitude                                                   |
| CAA          | Civil aviation authority (regulator)                                 |
| CANSO        | Civil Air Navigation Services Organisation                           |
| CBT          | Computer based training                                              |
| CCO          | Continuous climb operations                                          |
| CDO          | Continuous descent operations                                        |
| CF           | Course to a fix                                                      |
| CFIT         | Controlled flight into terrain                                       |
| CNS/ATM      | Communications, navigation and surveillance / air traffic management |
| COM          | Company Operations Manuals                                           |
| ConOps       | Concept of operations                                                |
| DME          | Distance measuring equipment                                         |
| FDR          | Flight data recorder                                                 |
| FIR          | Flight information region                                            |
| FMC          | Flight management computer                                           |
| FMS          | Flight management system                                             |
| FPL          | Flight plan                                                          |
| FRP          | Fixed radius path                                                    |
| FRT          | Fixed radius transition                                              |
| FTE          | Flight technical error                                               |
| GHG          | Greenhouse gas                                                       |
| GNSS         | Global navigation satellite system (e.g. GPS, GLONASS)               |
| GPS          | Global positioning system                                            |
| IAF          | Initial approach fix                                                 |
| IATA         | International Air Transport Association                              |
| ICAO         | International Civil Aviation Organization                            |
| IAP          | Instrument approach procedure                                        |
| IAS          | Indicated airspeed                                                   |

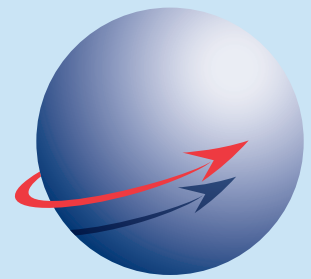


|                  |                                                                                   |
|------------------|-----------------------------------------------------------------------------------|
| IF               | Intermediate approach fix                                                         |
| IFP              | Instrument flight procedure                                                       |
| IFR              | Instrument flight rules                                                           |
| ILS              | Instrument landing system                                                         |
| IMC              | Instrument meteorological conditions                                              |
| IRS              | Inertial reference system                                                         |
| KPI              | Key performance indicator                                                         |
| KT               | Knots                                                                             |
| LNAV             | Lateral navigation                                                                |
| LOA              | Letter of authority                                                               |
| LPV              | Localizer performance with vertical guidance                                      |
| MAPT             | Missed approach point                                                             |
| MASPS            | Minimum aviation system performance standards                                     |
| MOPS             | Minimum Operational Performance Standards                                         |
| NAVAID           | Navigation(al) aid                                                                |
| Nav-spec         | Navigation specification                                                          |
| NextGen          | Next generation air transportation system (United States)                         |
| NDB              | Non-directional radio beacon                                                      |
| NM               | Nautical mile                                                                     |
| NSE              | Navigation system error                                                           |
| Ops Specs        | Operations specifications                                                         |
| PBN              | Performance-based navigation                                                      |
| PDE              | Path definition error                                                             |
| RF               | Constant radius to a fix                                                          |
| RNAV             | Area navigation                                                                   |
| RNP              | Required navigation performance                                                   |
| RNP AR           | RNP authorisation required (approach)                                             |
| RTF              | Radiotelephone                                                                    |
| SALS             | Simple approach lighting system                                                   |
| SARPs            | Standards and recommended practices                                               |
| SBAS             | Satellite-based augmentation system (GNSS augmentation)                           |
| SESAR            | Single European Sky ATM Research                                                  |
| SID              | Standard instrument departure                                                     |
| SME              | Subject matter expert                                                             |
| SMS              | Safety management system                                                          |
| STAR             | Standard instrument arrival                                                       |
| TF               | Track to fix                                                                      |
| TMA              | Terminal control area                                                             |
| TSO              | Technical standard order (minimum performance standard)                           |
| VOR/DME          | VHF omnidirectional range / distance measuring equipment                          |
| VNAV             | Vertical navigation                                                               |
| <b>Reference</b> | <b>Document</b>                                                                   |
| FAA              | Doc 8260 - United States Standard for Terminal Instrument Procedures              |
| ICAO             | EUD Doc 025 – Eur RNP APCH Guidance Material 2012                                 |
| ICAO             | Doc 8400 - Abbreviations and Codes                                                |
| ICAO             | Doc 8168 - Procedures for Air Navigation Services – Aircraft Operations (PANSOPS) |
| ICAO             | Doc 9613 - Performance Based Navigation Manual (4th Edition)                      |
| ICAO             | Doc 9750 - Global Air Navigation Plan                                             |
| ICAO             | Doc 9992 - Performance Based Navigation in Airspace Design                        |

# CANSO Members

CANSO – the Civil Air Navigation Services Organisation – is the global voice of air traffic management (ATM) worldwide. CANSO Members support over 85% of world air traffic. Members share information and develop new policies, with the ultimate aim of improving air navigation services (ANS) on the ground and in the air.

CANSO represents its Members' views to a wide range of aviation stakeholders, including the International Civil Aviation Organization, where it has official Observer status. CANSO has an extensive network of Associate Members drawn from across the aviation industry. For more information on joining CANSO, visit [www.canso.org/joiningcanso](http://www.canso.org/joiningcanso).



# canso

civil air navigation services organisation

## Full Members - 89

- Aeronautical Radio of Thailand (AEROTHAI)
- Aeroportos de Moçambique
- Air Navigation and Weather Services, CAA (ANWS)
- Air Navigation Services of the Czech Republic (ANS Czech Republic)
- AirNav Indonesia
- Air Traffic & Navigation Services (ATNS)
- Airports and Aviation Services Limited (AASL)
- Airports Authority of India (AAI)
- Airports Fiji Limited
- Airservices Australia
- Airways New Zealand
- Albcontrol
- Austro Control
- Avinor AS
- AZANS Azerbaijan
- Belgocontrol
- Bulgarian Air Traffic Services Authority (BULATSA)
- CAA Uganda
- Cambodia Air Traffic Services Co., Ltd. (CATS)
- Civil Aviation Authority of Bangladesh (CAAB)
- Civil Aviation Authority of Botswana
- Civil Aviation Authority of Mongolia
- Civil Aviation Authority of Nepal (CAAN)
- Civil Aviation Authority of Singapore (CAAS)
- Civil Aviation Authority of Swaziland
- Civil Aviation Regulatory Commission (CARC)
- Comisión Ejecutiva Portuaria Autonoma (CEPA)
- Croatia Control Ltd
- DCA Myanmar
- Department of Airspace Control (DECEA)
- Department of Civil Aviation, Republic of Cyprus
- DFS Deutsche Flugsicherung GmbH (DFS)
- Dirección General de Control de Tránsito Aéreo (DGCTA)
- DSN France
- Dutch Caribbean Air Navigation Service Provider (DC-ANSP)
- ENANA-EP ANGOLA
- ENAV S.p.A: Società Nazionale per l'Assistenza al Volo
- ENAIRe
- Estonian Air Navigation Services (EANS)
- Federal Aviation Administration (FAA)
- Finavia Corporation
- General Authority of Civil Aviation (GACA)
- Ghana Civil Aviation Authority (GCAA)
- Hellenic Civil Aviation Authority (HCAA)
- HungaroControl Pte. Ltd. Co.
- Instituto Dominicano de Aviación Civil (IDAC)
- Israel Airports Authority (IAA)
- Iran Airports Co
- Irish Aviation Authority (IAA)
- ISAVIA Ltd
- Japan Civil Aviation Bureau (JCAB)
- Kazaeronavigatsia
- Kenya Civil Aviation Authority (KCAA)
- Latvijas Gaisa Satiksme (LGS)

- Letové prevádzkové Služby Slovenskej Republiky, Štátny Podnik
- Luchtverkeersleiding Nederland (LVNL)
- Luxembourg ANA
- Maldives Airports Company Limited (MACL)
- Malta Air Traffic Services (MATS)
- National Airports Corporation Ltd.
- National Air Navigation Services Company (NANSC)
- NATS UK
- NAV CANADA
- NAV Portugal
- Naviair
- Nigerian Airspace Management Agency (NAMA)
- Office de l'Aviation Civile et des Aeroports (OACA)
- Office National de L'Aviation Civile (OFNAC)
- ORO NAVIGACIJA, Lithuania
- PNG Air Services Limited (PNGASL)
- Polish Air Navigation Services Agency (PANSA)
- PIA "Adem Jashari" - Air Control J.S.C.
- ROMATSA
- Sakaeronavigatsia Ltd
- S.E. MoldATSA
- SENEAM
- Serbia and Montenegro Air Traffic Services Agency (SMATSA)
- Serco
- skyguide
- Slovenia Control
- State Airports Authority & ANSP (DHMI)
- State ATM Corporation
- Sudan Air Navigation Services Department
- Tanzania Civil Aviation Authority
- Trinidad and Tobago CAA
- The LFV Group
- Ukrainian Air Traffic Service Enterprise (UkSATSE)
- U.S. DoD Policy Board on Federal Aviation
- Viet Nam Air Traffic Management Corporation (VATM)

## Gold Associate Members - 11

- Airbus ProSky
- Anhui Sun Create Electronics Co., Ltd.
- Boeing
- FREQUENTIS AG
- GroupEAD Europe S.L.
- ITT Exelis
- Lockheed Martin
- Metron Aviation
- Raytheon
- Selex ES
- Thales

## Silver Associate Members - 72

- Adacel Inc.
- Aeronav Inc.
- Aireon
- Air Traffic Control Association (ATCA)
- 'Association Group of Industrial Companies "TIRA" Corporation
- ATAC

- ATCA – Japan
- ATECH Negócios em Tecnologia S/A
- Aveillant
- Aviation Advocacy Sarl
- Aviation Data Communication Corp (ADCC)
- Avibit Data Processing GmbH
- Avitech GmbH
- AZIMUT JSC
- Barco Orthogon GmbH
- Brüel & Kjaer EMS
- Comsoft GmbH
- CGH Technologies, Inc
- CSSI, Inc.
- EADS Cassidian
- EIZO Technologies GmbH
- European Satellite Services Provider (ESSP SAS)
- Emirates
- ENAC
- Entry Point North
- Era Corporation
- Etihad Airways
- Guntermann & Drunck GmbH
- Harris Corporation
- Helios
- Honeywell International Inc. / Aerospace
- IDS – Ingegneria Dei Sistemi S.p.A.
- Indra Navia AS
- Indra Sistemas
- INECO
- Inmarsat Global Limited
- Integra A/S
- Intelcan Technosystems Inc.
- International Aero Navigation Systems Concern, JSC
- Jeppesen
- JMA Solutions
- Jotron AS
- LAIC Aktiengesellschaft
- LEMZ R&P Corporation
- LFV Aviation Consulting AB
- MDA Systems Ltd.
- Micro Nav Ltd
- The MITRE Corporation – CAASD
- MLS International College
- MovingDot
- NEC Corporation
- NLR
- Northrop Grumman
- NTT Data Corporation
- Núcleo de Comunicaciones y Control, S.L.U.
- PASSUR Aerospace
- Quintiq
- Rockwell Collins, Inc.
- Rohde & Schwarz GmbH & Co. KG
- RTCA, Inc.
- Saab AB
- Saab Sensis Corporation
- Saudi Arabian Airlines
- Schmid Telecom AG
- SENASA
- SITA
- SITTI
- Snowflake Software Ltd
- STR-SpeechTech Ltd.
- Tetra Tech AMT
- Washington Consulting Group
- WIDE