



Policy for the Application of Performance-based Navigation in UK/Irish Airspace

In accordance with the Memorandum of Understanding on Co-operation between the UK Civil Aviation Authority and the Safety Regulation Division of the Irish Aviation Authority in relation to the UK/Ireland Functional Airspace Block dated 12 June 2008, we hereby approve the joint Policy for the Application of Performance-based Navigation in UK/Irish Airspace.

Signed for and on behalf of the SRD/IAA

Signed for and on behalf of the UK CAA

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Dated: 13 October 2011

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Policy for the Application of Performance-based Navigation in UK/Irish Airspace

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Executive Summary

The Future Airspace Strategy (FAS) is designed to ensure the UK airspace provides sufficient capacity to meet forecast demands whilst minimising environmental impact by allowing flight profiles closer to optimum. This will be achieved principally by adapting the UK Air Traffic Management (ATM) system to establish an enduring and resilient structure that will: greatly reduce the number of potential conflicts between airspace users; allow aircraft to fly more direct routes; greatly improve the efficiency of departures and arrivals, in particular in terminal airspace; and use smarter, more joined-up traffic management techniques to optimise airspace capacity and runway throughput. However, as a strategy it can only provide the future framework for change. In order to realise the changes that will be delivered on the back of the FAS objectives, the application of technical and operational enablers will be key. Amongst these, the specifications associated with the ICAO Performance-based Navigation (PBN) Concept offers the most opportunities for future airspace development.

The implementation of PBN as a design tool is principally a matter for the applicant sponsoring the airspace change. However, choice of an appropriate ICAO PBN specification and its application is critical to maximising the benefits to cost ratio and to ensure the ordered evolution of the airspace system. To that end, appropriate regulatory policy and implementation guidance is required to set the parameters around which PBN may be used. This document contains the Policy for the Application of PBN in United Kingdom and Irish Airspace in support of the FAS Implementation Programme. As a pre-cursor to future airspace development activities, it sets the framework around which PBN can be applied as well as providing the regulatory mechanism for the scale of change that will have to be undertaken by the respective Air Navigation Service Providers (ANSPs) in order to realise the projected benefits.

Any policy has to take account of developments elsewhere. In the global context, PBN is on the forward path for both the Future Air Traffic Management Concept envisaged by ICAO and is consistent with the recent ICAO Assembly Resolution (A37-11). In Europe, PBN is an essential component in the Single European Sky Air Traffic Management Research programme (SESAR) and this policy places the UK and Ireland at the vanguard of change, leading by example and thereby enhancing both our reputation and standing on the international stage.

This is, therefore, a regulatory policy that meets the industry expectations and requirements on the CAA and IAA and is entirely consistent with international initiatives. However, it is only a policy and implementation will require both the political will and commitment to make the necessary changes to modernise the ATM system.

This policy has been developed under the auspices of the FAB Supervisory Committee (FSC) of the National Supervisory Authorities (NSAs) and the FAB Management Board (FMB) comprised of the ANSPs.

1 Introduction

1.1 The Future Airspace Strategy

The Future Airspace Strategy (FAS)¹ is designed principally to modernise the UK ATM system to establish an enduring and resilient structure that will: greatly reduce the number of potential conflicts between airspace users; allow aircraft to fly more direct routes; greatly improve the efficiency of departures and arrivals, in particular in the busy south-east of England; and use smarter, more joined-up traffic management techniques to optimise capacity in the air and runway throughput on the ground. The Strategy aims to establish a much safer and more efficient system than at present, with the ability to absorb significant increase in demand without resorting to additional major changes to the airspace.

The FAS sets out three strategic drivers to modernise the UK airspace system, namely Safety, Capacity and Environment. It also sets out a further three key areas of consideration required to achieve the vision, recognising that any work will have to be aligned with European developments and the Implementing Rules of the Single European Sky (SES), whilst also ensuring that the longer term vision of the SESAR Concept of Operations is realisable. By this means it provides a robust and sustainable policy and regulatory framework, whilst also responding to national defence and security needs. The FAS sets out the five separate areas which will deliver the modernisation of the overall airspace system which we seek. These are:

- Airspace Structure
- Communication
- Navigation
- Surveillance
- ATM Capability

Of these, navigation is perhaps one of the more significant enablers in that it impacts aircraft capability, flight operations standard operating procedures (SOPs), ground and space-based navigation infrastructure, instrument flight procedure design and separation standards. The International Civil Aviation Organisation (ICAO), has long recognised the importance and role of navigation in a CNS and ATM context, but has only in recent years put in place a concept that fully addresses all of the requirements necessary to implement a performance-based set of changes. This is now referred to as the ICAO Performance-based Navigation Concept, or PBN Concept.

1.2 Performance-based Navigation (PBN)

Performance-based Navigation is the broad term used to describe the technologies that allow aircraft to fly flexible, accurate, repeatable and therefore deterministic three-dimensional flight paths using onboard equipment and capabilities. It has variously been described as reengineering the way we fly. Indeed, it has the potential to unlock many of the safety, efficiency and capacity targets facing the aviation industry, and not surprisingly, it plays an important role in airspace modernisation programmes such as the Single European Sky ATM Research programme (SESAR) and the US equivalent, NextGen. Although backed by the International Civil Aviation Organisation (ICAO), International Air Transport Association (IATA), national governments and industry, the implementation remains fragmented and irregular, which is why clear and concise policy on the application of PBN is

¹ The UK's Future Airspace Strategy (FAS) can be found at www.caa.co.uk/fas

so keenly awaited by industry. The European Commission is minded to develop an Implementing Rule in this area in due course, although the time frame, as currently envisaged, is longer than required to develop the necessary enhancements in UK and Irish airspace. There is mounting pressure from adjacent Functional Airspace Blocks (FABs) and operators to bring this date forward.

Aircraft Area Navigation² (RNAV) system capabilities are increasingly being exploited with a view to maximising constrained airspace resources. The use of RNAV systems lies at the core of PBN, which introduces standards and approval requirements for the application of area navigation techniques in airspace structures.

The ICAO PBN Manual (Doc 9613) definition is:

Area navigation based on performance requirements for aircraft operating along an ATS route³, on an instrument approach procedure or in a designated airspace.

Where:

Airborne performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity and functionality needed for the proposed operation in the context of a particular airspace concept. Within the airspace concept, the availability of GNSS Signal-In-Space (SIS) or that of some other applicable navigation infrastructure has to be considered in order to enable the navigation application.

PBN is then described through means of RNAV and RNP⁴ applications with respective RNAV and RNP operations.

Figure 1 below depicts the ICAO Performance-based Navigation concept and the relationship between Navigation and the Airspace Concept and aspects of Communications, Surveillance and ATM Capability.

² Area Navigation (RNAV) is a method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

³ The use of the term ATS route in the PBN definition is consistent with the former's definition in Annex 11 i.e., an ATS route is used to mean variously, an airway, advisory route, controlled or uncontrolled route, arrival or departure. In the UK, ATS route is generally understood to exist in the en-route phase of flight only.

⁴ Required Navigation Performance (RNP) applications require performance monitoring and alerting as a function of the onboard systems.

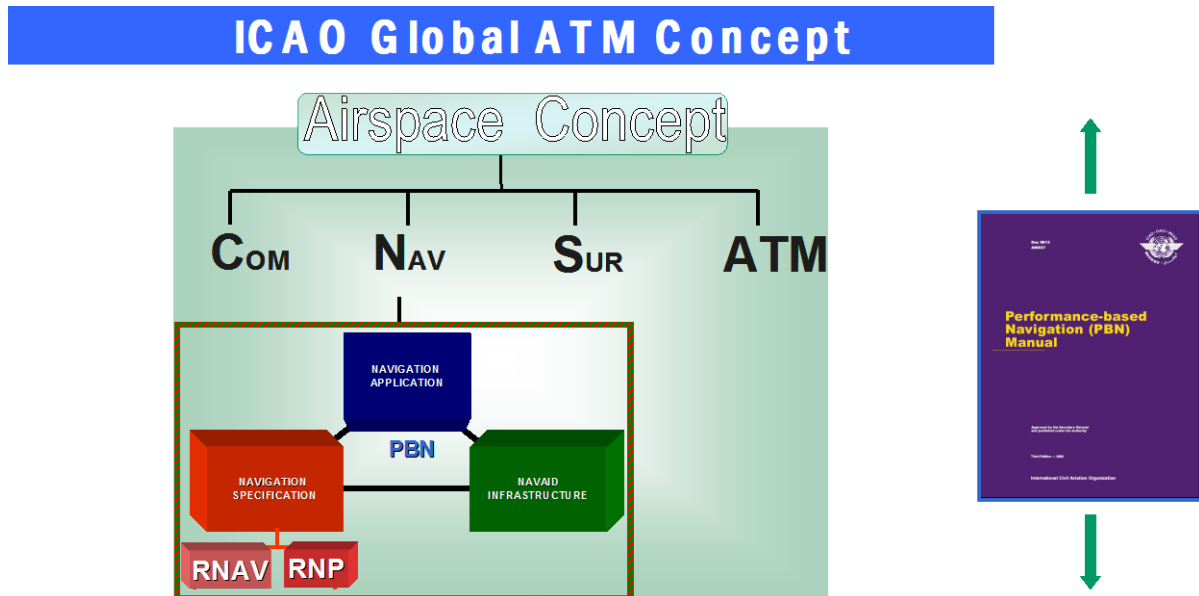


Figure 1 ICAO Performance-based Navigation Concept and PBN Manual

1.3 PBN – The Global Dimension

PBN has its origins in the ICAO Future Air Navigation System (FANS) Concept of the late 1980s. Unfortunately, that concept was defined in isolation from the airspace and as a consequence led to a global proliferation of standards which presented a cost to industry from having multiple certification requirements against differing specifications. PBN now offers navigation applications based on specified system performance requirements (not specific to any one type of equipment) for aircraft operating on an air traffic route, instrument approach procedure or in designated airspace. In so doing, it offers the potential for aircraft to demonstrate requirements compliance through a mix of capabilities, rather than specific sensor-based equipment.

Whilst the ICAO PBN Manual was published in 2008, the navigation specifications contained within the manual have captured a number of existing navigation applications e.g., ECAC Basic RNAV (en-route) and Precision RNAV (terminal airspace), RNP 4 (oceanic) and RNP Approach. So, whereas the priority for ICAO and IATA in their Global PBN Task Force initiative is to take these regularised standards to less well developed regions, the primary interest for Europe, the US and parts of the Asia Pacific region is the development of new and more advanced navigation applications to further exploit the navigational capability of modern aircraft in order to respond to future ATM demands and it is in this context that PBN has most to offer the UK and Ireland.

1.4 PBN in a FAS Context

PBN is an essential component of delivering the objectives underpinning the Future Airspace Strategy and consequential modernisation of the UK airspace system. That modernisation envisages transition from airspace, routes and instrument flight procedures (including holds), predicated on conventional navigation systems e.g., VOR, DME, NDB to an airspace described in terms of Performance-based Navigation. This provides the opportunity for a significant airspace re-design, especially of the terminal airspace structure, which will enable the ATM system to be modernised and deliver a series of environmental, capacity and efficiency benefits. See ANNEX 2 for further details of the perceived benefits.

PBN is therefore laying the foundations for the airspace system not just of tomorrow, but for years to come as future navigation developments such as three-dimensional (3D) and four-dimensional (4D) user preferred trajectories evolve.

1.5 International Obligations

In applying PBN, the UK and Ireland are required to meet their international obligations. Principal of these is the commitment to ICAO. The ICAO vision is for a future ATM operational concept with transition to a performance-based environment. At the 37th Assembly held in 2010, Resolution A37-11⁵ required States to implement navigation applications in accordance with the Assembly Resolution, which requires 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 and;
2. Implementation of Approach Procedures with Vertical guidance (APV), either Barometric Vertical Navigation (Baro-VNAV) and/or augmented GNSS, including Lateral Navigation (LNAV) only minima for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 (with 30 per cent by 2010 and 70 per cent by 2014);
3. Implementation of straight-in LNAV only procedures (as an exception to 2. above) where the fleet is not APV capable.

In the UK, the en-route structure is PBN compliant. Over the last ten years there have been numerous trials of terminal airspace PBN applications, although to date, none of which has led to permanent procedures. With the provision of Air Navigation Services separate from State control and a competitive environment for UK airports, it was always going to be impractical for the CAA to publish a PBN Implementation Plan for the UK. That is the responsibility for those that manage the airspace and air traffic operations i.e., the Air Navigation Service Providers (ANSPs). Against the ICAO Resolution's call for greater numbers of instrument approach procedures, the CAA is proactively promoting APV, although it can only go so far as to issue policy, guidance and provide education for what is ultimately a business decision that has to be taken by each privatised aerodrome.

In Ireland, both the en-route and terminal airspace structures are already PBN compliant.

Other international obligations require the UK and Ireland to remain cognisant of available SESAR Implementation Package (IP) enablers although most of what is envisaged from a PBN context is already emerging, separate from the research community. However, one aspect of Single European Sky (SES) legislation that is pertinent to FAS and the PBN policy is the proposed PBN Implementing Rule (IR) in the 2018-2020 timeframe. Through working closely with the Commission, and thereby influencing European thinking, the intention is to anticipate the IR and indeed, lead the rest of Europe with modernisation of UK and Irish terminal airspace ahead of the projected 2018 date.

1.6 National Performance Plan (NPP)

It is envisaged that Performance-based Navigation, as a key enabler for the Future Airspace Strategy – will become increasingly significant during the National Performance Plan (NPP)

⁵ Resolution A37-11 supersedes Resolution A36-23 from the 2007 Assembly.

Reporting Period 1 (RP1) i.e., 2012 to 2014 with selective changes to both en-route and terminal airspace. Within RP2 i.e., 2015 to 2019, more widespread terminal airspace changes are foreseen together with the benefits derived from the introduction of the PBN IR. PBN will enable performance improvements in safety, capacity, efficiency and the environment although the scale of improvement will be governed by the scope of the individual airspace changes.

2 Scope

2.1 General

The primary purpose of the PBN policy is to set out a specific regulatory framework and support to ANSPs and operators to help facilitate development and implementation of airspace changes consistent with the FAS. The policy should therefore take account of the requirements of the ANSPs i.e., those responsible for management of the airspace and be consistent with our international obligations.

It is considered appropriate to outline a PBN Policy to ensure both interoperability at global level and common understanding between both the UK and Irish aviation authorities. In view of the above, this policy addresses the application of PBN in UK/Irish airspace where use is made of area navigation techniques for operation on ATS routes, SIDs & STARs and Instrument Approach Procedures and is referred to as the *policy* in this document.

UK and Ireland airspace encompasses the region defined by the UK and Ireland Functional Airspace Block (FAB) together with the remainder of the Cork, Dublin and UK Flight Information Regions (FIRs). For the purposes of this policy, it excludes the Shanwick FIR and the Minimum Navigation Performance Specification (MNPS) applied on the North Atlantic.

Note: MNPS pre-dates the PBN Concept and although out of scope of this policy, the authorities would expect any successor to MNPS for the North Atlantic to comply with the PBN concept. The UK and Irish Aviation Authorities are committed to moving towards this goal.

2.2 Out of Scope of this Policy

2.2.1 Environmental Considerations

The topic of environmental considerations is complex and goes beyond the concept of PBN and for this reason, is considered as out of scope of this policy. The availability of PBN employed within an appropriate redesign of terminal airspace will allow instrument flight procedures to be designed that maximise the ability of aircraft to execute Continuous Descent Operations (CDO) and Continuous Climb Operations (CCO). This in turn will maximise overall efficiency with consequential environmental benefits. Therefore, where practicable, all new PBN-based Standard Arrivals and runway transitions should aim to apply Continuous Descent Operations (CDO) and all new PBN-based Standard Instrument Departures should aim to apply Continuous Climb Operations (CCO). No change will be made to operating procedures without an assessment of environmental impact as required by national procedures and processes.

2.2.2 Precision Approach and Landing Systems

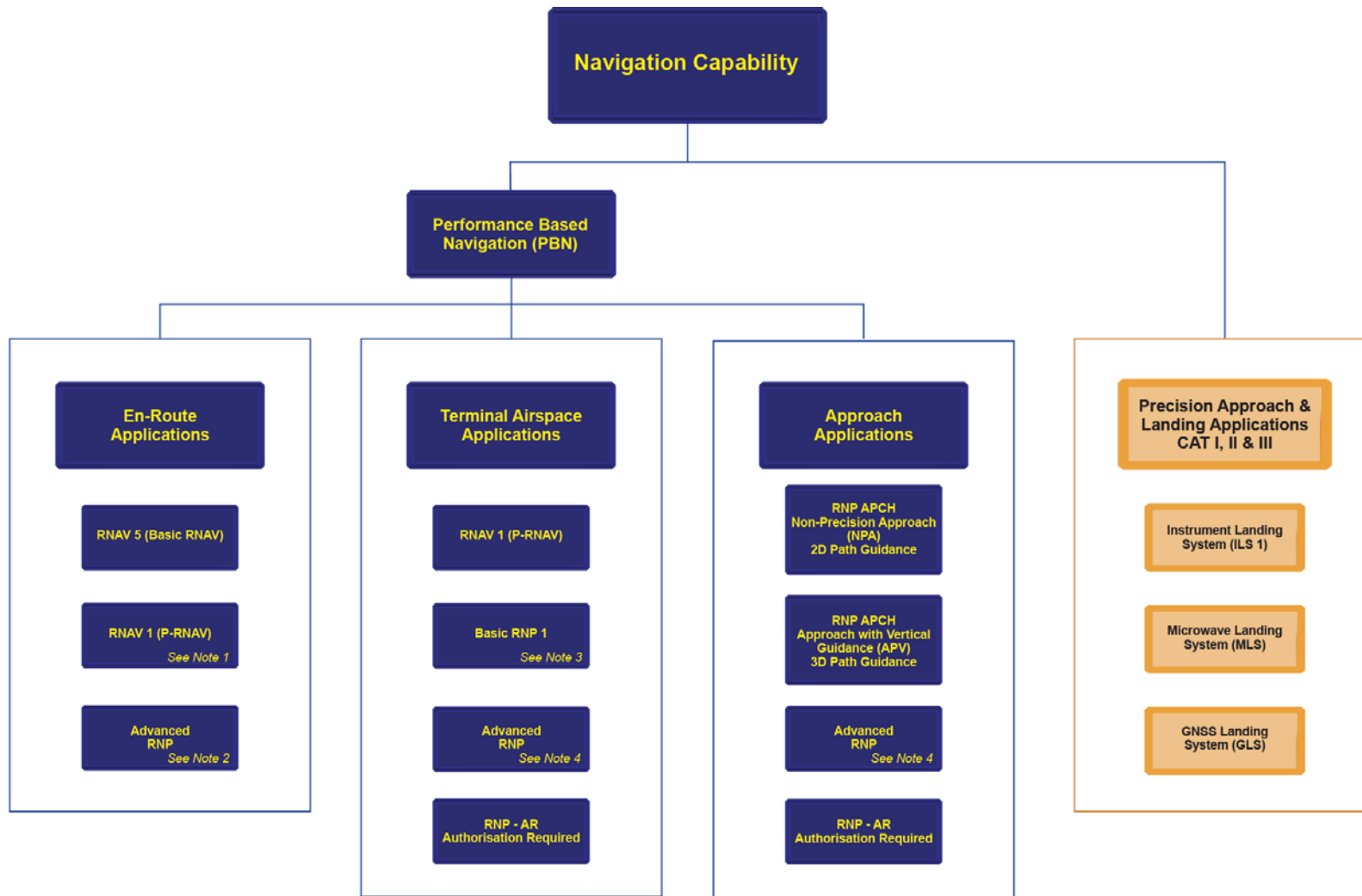
Precision approach and landing systems such as the Instrument Landing System (ILS), Microwave Landing System (MLS) and GNSS Landing System (GLS) form part of the navigation suite, but are not included within the concept of Performance-based Navigation. They differ from PBN applications in that they are not based on area navigation techniques. For completeness the following strategic roadmap for use of such systems is envisaged:

- Precision approach operations may continue to be provided using ILS (and MLS at Heathrow) but in line with SESAR, the UK and Ireland would anticipate a move to GLS once the robustness and resilience of the augmentation system has been demonstrated. Attainment of this goal may require deployment of new GNSS constellations (such as Galileo) and use of dual GNSS frequencies and will be dependent upon industry response to development of suitable receivers and operators' willingness to re-equip. As such, any transition to GLS will unlikely take place until the post 2020 timeframe.

Figure 2 depicts the overall "Navigation Capability" and the relationship between the navigation specifications defined within the ICAO PBN Concept and referred to in this policy and the Precision Approach and Landing Systems mentioned above.

2.2.3 Overlay Procedures

An overlay procedure is a conventionally designed instrument flight procedure which has been coded for use by a Flight Management System (FMS), by the operator's navigation database provider, to replicate the procedure as closely as possible using ARINC 424 path terminators. These procedures are outside of the scope of this policy and are the responsibility of the operator. Overlay procedures are considered to be a compromise solution and are not the preferred modus operandi for deploying PBN-based procedures.



Note 1 Application of RNAV 1 Performance aspects, not terminal airspace functionality

Note 2 Including Fixed Radius Transition (FRT)

Note 3 Equivalent to RNAV 1 + GNSS, typically associated with Radius to Fix (RF)

Note 4 Including Radius to Fix (RF)

Figure 2 Navigation Capability

3 Assumptions

This policy is based on an assumption that the Advanced-RNP navigation specification currently being defined by ICAO for inclusion in the next revision to ICAO Doc 9613, PBN Manual will then be agreed upon by the European Commission as part of the PBN Implementing Rule envisaged circa 2018-2020. In advance of the PBN IR the UK and Ireland may choose to make an early implementation of the core features of this new navigation specification, but will remain upwards compatible with the envisaged Single European Sky (SES II) legislation.

4 Policy for the Application of PBN in UK/Irish Airspace

In this chapter the Policy Statements are highlighted in **bold** text to facilitate ease of reading.

4.1 General

4.1.1 Policy Statement 1: Endorsement of the ICAO PBN Concept

The UK and Irish Civil Aviation Authorities have endorsed the ICAO Performance-based Navigation (PBN) Concept as defined in Doc 9613, Performance-based Navigation (PBN) Manual.

The Authorities strongly support the uptake of PBN as soon as possible, and wherever practicable. Any new ATS routes (including SIDs/STARs) as well as instrument approach procedures based on area navigation techniques should be predicated on an appropriate PBN specification.

Where the Regulator is separate and independent from the service provider(s) it is impractical for the State to produce a PBN Implementation Plan as required by ICAO's 2010 General Assembly Resolution A37-11. A Future Airspace Strategy has been developed as a means to convey the vision for the future modernisation across UK and Irish airspace. In so far as PBN is one of the key enablers to that strategy, this policy document conveys the States' views as to how the technical and operational advancements available through modern navigation techniques should be applied within UK and Irish airspace and at aerodromes. It therefore reflects the requirements from a regulatory perspective and provides the necessary framework for ANSPs to develop their own implementation plans.

4.1.2 Policy Statement 2: Application of ICAO PBN Specifications

Any new ATS routes (including SIDs/STARs) as well as instrument approach procedures based on area navigation techniques, are required to be developed, consistent with the specifications contained in the ICAO PBN Manual Doc 9613 and PBN Instrument Flight Procedure design criteria published in ICAO Doc 8168 as supplemented by any national or European policies.⁶

The UK and Irish CAAs do not support design of hybrid procedures i.e., a mix of conventional and RNAV criteria under the same procedure name.

⁶ Examples include UK CAP 778, Policy and Guidance for the Design and Operation of Departure Procedures in UK Airspace, EUROCONTROL Instrument Flight Procedure Design Criteria for B-RNAV Operations in Terminal Airspace.

Where an ANSP wishes to use a navigation specification outside of its anticipated application, they will be required to demonstrate how use of such a navigation specification can be implemented and then managed safely.

This implies that where RNAV or RNP is utilised, aircraft shall be certified and approved in accordance with regulatory guidance material based upon the navigation specification upon which the airspace design is based.

Further description of the current and planned PBN specifications and their application in UK and Irish airspace, is contained in ANNEX 3. A separate guidance document to support PBN implementation is also to be developed.

4.1.3 Policy Statement 3: PBN Mandates

Where a European Implementing Rule is foreseen to support PBN operations, this will likely be achieved through mandated carriage of a given equipment standard with a mandate on States to provide airspace and instrument flight procedure changes that make use of the capability. Such mandates require aircraft entering a specified airspace volume to be approved in accordance with regulatory criteria reflecting a given ICAO navigation specification. Such requirements will be specified via the relevant Aeronautical Information Publication (AIP).

In advance of any European regulation, the UK and Irish authorities will consider application of elements of the intended navigation specification providing the applied regulatory standards are upwards compatible with the European Commission legislation.

Depending upon the nature and scale of the airspace change proposal, the UK and Irish authorities will consider the case for a part volume of airspace to be notified⁷ for the carriage of PBN compliant equipment and operational approvals as a condition of making that change. The airspace change sponsor therefore should give due consideration to the level of mixed aircraft capability (conventional and PBN) that can be accommodated and provide adequate notification of intent to require PBN procedures in a given airspace volume.

Mindful of the need for a gradual transition to PBN, particularly with respect to terminal procedures, some conventional procedures may be permitted to remain to allow continued access for non-PBN approved aircraft, for a limited period to be determined by the Authorities in conjunction with the ANSP. After this date, all aircraft operating into airspace where PBN is notified will require appropriate approval in accordance with Policy Statement 3. PBN procedures will be optimised to deliver the inherent safety, capacity and environmental benefits; non-PBN procedures may result in sub-optimal routing or limited capacity or environmental benefit, see Section 5.1.

Note: An aircraft equipment mandate is different to an airspace notification. In the former instance, aircraft are required to be approved to a particular navigation specification by a certain date as a precursor to introducing an airspace change. Once the aircraft are suitably equipped and operators approved, selective airspace change can be implemented through notification of a particular airspace volume, route or set of terminal procedures.

⁷ In the UK, notification of airspace is enacted through The Air Navigation Order 2009 (CAP 393) Section 1, Part16, Articles 124 and 125.

4.2 En Route

4.2.1 Policy Statement 4: En route Navigation Specification Applied in the FAB

All ATS routes in the UK/Irish FAB should require aircraft compliance to the RNAV 5⁸ navigation specification and ensure infrastructure and ATM operations consistent with the RNAV 5 navigation specification except where a case can be made for application of a higher standard e.g., RNAV 1 or eventually, Advanced-RNP.

4.3 Terminal Airspace Procedures

4.3.1 Policy Statement 5: Arrivals

All existing conventional STARs should be phased out on an opportunity basis and replaced by either RNAV 5 arrivals or PBN terminal procedures e.g., RNAV 1, Basic-RNP 1 or Advanced-RNP, see ANNEX 3.

4.3.2 Policy Statement 6: RNAV Holding

All new holds shall be designed to be flown manually using a single RNAV fix⁹ as the holding waypoint. Where the fleet equipage can support holding functionality i.e., the RNAV system is able to compensate for the effect of wind coming from the outside of the outbound turn by a reduction in bank angle, holds may be designed in accordance with the appropriate ICAO Doc 8168 criteria.

In line with Policy Statement No. 4 and the introduction of RNAV 5 on all ATS routes, it is assumed that all aircraft, as a minimum, will be able to conduct the simplest form of RNAV holding.

Note: Policy regarding design criteria and separation standards for RNAV holding is under development.

4.3.3 Policy Statement 7: Departures

All existing conventional SIDs should be phased out on an opportunity basis and replaced by PBN terminal procedures e.g., RNAV 1, Basic-RNP 1 or Advanced-RNP.

4.4 Instrument Approach Procedures (IAPs)

4.4.1 Policy Statement 8: RNP APCH

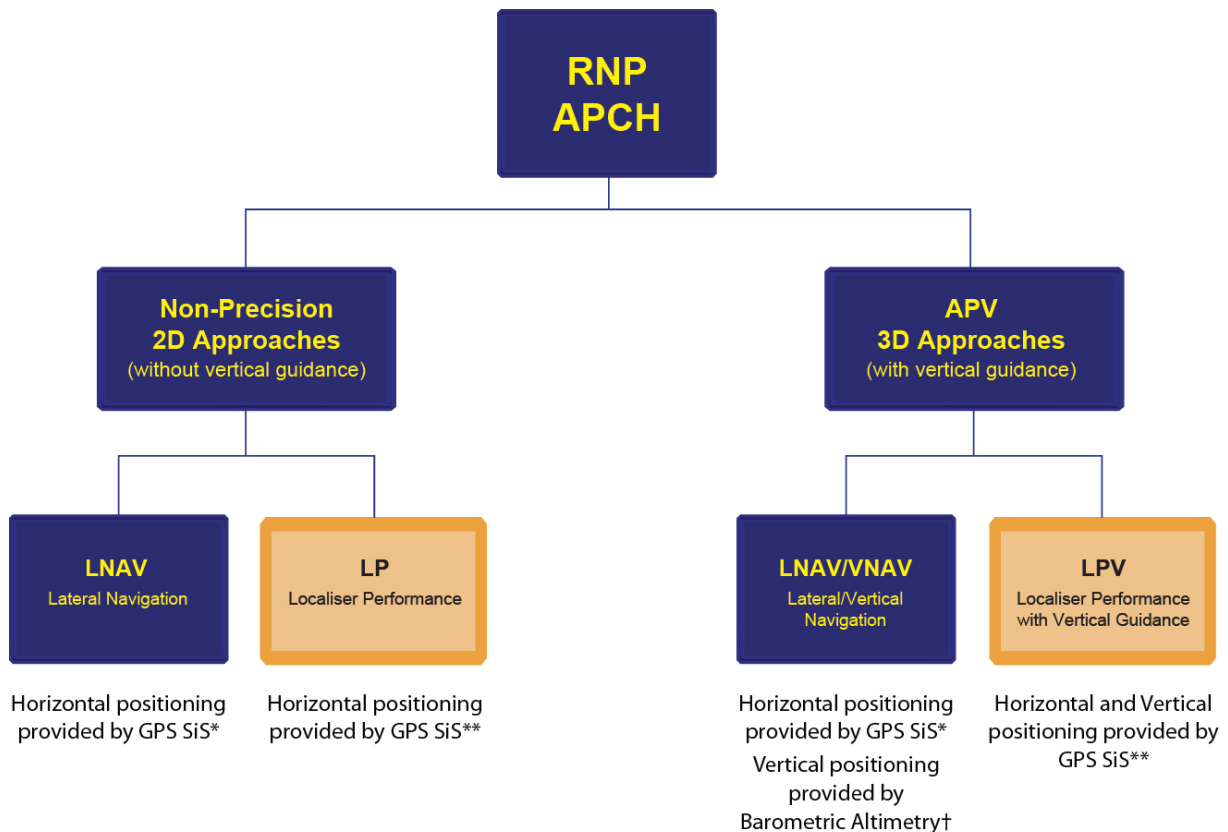
In line with the ICAO 37th General Assembly Resolution A37-11, aerodromes are encouraged to implement RNP APCH instrument flight procedures at all instrument

⁸ See CAA Policy Statement - Introduction of Basic Area Navigation in UK En-Route Airspace below FL95 dated January 2011.

⁹ An RNAV fix is the generic name given for a geographical position; used by the RNAV system when defining the desired path to be flown.

runway ends. Missed Approaches should be designed to be flown with RNAV systems¹⁰.

The applicable RNP APCH Operations include:



- * Augmentation of GPS Signal-in-Space is provided by an Aircraft-Based Augmentation System (ABAS). A common ABAS implementation is the Receiver Autonomous Integrity Monitoring (RAIM) algorithm.
- ** Augmentation of GPS Signal-in-Space is provided by a Satellite-Based Augmentation System (SBAS). In Europe this is provided by the European Geostationary Navigation Overlay Service (EGNOS).
- † Baro-VNAV equipment is mostly carried by larger Commercial Air Transport aircraft. Certain SBAS equipment also provides an LNAV/VNAV capability, which may be used, subject to the Instrument Approach Procedure accommodating this equipment.

Figure 3 RNP APCH Operations as Denoted by Aeronautical Chart Minima

4.4.2 Policy Statement 9: Runway Classification for APV Instrument Approaches

ICAO Annex 14 does not provide guidance on runway infrastructure requirements for instrument approach procedures designed in accordance with either PANS-OPS Doc 8168 APV Barometric VNAV or APV SBAS criteria. In order to assess whether the runway is suitable for an approach procedure with vertical guidance:

- (i) If the Obstacle Clearance Height (OCH) is not less than 90 m (300 ft), the runway and Obstacle Limitation Surface (OLS) should at least meet Annex 14 requirements for a non-precision approach runway;

¹⁰ Consideration should be given to the impact associated with the location of a Missed Approach hold. An RNAV Missed Approach would be expected to terminate in an RNAV hold.

- (ii) If the OCH is lower than 90 m (300 ft), the runway and Obstacle Limitation Surface (OLS) should at least meet Annex 14 requirements for a CAT I precision approach runway.

4.5 Navigation Infrastructure

4.5.1 Policy Statement 10: Navigation Infrastructure to support PBN

The navigation infrastructure (ground and/or space-based) must be able to support all of the airborne performance requirements¹¹ associated with the PBN application deployed within the coverage area of a given airspace.

Note 1: As a consequence of the rationalisation of traditional ground-based navigation aids¹² e.g., VOR and NDB, the decommissioning of a ground facility may impact on existing terminal airspace procedures including arrivals, runway transitions, approaches and departures.

Where the impact on existing terminal airspace procedures results in a replacement design, this procedure should be designed in accordance with the applicable PBN terminal airspace procedure criteria as per Policy Statements 5, 7 and 8 respectively. On a case-by-case basis, the CAA/IAA may permit a re-design whereby the existing conventional SID may be truncated and an ATS Route introduced using en-route criteria e.g., RNAV 5.

4.5.2 Policy Statement 11: Reversion from RNP to RNAV Operations

In designing an airspace application in accordance with RNP principles, the aircraft are required to support on-board performance monitoring and alerting¹³. The airspace design authority will have to take account of the loss of this function and managing the consequential airspace reversion i.e., fall back to an RNAV state. In particular, the availability of the navigation infrastructure (GNSS or DME/DME) and its ability to provide continuity of service for RNP operations must be considered and substantiated in the safety case for the operation.

As a guide, the loss of RNP capability on an individual aircraft may be managed without reversion of the airspace to an RNAV state. Loss of GNSS over a wide area may force reversion to an RNAV state e.g., RNP 1 to RNAV 1 with consequential reversion procedures and the implications for ANSPs e.g., alternate ATS procedures.

¹¹ PBN airborne performance requirements include navigation accuracy, integrity, continuity and functionality.

¹² See CAA Policy Statement - Changes to the UK Ground Navigation Infrastructure dated August 2010.

¹³ This is typically satisfied through use of GNSS positioning which will alert when the Horizontal Integrity Limit (HIL) is exceeded for the given flight phase. An alternative RNP alerting philosophy may be implemented by the aircraft manufacturer e.g., dedicated RNP alerting in accordance with RTCA / EUROCAE document DO-236B / ED-75B.

4.6 Route Spacing

4.6.1 Policy Statement 12: Route Spacing to be applied on PBN Routes and Procedures

The ANSP should apply route spacing appropriate for the airspace and ATS operation being undertaken.

Factors including aircraft fleet capability (RNAV or RNP), traffic density and radar separation standards should be factored into the assessment which should be validated as part of the overall safety case.

Route spacing is typically defined with respect to parallel routes but may be applied relative to all forms of traffic interaction including aircraft to aircraft and aircraft to a hold or to the edge of controlled airspace.

EUROCONTROL and ICAO studies have shown that improved navigation performance on both straight segments and in the turn enables route spacing between parallel tracks (same or opposite direction) to be reduced from current RNAV 5 limits. The following table summarises the findings:

Parallel Routes Based on	A-RNP		RNAV 1		RNAV 5
	En-Route	Terminal	En-Route	Terminal	En-Route
Same Direction	7 NM	7 NM ¹⁴	9 Nm	8 NM ¹⁴	16.5 NM
Opposite Direction					18 NM
Other					10-15 NM with increased ATC intervention rates
Spacing on turning segments	As above		Larger than above because no FRT		Much larger than above because no automatic leg change

Table 1 Route Spacing from EUROCONTROL and ICAO Studies

¹⁴ In the UK, the CAA has accepted 5 NM between parallel routes (same or opposing) for RNAV 1 terminal procedures based on a 3 NM radar separation standard. See CAA Guidance titled P-RNAV Route Spacing dated May 2007.

5 Implementation Considerations

5.1 General Considerations

5.1.1 Enablers

Several factors directly affect the implementation of future airspace concepts. In the context of the FAS, it is clear that the timely availability of ground and airborne enablers is essential before the UK and Ireland can proceed with modernisation of their respective airspace organisation.

This *policy* distinguishes between general and specific enablers.

- *General enablers* include clear and unambiguous political commitment necessary to ensure the realisation of FAS, for example; implementation programmes to direct the course of work and the arrangements to detail the development and achievement of change;
- *Specific enablers* include human, procedural or institutional and *system enablers* such as those included in the navigation application, the navigation specification and navigation infrastructure under consideration;
- *System enablers* can be broadly considered as clustered into two groups; ground and airborne. Despite their different roles, it is clear that many ground and airborne enablers will need to be integrated if the benefits of FAS are to be realised.

The interdependence of these enablers will necessitate synchronised implementation.

5.1.2 Implementation Scenarios

In the context of navigation enablers, three implementation scenarios can be considered.

Scenario 1: Phased implementation leading to mixed operations

This involves providing support necessary to permit ATC to handle mixed traffic operations. For this scenario, the following would need to be in place:

- Available ATC system support to allow the controller to know the capability of the aircraft (this involves the Flight Data Processor being able to extract the relevant information from Item 18 of the ICAO ATC FPL); and
- Available ATC system support that permits handling the traffic according to their navigation capability; and
- Guidance material on handling mixed traffic is provided to the service provider. Such material would include airspace design considerations, allocation of the appropriate clearances, the factors to be considered in determining the percentage number of approved aircraft needed etc.; and
- Safety and Business cases; and
- Implementation Plans.

This scenario involves an investment from the service provider be that the airport and/or the ANSP (with an extended notice period) but is not likely to incur significant costs for the airspace user. However, this mixed traffic scenario may lead to a reduction in capacity and may not be appropriate in a congested airspace environment. Additionally, this scenario will require maintaining the current ground infrastructure (navigation aids), which in turn could limit the pace of transitioning towards GNSS as per the ICAO Global ATM Concept.

Scenario 2: Mandate airborne navigation enabler

This solution would be appropriate if, for example, the ATC system support is not available to handle mixed traffic operations or it is shown that such operations would not realise the required capacity gains (this is mostly the case today). In such a case, the following considerations should be included:

- Business case; and
- The lead-time to be given to airspace users and, depending on the nature of the mandate, various service providers such as airports and/or ANSPs; and
- The extent of the mandate (local, regional or ECAC-wide) ; and
- Safety cases; and
- Implementation Plans.

This scenario involves an investment for the airspace user (including a notification lead time) with less costs being incurred by the airport and/or ANSPs. This scenario will ensure that capacity is maintained or increased. However, it may result in slowing the pace of change (to more advanced navigation capability) if the lowest common denominator is selected as a mandate for the airborne navigation enabler. There may also be a conflict with future EU regulations if the mandate is in an area where the Commission is about to mandate and the standards are not forward compatible.

Scenario 3: The integrated nature of PBN implementation

In reality, depending on the airspace/procedure change and the supporting navigation application required, it will be necessary for any successful implementation to encompass elements of both of the above scenarios i.e., airport and/or ANSP investment in system change aligned with user investment in certification and approvals and regulatory measures to drive equipage. This will require a much closer collaboration between all stakeholders and greater integration of ground and air capabilities than has been the case up until now.

An equal level of commitment is therefore required on all parties in order to deliver the required service improvements. Scenario 3 should therefore be seen as the model to be applied, regardless of the type, size and scope of the proposed introduction and reflecting the integrated nature of the PBN implementation process.

Ideally, by building on the already available capability that is present in modern day air transport aircraft fleets, it may be possible to deliver this scenario with minimum additional cost.

5.1.3 General Considerations

There are a number of general points that have a bearing on implementation and can influence the pace of change. These points have been borne out of past navigation implementations and hold true for future evolutions. What can be concluded is that each situation may attract its own implementation strategy and that no one size option fits all, be that for En-route, Terminal or Approach flight phases or for dense versus less dense airspace. Trade-offs will likely have to be made between capacity, flight efficiency and environmental mitigation before deciding on an implementation strategy for a given airspace organisation/volume.

5.1.3.1 The Inter-relationship between Navigation Applications and Navigation Infrastructure

The inter-relationship between the Navigation Application and Navigation Infrastructure can be viewed from both sides:

- With an increased reliance on RNAV, the introduction of a new navigation application facilitates rationalisation of conventional ground based infrastructure. Decommissioning of redundant VOR and NDB facilities and alignment of DME to provide core backbone architecture can lead to cost savings for the ANSP, which will, in due course, be passed on to customers.

Alternatively,

- Introduction of infrastructure technology e.g., Galileo, GPS L5, EGNOS and GBAS can in themselves open opportunities for the development of new navigation applications e.g., in the approach phase, which in itself might lead to decommissioning of approach aids.

Both are therefore general considerations in the implementation planning.

Another consideration for the ANSP is the renewal/replacement costs associated with ground based navigation aids. Particularly in the case for VOR, if the implementation of a navigation enabler (application) and infrastructure rationalisation can be timed to coincide, opportunities exist for significant cost savings. Conversely, if the navigation infrastructure is relatively young, there will not be the same motivation for removal. The navigation infrastructure lifecycle costs therefore become a general consideration in any implementation planning and can significantly influence the pace of change, especially over the short term.

With radio spectrum becoming an increasingly valuable commodity, charging for use of spectrum is another cost consideration. More efficient use of spectrum is therefore a business driver which can be offset through the move to satellite-based applications.

5.1.3.2 Aircraft Considerations

Airborne technology is largely unconstrained (apart from cost) and tends to move ahead of implementation for a number of reasons. Getting a Navigation Application from a proof of concept or trial into the field for any flight phase, takes considerable planning. As already mentioned, aircraft equipage is a major factor and in turn the availability of complaint equipment, either for retrofit or for inclusion in new production build, is a critical path. It is a fact that in looking ahead to 2018, most of the features of a new Navigation Application will probably have to be available today or else there will be little chance of the capability being available on sufficient airframes for that timeframe. Designs for a new aircraft type are frozen long before Type Certification so it is arguable that anything new has missed the Airbus A350 and the Boeing B787. New and replacement designs for short haul aircraft (C-Series, A320 neo and B737 MAX) are under consideration and the risk is that airspace development will be constrained with what is available on our most capable aircraft of today. The life cycle for a new Navigation Application, which requires functionality not currently available, is estimated at approximately 10 to 15 years.

Service life of airframes is also a major consideration. Depending on utilisation, the average life of an aircraft can extend up to 25 or 30 years. Without mid-life updates, navigation equipment design easily becomes outdated. But those updates come at a recurring cost and operators will only choose to upgrade if the commercial disadvantages against the

competition become significant i.e., restricted access to airspace or procedures leads to a commercial disadvantage. What this means is that at any one time there are multiple generations of aircraft types and navigation capability operating within any given airspace volume and managing this performance mix is challenging for ATC. Airspace or equipment mandates therefore serve to harmonise the required performance - usually with a compromise to the lowest common (performance) denominator. The downside of a mandate is for those operators who have invested in the latest equipment, they fail to get a return from its use.

When planning an implementation it is therefore important to take account of:

- Current aircraft capability commonly available. This requires good survey data and then careful analysis;
- The service life of aircraft and navigation equipment designs;
- The time taken to introduce a Navigation Application not available today.

It should be noted that in ECAC with both B-RNAV and P-RNAV, the standards were written around what was already available on the majority of aircraft types or at least could be made available without significant retrofit cost. At least for the short and medium term, it is envisaged that future implementations, to remain cost effective, will continue to be based around taking what a significant number of aircraft have today and defining the Navigation Specification and its application around that capability.

5.1.3.3 Airborne Navigation Equipment Redundancy

The move towards RNAV/GNSS and away from routes and procedures predicated on conventional navigation aids, means that continuity of function becomes a consideration. Whilst reversion to either a conventional route/procedure or recovery through ATC is a contingency option today, with rationalisation of the navigation infrastructure and eventual dependency on GNSS, this will not always be the case. Large air transport aircraft are typically equipped with dual redundant navigation sensors e.g., VOR, DME, ADF. With operations becoming more dependent upon RNAV equipment e.g., Flight Management Systems (FMS), there will be a need to identify the degree of dependence upon RNAV and the back-up navigation capability provided through conventional aids. In the long term it would be expected that there will be a need for a regulatory requirement for dual RNAV equipment. Most new production aircraft will not be affected, but for a significant number of older types and airframes, the operators may have to consider outlay for dual equipment. Introduction of such a continuity requirement will be linked to the safety case supporting implementation of a Navigation Application and take account of the available infrastructure. Therefore, infrastructure rationalisation whilst making a cost saving for the ANSP can have a direct impact on the operator. A balance has to be found with a trade-off between conventional infrastructure and airborne equipment costs. The cost benefit analysis will need to consider this as part of any implementation strategy.

5.1.3.4 Regulatory Oversight

As part of any implementation, regulatory oversight is another key enabler. The timely availability of certification criteria addressing both airworthiness and flight operations considerations and that governing the oversight of ANSPs, is essential.

Even with aircraft capable of meeting a given new navigation specification, recognition of that specification through relevant certification material and any necessary assessment or demonstration to the Authorities will have to be factored into the implementation time-line.

The operators will then have to address flight crew operating procedures and training as a function of the operational approval that accompanies the navigation application in a given airspace. If training requires a flight simulator assessment, this can introduce a 6-12 month lead time depending on opportunities to conduct re-current training. As RNAV becomes part of the everyday working of flight crews, new applications will likely become “delta” changes to an already established set of standard operating procedures and practices.

The ANSP will have to consider within the design, factors such as interactions with adjacent airspace configurations, ATS procedures and controller training. Simulation exercises and potential iterative changes to either design and/or procedures will impact the overall time-line.

The airspace design will have to be supported with an end-to-end safety case having previously identified potential hazards and developed appropriate risk mitigation strategies.

Finally, the airspace change will have to be submitted for regulatory approval having considered the benefits and dis-benefits on all airspace users and with due consideration to the environmental impact, having conducted an appropriate level of consultation with the affected community.

5.1.4 Summary of General Considerations

The complexities surrounding an airspace change should not be under-estimated, especially when the scale of change is applied through a mandate or affects a significant airspace volume. In summary:

- The scenario for phased implementation suits airspace users but can be very difficult for the airport and/or ANSP to manage safely and effectively;
- Mandates of airborne equipment are the favoured option for efficient ATM, but can be costly for the airspace users (if the mandate is too demanding) and if set too low, can fail to deliver the anticipated benefits;
- Navigation applications and navigation infrastructure are two sides of the same coin;
- Natural equipage will only deliver gradual change in navigation capability as the aircraft fleet is either modernised or renewed;
- In the future, there will be higher requirements for continuity as the dependency on satellite-based navigation replaces the traditional ground-based navigation aids;
- Regulatory oversight and timely availability of certification criteria is a critical item on the implementation time-line.

Above all, the close cooperation and coordination between stakeholders is essential, as highlighted in scenario 3. One of the significant differences between implementation of PBN applications and the routes and procedures of previous years is the required level of integration between the *general* and *specific* enablers, including the airborne and ground aspects, in delivering an overall navigation capability to a volume of airspace. From an implementation perspective, the challenge is managing the transition to a FAS target situation with the support and working-together of all of the affected players.

5.2 Safety Assessment Considerations

When implementing PBN, a number of safety considerations have to be assessed.

Aircraft performance can be considered as having characteristics of normal performance and non-normal performance. The errors which contribute to the non-normal performance

include RNAV system failures as well as blunder type errors such as selection of the wrong route or instrument procedure. RNP specifications address elements of non-normal performance through the onboard performance monitoring and alerting requirements, including aircraft and signal-in-space failure conditions. Blunder errors are not included and must be handled through flight crew procedures, training and detection through surveillance or additional separation.

Aircraft system failures must be considered in the safety assessment process. In particular, where the airborne continuity requirement can be met through a single RNAV system, consideration should be given to the nature of aircraft system failures, availability of alternate means of navigation and the available CNS ATM environment. For example, loss of function on a single aircraft in a surveillance environment will require a different mitigation strategy than in a non-surveillance environment. In either situation, the mitigations will need to be incorporated into the operating procedures in support of the navigation application. Allowance for density of traffic and the desired route spacing will also have to be taken into account within the assessment.

With the navigation infrastructure intrinsically linked to delivering navigation performance, failures of either ground or space-based segments will have to be assessed including their ability to continue to deliver the navigation application. Apart from influencing the required redundancy in coverage, consideration will also have to be given to the reversionary means under the failure condition. Where ATS surveillance is proposed as mitigation, the acceptability of the resulting ATC workload will have to be evaluated, especially when considering a potential common-mode failure of say, the near-simultaneous loss of navigation capability by a number of aircraft. Depending on the navigation specification, other potential mitigations could include carriage of autonomous navigation capability e.g., Inertial Reference Units (IRU), or an alternative terrestrial navigation input to the RNAV position solution such as from DME/DME. See also Section 4.5.2, Policy Statement No. 11 and Section 5.4 (Managing Risk).

In addition to the aircraft performance requirements and the available navigation infrastructure for both primary and reversionary navigation capability, the contributions of ATS surveillance and communications to achieve a target level of safety (TLS) for a desired route spacing, must also be considered. ATS surveillance and communications can contribute to the mitigation of non-normal navigation performance, and in doing so; the availability of those systems and the required redundancy has to be factored in. In utilising ATS surveillance and communications, the effectiveness of ATC intervention in the event of an aircraft not following the route centreline, must be considered. In particular, controller workload and their ability to detect an unacceptable route deviation, unless perhaps supported by tools such as route-conformance monitors, should be addressed. Furthermore, if ATS surveillance is provided using ADS-B the potential impact of a common mode failure e.g., loss of GNSS, should be considered in terms of the resulting operating scenario.

In addition to national safety policies, each navigation specification within the ICAO PBN Manual includes references to related safety assessment material, designed to assist the applicant in identifying the applicable safety objectives and then presenting arguments and evidence as part of the overall safety process.

5.3 State Aircraft Compliance

From a compliance perspective the ANSP has to ensure they can meet the requisite safety objectives and will require assurance that all aircraft participating to a given navigation application are interoperable. This implies that aircraft that routinely use the civil ATS structure as GAT, are certified to equivalent standards of performance such as accuracy,

integrity, continuity and most importantly, are interoperable with respect to aircraft functionality and the ability to conduct required operations e.g., flying a Radius to Fix (RF) or future Fixed Radius Transition (FRT).

The State Authorities will, where possible, look to comply with appropriate elements of the PBN requirements either through equipage or the demonstration of equivalence. This may prove challenging and therefore alternative means of handling non-PBN compliant State aircraft may have to be part of the solution and resulting airspace management arrangements. As an example, depending upon the nature of the mission, there may be delays and/or non-optimum routings/cruising levels by which ATC accommodate such traffic movements.

The certification standards for the respective PBN applications are well defined and can be clearly stipulated for the military platforms. The finding of compliance and where appropriate, any equivalent means of compliance, is the responsibility of the respective Military Aviation Authority (MAA).

5.4 Managing Risk

In any implementation, the applicant should consider both the risks to safety and business and provide adequate risk mitigation strategies to reduce this to acceptable levels. This should include the management of so called “Black Swan” events i.e., events which are highly unlikely such as the total loss of GNSS signal-in-space.

In moving forward with PBN as a key enabler to FAS, the risks have been considered in terms of the overall success of the modernisation of the UK/Irish airspace system in addition to those associated directly with publication of a PBN policy.

- (i) The success of FAS will depend on being able to make timely airspace design changes, applying the concepts and techniques of PBN (and other enablers) commensurate with the aircraft fleet having the requisite equipment functionality, navigation performance capability and the necessary regulatory approvals. Finding the balance between setting a design standard for a future implementation date that can be achieved by a sufficiently high percentage of the aircraft fleet movements (typically in the 90 to 95% range), without having to make compromises such that projected benefits cannot be realised, is key. The importance of accurate surveyed fleet data, adequate advanced notice of change and effective dialogue with the user community cannot be overstated.
- (ii) Previous experience shows that making terminal airspace changes, especially in dense and complex airspace structures, with an allowance for mixed equipment capabilities i.e., preserving legacy compatibility, is both inefficient and can lead to safety risks from having to support different types of operation. In order to facilitate airspace change without incurring a non-optimised design or the aforementioned safety risks, the PBN policy permits the notification / prescription / designation of a given navigation performance capability for a particular volume of airspace, route or procedure.
- (iii) With changes to a more systemised airspace structure comes a change in role for the air traffic controller from one of active management to a more passive monitoring/reactive task within a highly systemised structure. To assist the controller in this new role there will be a greater dependence upon the development and correct operation of controller monitoring tools and the need for

associated human factors analysis of this new concept of operation. Clear safety and capacity benefits accrue from such a method of operation.

- (iv) A new method of managing the airspace will also bring with it challenges for both the ANSP and the NSA. This will include, ensuring resilience of the service itself e.g., due to a weather (vector around a thunderstorm cell) and accounting for fallbacks in the event of system failures (full and partial) and the controller's ability to maintain a safe service during the transition phase in differing levels of service or navigational capability.
- (v) With the benefits from accurate, repeatable and predictable paths associated with RNP applications, comes the concentration of environmental effects, especially on those living close to major UK airports. In the future, reductions in aircraft engine noise and emissions will help mitigate these effects as will new instrument flight procedures defining precisely threaded noise abatement routes and taking advantage of today's aircraft climb performance. However, environmental policy, consultation requirements and decisions affecting where the effects should lie i.e., town versus country, concentration versus dispersion, will all have an impact that will have to be managed.
- (vi) Finally, the lack of a political will and commitment to move airspace changes forward, either when applying this policy or in the lack of clarity of other related policies has the potential to seriously impact progress e.g., lack of clear airport development policy, consultation requirements etc.

6 Authorities Review

In order to satisfy their Statutory Duties, NSAs may also require controlling authorities to initiate a review of their airspace to ensure that existing arrangements continue to be fit for purpose.

This policy will be reviewed periodically and amended to reflect latest developments within the PBN concept.

7 References

7.1 ICAO

- Procedures for Air Navigation Services – Aircraft Operations, Volumes I and II (PANS-OPS), (Doc 8168)
- Performance-based Navigation (PBN) Manual, (Doc 9613)
- Required Navigation Performance Authorisation Required (RNP AR) Procedure Design Manual, (Doc 9905)
- General Assembly Resolution, A37-11
- Guidance material for the issuance of required navigation performance approach (RNP APCH) operational approvals, (State Letter SP 65/4-10/53)

7.2 EUROCONTROL

- EUROCONTROL Instrument Flight Procedure Design Criteria for B-RNAV Operations in Terminal Airspace
- Introducing Performance Based Navigation (PBN) and Advanced-RNP (A-RNP)
- Airspace Concept Handbook for the Implementation of Performance-based Navigation (PBN)
- RNAV Approaches (Leaflet)

7.3 EASA

- Airworthiness Approval and Operational Criteria For the Use of Navigation Systems in European Airspace Designated For Basic RNAV Operations, (AMC 20-4)
- Airworthiness Approval and Operational Criteria for RNP Authorisation Required (RNP AR) Operations, (AMC 20-26)
- Airworthiness Approval and Operational Criteria for RNP Approach (RNP APCH) Operations Including APV Baro-VNAV Operations, (AMC 20-27)
- Airworthiness Approval and Operational Criteria for onboard equipment related to Area Navigation for Global Navigation Satellite System approach operation to Localiser Precision with Vertical guidance minima using Satellite Based Augmentation System, (Draft AMC 20-28)

7.4 JAA

- Airworthiness and Operational Approval For Precision RNAV Operations In Designated European Airspace (Temporary Guidance Leaflet, (TGL) No. 10 Rev 1)

7.5 CAA

- Future Airspace Strategy (FAS)
- Policy and Guidance for the Design and Operation of Departure Procedures in UK Airspace, (CAP 778)
- Introduction of Basic Area Navigation in UK En-Route Airspace below FL95 (CAA Policy Statement)
- Changes to the UK Ground Navigation Infrastructure (CAA Policy Statement)
- The Air Navigation Order 2009 (CAP 393)
- P-RNAV Route Spacing (CAA Guidance Document)
- APV - Approach Procedures with Vertical Guidance (Leaflet)

7.6 RTCA / EUROCAE

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

7.7 ARINC

- Navigation System Data Base, (Specification 424-())

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Annex 1

Glossary of Terms

ABAS	Aircraft-Based Augmentation System
AC	Advisory Circular
ADF	Automatic Direction Finder
ADS-B	Automatic Dependent Surveillance - Broadcast
AIP	Aeronautical Information Publication
AMC	Acceptable Means of Compliance
ANSP	Air Navigation Service Provider
AOA	Airport Operators Association
APCH	Approach
APV	Approach Procedure with Vertical guidance
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
Baro-VNAV	Barometric Vertical Navigation
B-RNAV	Basic RNAV
CAA	Civil Aviation Authority
CAP	CAA Publication
CCO	Continuous Climb Operations
CDO	Continuous Descent Operations
CNS	Communication, Navigation and Surveillance
DME	Distance Measuring Equipment
EASA	European Aviation Safety Agency
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay Service
EUROCAE	The European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
FAB	Functional Airspace Block
FANS	Future Air Navigation System
FAS	Future Airspace Strategy
FIR	Flight Information Region
FMB	FAB Management Board
FMS	Flight Management System
FOSA	Flight Operations Safety Assessment
FRT	Fixed Radius Transition
FSC	FAB Supervisory Committee
FTE	Flight Technical Error
GAPAN	The Guild of Air Pilots & Air Navigators
GAT	General Air Traffic
GBAS	GNSS-Based Augmentation System
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
GPS	US DoD Global Positioning System
HIL	Horizontal Integrity Limit
IAA	Irish Aviation Authority
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IFP	Instrument Flight Procedure
ILS	Instrument Landing System
IRU	Inertial Reference Unit
LNAV	Lateral Navigation
LP	Localiser Performance

LPV	Localiser Performance with Vertical guidance
MAA	Military Aviation Authority
MASPS	Minimum Aviation System Performance Standards
MLS	Microwave Landing System
NATMAC	National Air Traffic Management Advisory Committee
NDB	Non-Directional radio Beacon
NextGen	Next Generation Air Transportation System
NM	Nautical Mile
NPA	Non-Precision Approach
NPP	National Performance Plan
NSA	National Supervisory Authority
NSE	Navigation System Error
OCH	Obstacle Clearance Height
OLS	Obstacle Limitation Surface
PDE	Path Definition Error
PBN	ICAO Performance-based Navigation
P-RNAV	Precision RNAV
RAIM	Receiver Autonomous Integrity Monitoring
RF	ARINC 424 Radius to Fix Path Terminator
RNAV	Area Navigation
RNP	Required Navigation Performance
RNP APCH	RNP Approach
RNP AR	RNP Authorisation Required
RTA	Required Time of Arrival
SBAS	Satellite-Based Augmentation System
SES	Single European Sky
SESAR	Single European Sky ATM Research programme
SID	Standard Instrument Departure
SiS	Signal-in-Space
SOPs	Standard Operating Procedures
STAR	Standard Arrival
TBO	Trajectory Based Operations
TGL	Temporary Guidance Leaflet
TSE	Total System Error
VNAV	Vertical Navigation
VOR	Very high frequency Omnidirectional radio Range

Annex 2 PBN Benefits

The principal benefit derived from PBN is the transition to a total RNAV environment. This will lead to flight efficiency and allow optimisation of the airspace including reduced holding containment areas. Without the constraints of navigating via fixed, ground-based aids, the airspace designer has a powerful tool in terms of positioning of routes and instrument flight procedures in relation to areas of congestion or population density.

Of concern to the industry is the potential cost from proliferation of regional and State navigation specifications. PBN brings about a more disciplined approach through a limited set of specifications which are globally applied. The aircraft and equipment manufacturers therefore have greater certainty in their market place and can anticipate a tangible return on their capital investment in the aircraft's performance capability.

From an aircraft operator perspective, certain carriers have long claimed that their fleet capability far exceeded anything the airspace could offer by way of capacity and environmental benefits. So with the modern air transport aircraft having this enhanced performance and functionality, PBN starts to harness that aircraft capability. For those with less well equipped aircraft, pressure to upgrade or be faced with exclusion from certain routes or procedures, has to be applied as an incentive rather than as a threat to their business.

What PBN can offer is:

- Predictable and repeatable path trajectories moving to a systemised environment with designed interactions;
- Closer spaced routes;
- Curved path transitions;
- Greater tactical flexibility through parallel offsets; and
- Higher integrity from RNP which brings greater assurance to the safety equation and reduces flight crew workload.

From an airspace and airports perspective the envisaged benefits of PBN include:

- Increase in capacity in controlled airspace;
- Greater access to airports, especially for General Aviation (GA) aircraft which have traditionally been limited to higher operating minima due to their basic equipment;
- Improvement in safety through onboard monitoring and performance alerting to the flight crew; and
- Reduction in the effects that flights have on the environment from more efficient routes, more accurate path keeping for noise abatement and, in conjunction with other airspace initiatives such as increased Transition Altitude (TA), the increased use of Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO).

From an ATM service provider perspective the envisaged benefits of PBN include:

- Reduced service cost through reduced navigational infrastructure, increased systemisation and increased controller productivity;
- Improvement in safety through the introduction of flight path monitoring tools and alerting to controllers; and
- Improvement in the quality of the service to meet new airspace-user requirements.

The navigation infrastructure is a key element in PBN and the transition to an RNAV environment is linked to a move towards a space-based navigation environment (Global Navigation Satellite System – GNSS) and a move away from dependence on traditional ground-based navigation infrastructure such as VOR and NDB facilities. This in turn will allow rationalisation of infrastructure leading to savings from capital investment; maintenance and spectrum utilisation with commensurate savings passed onto the operators through reduced navigation services charges and a requirement to carry less equipment.

Annex 3 PBN Specifications and their Application in UK and Irish Airspace

A3.1 PBN Specifications

The ICAO PBN Manual, Doc 9613 comprises two volumes. Volume I contains a description of the PBN concept and implementation guidance including a step-by-step set of implementation processes. Further descriptive guidance on airborne RNAV systems and aeronautical data processes is also provided. Volume II of the manual provides the direct support for implementing both RNAV and RNP navigation applications. Having discussed the differences between RNAV and RNP and safety assessment considerations, it lists guidance for implementing each of the identified navigation applications. This includes a background and purpose for each application and then considerations for the ANSP e.g., navigation infrastructure, communication and surveillance dependencies, aeronautical publication, controller training and status/ATS system monitoring, before detailing the navigation specification itself. The navigation specifications provide an outline of the approval processes, the detailed aircraft requirements and operating procedures. Specific pilot knowledge and training is also identified where applicable. The navigation specification also details any requirements for control of navigation databases and oversight of operators.

The structure of Volume II navigation specifications is detailed below:

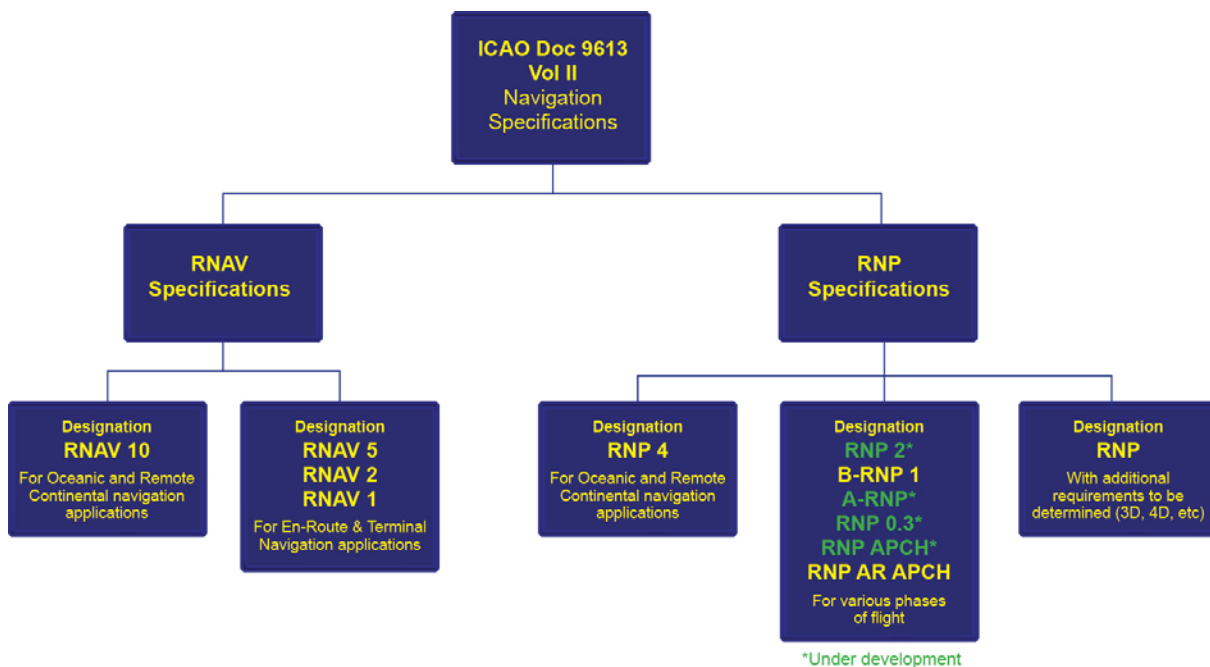


Figure 4 ICAO PBN Manual current and planned navigation specifications

RNAV X/RNP X = lateral Total System Error (TSE) must be within $\pm X$ NM for at least 95% of the total flight time.

The use of a designation without navigation accuracy e.g., RNP APCH, indicates that the navigation specification may be applied across multiple flight phase or leg segments with different navigation accuracy values.

Within the PBN concept the term RNP distinguishes one type of RNAV system from another. If an RNAV system has an on-board performance monitoring and alerting capability then, for the purposes of classification under PBN it is referred to as an RNP capable system and able to support RNP navigation applications.

This additional conformance monitoring and alerting functionality in the RNP specification effectively provides the flight crew with an alert when the system is incapable of determining that the aircraft navigation performance is within a pre-determined value. It does not indicate that system accuracy has necessarily been degraded but rather that it should not be trusted. From a controller's perspective no divergence from the aircraft's cleared route may be observed even though the pilot may have received a system integrity alert.

A3.2 Current PBN Specifications

There follows a brief description of the features and anticipated application of the navigation specifications currently included in the PBN Manual, per flight phase.

A3.2.1 En-route Oceanic/Remote

RNAV 10 has its origins in RNP 10 and the earlier ICAO RNP concept. With the introduction of the PBN concept, the navigation application, which allows for compliance using the aircraft's Inertial Reference Units (IRU), has no requirement for onboard performance monitoring and alerting and therefore is strictly an RNAV navigation application. Given that certification criteria and operational approvals are still describing RNP 10, the two are considered synonymous with one another.

RNP 4 was developed as a more accurate navigation application to RNAV 10, specifically to support reduced route spacing e.g., 30 NM lateral and 30 NM longitudinal. It is predicated on use of Basic GNSS e.g., GPS, which inherently provides onboard performance monitoring and alerting.

A3.2.2 Continental En-route

RNAV 5 is directly equivalent to the European Basic RNAV (B-RNAV) navigation application introduced in ECAC in 1998. It therefore predates the PBN concept and existing airworthiness approval criteria continue to be used. In comparison with other navigation specifications, RNAV 5 has only rudimentary functionality e.g., there is no requirement for a navigation data base. RNAV 5 is therefore an entry-level navigation specification for many States and Regions looking to modernise their airspace structure, yet without an extensive navigation infrastructure. As such, the ± 5 NM navigation accuracy can be met using VOR/DME RNAV or even IRS under time-limited conditions.

RNAV 2 has the same functional requirements as RNAV 1 and indeed they share the same chapter in Part B of Volume II of the PBN Manual. The ± 2 NM navigation accuracy is intended to support routes where DME coverage may not be continuous. Therefore such routes are typically only authorised for aircraft carrying DME/DME/IRU or GNSS.

RNAV 1 was primarily developed as a terminal airspace navigation application (discussed below), although it may be applied in the en-route environment to support reduced route spacing, subject to the navigation infrastructure supporting use of the navigation specification. Flight crew procedures typically applied for use of RNAV 1 in terminal airspace would also have to be adapted for the en-route application.

A3.2.3 Terminal Airspace

RNAV 1 is the ICAO term for terminal airspace navigation applications based on a navigation infrastructure predicated on use of GNSS or DME/DME or DME/DME/IRU. In ECAC airspace, P-RNAV was introduced in 2000 and therefore pre-dates RNAV 1. Although P-RNAV is directly equivalent to RNAV 1 in terms of performance and functionality, the underlying navigation infrastructure was assumed to be either GNSS or DME/DME. Consequently, an aircraft approved for European Precision RNAV having only a DME/DME terminal airspace capability may not qualify for RNAV 1 operations in another Region where the infrastructure has been based on aircraft being equipped with Inertial Reference Units (IRU) i.e., supporting DME/DME/IRU.

RNAV 1 is intended to support Standard Arrival (STAR), Runway Transition¹⁵ and Standard Instrument Departure (SID) flight phases. It requires a navigation data base and support of specific ARINC 424 Path Terminators. As a condition of an operational approval, the operator should obtain their navigation data base (and updates) from an approved supplier so as to provide a measure of integrity in the aeronautical data process.

An arrival route (STAR) can be based on RNAV 5, providing the following parameters are satisfactorily addressed:

- The RNAV 5 portion of the route must be above Minimum Sector Altitude/Minimum Flight Altitude/Minimum Radar Vectoring Altitude (as appropriate) and must be in accordance with established PANS-OPS criteria for en-route operations and conform to RNAV 5 en-route design principles.
- The RNAV 5 portion of an arrival route must terminate at a conventional fix in accordance with the criteria given above and the arrival completed by an alternative final approach procedure also appropriately approved.
- Due regard has been taken of the standard operating procedures (SOPs) of the users.

Illustration of the different types of Instrument Flight Procedure (IFP) schemas that might be applied for STARs in high density and medium to low density Terminal Areas is provided in Figure 5.

¹⁵ The Runway Transition is the flight segment that links the Standard Arrival Route (STAR) to the runway final approach segment where a continuous path is described to that approach segment. Typically described in an FMS as a “via” it may include the Initial and Intermediate Approach segments that would otherwise be described on a stand-alone instrument approach procedure.

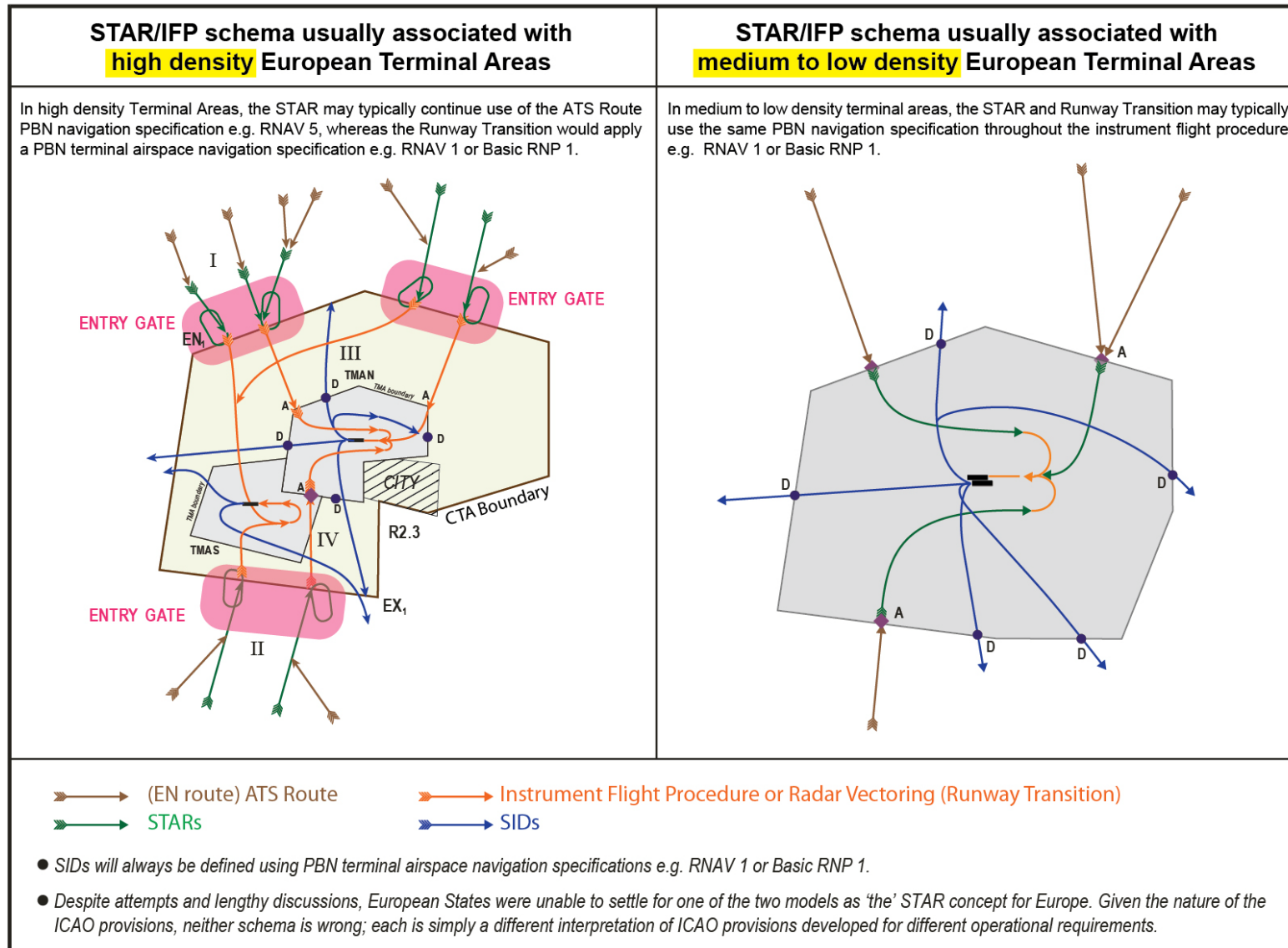


Figure 5 Illustrations of STAR/IFP Schemas

Basic-RNP 1 has the identical navigation performance and functionality as RNAV 1 except it requires onboard performance monitoring and alerting, typically supported by GNSS. Intended for terminal airspace environments without adequate DME coverage, the claim that Basic-RNP 1 is equivalent to RNAV 1 in a non-radar environment is a somewhat simplistic as one has to consider how the navigation specification is intended to be used in the given CNS and ATM environment and other mitigating factors e.g., route spacing and traffic density.

If GPS equipment is used outside of 30 NM from the aerodrome reference point, the alerting will switch to an en-route value (± 2 NM). Consequently, when implementing Basic-RNP 1 SIDs and STARs beyond 30 NM from the aerodrome, flight crew procedures must account for the automatic switching e.g., manually select the lateral deviation indicator full-scale sensitivity to not greater than 1 NM.

A3.2.4 Instrument Approach Operations

RNP APCH covers the four flight segments of an instrument approach procedure. The segments have the following assigned navigation accuracy values:

- Initial Approach Segment ± 1 NM
- Intermediate Approach Segment ± 1 NM
- Final Approach Segment ± 0.3 NM
- Missed Approach Segment ± 1 NM

The chart name is RNAV (GNSS) to reflect the dependence on lateral positioning on GNSS Signal-In-Space (SIS). With the inherent onboard performance monitoring and alerting provided by GNSS, the navigation specification qualifies as RNP and yet like many navigation applications, GPS based approaches pre-date PBN, so the chart name has remained. RNP APCH procedures may be designed as stand-alone “T” or “Y” with the four segments as indicated above, or may be linked to a Runway Transition provided by either RNAV 1 or Basic-RNP 1 up to the Final Approach segment and followed by the Missed Approach. The Final Approach segment may be flown either as a 2 Dimensional Approach (Non-Precision Approach) or as a 3 Dimensional Approach (Approach Procedure with Vertical guidance). For the latter, the vertical path positioning is provided by either onboard barometric systems or Space-Based Augmentation of Basic GNSS. From this the terms APV Baro-VNAV and APV SBAS are coined.

Note: The current PBN Manual contains only Basic GNSS RNP APCH (NPA) and APV Baro-VNAV. In 2010, ICAO published State Letter SP 65/4-10/53 which amended the PBN Manual Volume II, Part C, Chapter 5 criteria to extend the PBN concept to include SBAS based approaches. Although SBAS is angular in the final approach, it requires an RNAV system and navigation data base coding similar to the other PBN specifications, therefore ICAO determined to make SBAS a PBN infrastructure allowing compliance to a wider range of equipments for all navigation specifications. The planned update to the PBN Manual includes the State Letter material.

RNP AR APCH is a “high-end” instrument approach navigation specification. RNP AR provides an added level of assurance over standard operations and as the designation indicates, a special **Authorisation is Required**. ICAO has identified specific instrument approach design criteria in the RNP AR Manual and whilst criteria in this and the PBN Manual cater today for approach operations, work is underway to update both to address Departures. The advanced features of RNP AR include operations with navigation accuracy less than 0.3 NM, use of Radius to Fix (RF) Path Terminator in all flight segments and reduced obstacle assessment criteria reflecting the assurance accounted for in a Flight Operations Safety Assessment (FOSA).

Airspace and airport sponsors should discuss with the CAA/IAA any plans for implementing procedures using the RNP AR navigation specification at the earliest opportunity. Instrument procedure design, aircraft capability, flight crew qualification, ATC procedures and safety assessment will all need to be specifically addressed against dedicated criteria as part of this special authorisation.

A3.3 Planned PBN Specifications

Doc 9613 is currently being revised by ICAO to include additional navigation applications. It is envisaged that the following navigation applications could be applied in UK and Irish airspace in accordance with the Policy Statements contained herein:

RNP 2 is an en route continental/oceanic and remote area specification reflecting differing applications in those flight regimes. At the “low-end”, it is envisaged to be used to support previous GNSS sensor derived route spacing whilst at the “high-end” the continuity requirements distinguish a different airspace environment.

RNP 0.3 is primarily intended to support helicopter operations with SBAS avionics and advanced flight control systems. The fixed 0.3 navigation accuracy is intended to facilitate operations such as Helicopter Emergency Services (HEMS) with Point-in-Space (PINS) instrument approaches.

Radius to Fix (RF) may be associated as an option with all RNP terminal airspace navigation applications e.g., Basic-RNP 1, RNP 0.3, RNP APCH. RF is a required function within Advanced-RNP. It is initially intended that, RF will only be used up to the Final Approach Fix of an instrument approach procedure and then only in the later stages of the Missed Approach. Once further data is gathered from use of RF, it is hoped that the scope of operation can eventually be expanded. In the meantime, for use of RF outside of the above mentioned B-RNP 1 and RNP APCH segments and phases, see RNP AR operations.

Advanced-RNP is designed to encompass en-route, terminal and approach operations with a discrete set of flight phase navigation accuracies from RNP 2 to RNP 0.3, selectable through the navigation database. As such, Advanced-RNP is designed as a navigation specification reflecting the modern aircraft capability rather than separate flight phase navigation applications. This will enable cost savings to be made for the aircraft manufacturers through having a single airworthiness assessment, from which the specific operational approvals can be granted depending on the nature of the airspace application. In this way, proliferation of navigation specifications should be avoided. The navigation specification has certain “core” features with growth options for functions including Fixed radius Transition (FRT) and Trajectory Based Operations comprising Required Time of Arrival and the commensurate integrated VNAV functionality that will have to accompany it. Advanced-RNP is significant in that it is the cornerstone for the proposed PBN Implementing Rule in Europe.

The functions associated with Advanced-RNP are explained in more detail below.

RNP AR Departures is an extension to the current navigation specification to address instrument departure procedures with “Authorisation Required.”

Advanced-RNP Functionality

Functionality	Description	Comment
RNP	Will provide benefits in that it allows a range of predetermined navigation accuracy values (from 2.0 to 0.3 NM) to be applied in different flight phases at different locations, see Table 3. Onboard performance monitoring and alerting as a standard requirement.	Of significance where reduced route spacing can benefit constrained airspace or provide access in terrain challenged environments.
RF (Radius to Fix)	For use within Terminal Airspace. The RF leg is an ARINC 424 path terminator and is used as part of a coded procedure in the navigation database. It typically replaces existing “fly-by” path transitions providing much tighter containment on the turns.	Will allow parallel SIDs, STARs and runway transitions to be designed with closer route spacing on both straight and turning segments. Especially of significance on the first turn of departure procedures where environmental containment is critical.
FRT (Fixed Radius Transition)	For use within En-route airspace. FRT provides a fixed radius (22.5 NM above FL195 and 15 NM below) as part of the en-route record in the navigation data base.	FRT enables routes to be mapped out with defined turns in them and consequently, a high degree of conformance can be expected. Therefore it provides for consistent route spacing around turns and this is essential to supporting a more efficient airspace design.
RNAV Holding	Either flown manually using a single RNAV holding fix or with holding functionality.	Will reduce the overall footprint of holds and therefore facilitate more efficient airspace design.
Basic VNAV	Today’s VNAV functionality.	Will allow altitude constraints (AT, AT or BELOW, AT or ABOVE) or window constraints to be programmed at any waypoint in the flight plan or alternatively will allow any flight plan leg to be coded with a constant Flight Path Angle (FPA). This will allow strategic de-confliction of crossing arriving and departing routes and will allow the planned vertical profile to take into account airspace restrictions.

TBO (Trajectory Based Operations)	Use of Required Time of Arrival (RTA) with integrated VNAV functionality will provide ATM benefits in a SESAR environment, especially metering of traffic from en route into terminal airspace.	It is expected that the early SESAR developments will provide initial operating capability for these functions in the 2015-20 timescale.
Tactical Parallel Offset	Allows ATC intervention to instruct tactical offset to be flown against a parent route or track at integer values, even around turns.	Will allow faster aircraft to be offset and overtake slower aircraft thus allowing the former to reach optimum cruising altitude earlier and operate at fuel optimum speeds. The use of FRT on both the host and offset tracks will enable minimum route spacing to be applied between both tracks.

Table 2 Advanced-RNP Functionality

The table below depicts the envisaged application of Advanced-RNP based on aircraft navigation accuracies that have been demonstrated through existing aircraft certification programmes.

Nav Spec	Flight Phase						
	En-route	Arrival	Approach				Departure
			Initial	Intermediate	Final	Missed	
Advanced-RNP	2, 1, 0.5	1, 0.5	1, 0.5	1, 0.5	0.3	1, 0.5, 0.3*	1, 0.5, 0.3*

* Use of RNP 0.3 in the Missed Approach and Departure is likely to be restricted to initial straight path segments i.e., prior to the first turn.

Table 3 Envisaged Application of Advanced-RNP

A3.4 Regulatory Guidance Material

The following table lists the relevant PBN regulatory guidance material available today:

Airspace Application	Navigation Specification	Applicable Regulatory Guidance
Oceanic & Remote		
	RNAV 10	FAA order 8400.12A EASA AMC 20-12
	RNP 4	FAA order 8400.33 EASA Rulemaking Task No. MDM.062 (JAA CNS/ATM SG pp045)
	RNP 2	To Be Developed
Continental En-route		
	RNAV 5	FAA AC 20-138B, AC 90-96A EASA AMC 20-4
	Advanced-RNP	To Be Developed
Terminal Airspace		
	RNAV 2	FAA AC 90-100A
	RNAV 1 (P-RNAV)	FAA AC 90-100A JAA TGL 10 Rev 1
	Basic-RNP 1	FAA AC 20-138B, AC 90-105
	RNP 0.3	To Be Developed
	Advanced-RNP	To Be Developed

Approach Operations		
	RNP APCH ¹⁶	FAA AC 20-138B, AC 90-105 EASA AMC 20-27
	RNP APCH ¹⁷	FAA AC 20-138B, AC 90-105 EASA AMC 20-27
	RNP APCH ¹⁸	FAA AC 20-138B, AC 90-107 EASA AMC 20-28*
	RNP AR Operations	FAA AC 90-101A EASA AMC 20-26

* EASA AMC 20-28 publication anticipated at the end 2011

Table 4 Available Regulatory Guidance Material

¹⁶ Initial, Intermediate and Missed Approach Segments, with or without RF legs

¹⁷ Final Approach Segment of instrument approach procedure, designed to LNAV and/or LNAV/VNAV minima

¹⁸ Final Approach Segment of instrument approach procedure, designed to LP or LPV minima