RNP SPECIAL OPERATIONAL REQUIREMENTS STUDY GROUP (RNPSORSG)

PBN MANUAL
WORKING DRAFT 4.1

To be reviewed by: RNPSORSG, SASP, OCP, NSP, OPS/P during the period 30th October – 31st December 2006.

(Please use the comment disposition form,
PBN Manual W-Draft 4.1 Comment Disposition.doc
to provide comments. Please send comments to *ELassooij@icao.int* by 31st December 2006.)

CHANGES MADE TO VOLUME I

- Moved some sections from Executive Summary to Foreword (i.e History of Manual)

- Part A - Clarifications where useful to reinforce understanding of the term "Navigation Application" as meaning to apply a navigation specification in an available infrastructure in order to achieve ATS routes, procedures, or designated airspace volume (as in "RNP 4 airspace")

- Part B - Simplification of the three Processes (Part B) to aid in determining requirements, selecting a navigation specification, and planning/implementing the selected specification. Deleted "Process 2-EX" and reframed that material as guidelines for the development of a new navigation specification in (rare) case where it might be needed.

- Minor Editorial corrections made to Attachment A of Volume I

CHANGES MADE TO VOLUME II

- Part A – Expanded from 1 to 3 Chapters. Chapters 2 & 3 cover on-board performance monitoring and alerting and Safety Assessment, respectively.

- Parts B & C: Each RNAV and RNP chapter reflects consistency, both in organizational format and general text. The original concepts remain, but emphasis was placed on producing a consistent manual vs. a collection of individual submissions. Therefore, individual authors should recognize the overall purpose remains unchanged. The emphasis on performance is prevalent in both Part B and C

- PART B, IMPLEMENTING RNAV
  RNAV chapters 1 and 2 (RNAV 10 and RNAV 5) were reformatted, mindful of the fact current criteria could not be changed due to existing guidance. Histories/backgrounds were shortened for consistency. Since Chapter 3 (RNAV 1 and RNAV 2) received the most scrutiny from the study group, it was considered to be the most mature example and was used as a template for the other RNAV, RNP and Baro VNAV specifications.

- PART C, IMPLEMENTING RNP
  Overview of changes: RNP chapters were conceptually aligned with submitted material and changed where necessary for consistency.

- end -

RNP SPECIAL OPERATIONAL REQUIREMENTS STUDY GROUP (RNPSORSG)

PERFORMANCE BASED NAVIGATION MANUAL

VOLUME I

- CONCEPT AND IMPLEMENTATION GUIDANCE -

Version:	Working Draft 4.1
Date	27 OCTOBER 2006
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W-Draft 2	JUNE2006	All, to be reviewed by RNPSORSG/8 (JUN2006) – new format
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W-Draft 3.2	SEP2006	Modifications made by separate authors
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EXECUTIVE SUMMARY

Background

The continuing growth of aviation places increasing demands on airspace capacity and emphasizes the need for the optimum utilization of the available airspace. Together with the improved operational efficiency derived from the application of Area Navigation (RNAV) techniques, this has resulted in the development of navigation applications in various regions and for all phases of flight. Navigation applications could potentially be expanded to the provision of guidance for ground movement.

In setting out requirements for navigation applications on specific routes or within a specific airspace, it is necessary to define requirements in a clear and concise manner. This is to ensure that the both flight crew and ATC are aware of the on-board area navigation (RNAV) system capabilities and to ensure that the performance of the RNAV system is appropriate for the specific airspace requirements.

The early use of RNAV systems arose in a manner similar to conventional ground-based routes and procedures. A specific RNAV system was identified and its performance was evaluated through a combination of analysis and flight testing. For domestic operations the initial systems used VOR and DME for their position estimation. For oceanic operations, inertial navigation systems (INS) were employed. These 'new' systems were developed, evaluated and certified. Airspace and obstacle clearance criteria were developed on the basis of available equipment performance. Requirements specifications were based upon available capabilities and, in some implementations, it was necessary to identify the individual models of equipment that could be operated within the airspace concerned. Such prescriptive requirements results in delays to the introduction of new RNAV system capabilities and to higher cost for maintaining appropriate certification. To avoid such prescriptive specifications of requirements, this Manual introduces an alternative method for defining equipage requirements by specification of the performance requirements. This is termed Performance-Based Navigation (PBN).

Performance Based Navigation

The PBN concept specifies RNAV system performance requirements in terms of accuracy, integrity, availability and functionality needed for the proposed operations in the context of a particular airspace concept. The PBN concept represents a shift from sensor-based to performance-based navigation. Performance requirements are identified in navigation specifications, which also identify the choice of navigation sensors and equipment that may be used to meet the performance requirements. These navigation specifications are defined at a sufficient level of detail to facilitate global harmonization by providing specific implementation guidance for States and operators.

Under PBN, generic navigation requirements are defined based on the operational requirements. Operators are then able to evaluate options in respect of available technologies and navigation services that could allow these requirements to be met. The chosen solution would be the most cost effective for the operator, rather than a solution being imposed as part of the operational requirements. Technologies can evolve over time without requiring the operation itself to be revisited, as long as the requisite performance is provided by the RNAV system.

PBN offers a number of advantages over the sensor-specific method of developing airspace and obstacle clearance criteria:

a) Reduction of the cost of maintaining sensor-specific routes and procedures.

b) Developing system-specific operations with each new evolution of navigation systems would be cost-prohibitive.

c) Allows more efficient use of airspace (route placement, fuel efficiency, noise abatement)

d) Clarifies the way in which RNAV systems are used.

e) Facilitation of the operational approval process for operators by making more visible a limited set of navigation specifications intended for global use.

Within an airspace concept, PBN requirements will be affected by the communication, surveillance and ATM environment, as well as the navaid infrastructure and the functional and operational capabilities needed to meet the ATM application. PBN performance requirements will also depend on what reversionary, non-RNAV means of navigation are available and hence what degree of redundancy is required to ensure an adequate continuity of function.

The development of the Performance Based Navigation Concept recognizes that advanced aircraft RNAV systems are achieving a predictable level of navigation performance accuracy which, together with an appropriate level of functionality, allows a more efficient use of available airspace. It also takes account of the fact that RNAV systems have developed over a 40 year period and as a result there are a large variety of implementations. Identifying navigation requirements, rather than the means of meeting the requirements, will allow use of all RNAV systems meeting these requirements irrespective of the means by which these are met.

Purpose, Objectives and Scope of Manual

This manual identifies the relationship between RNAV and RNP applications and sets out issues associated with the identification of the advantages and limitations of choosing one or the other as the Navigation requirement for an airspace concept. It also aims to give practical guidance to States, Air Navigation Service Providers and airspace users on how to implement RNAV and RNP applications, and how to ensure that the performance requirements are appropriate for the planned application.

Recognising that there are many airspace structures based on existing RNAV applications, and conscious of the high cost to operators of meeting different certification and operational approval requirements for each application, the manual seeks to support those responsible for assessing whether the application can use an existing navigation specification for a proposed implementation. The primary aim is to guide in the identification of whether, by a suitable adjustment of airspace concept, navigation application and/or infrastructure, it is possible to make use of an existing navigation specification, thereby obviating the need for a specific and potentially costly imposition of a new certification requirement for operation in an individual airspace.

Where analysis identifies that a new standard is needed, the manual identifies the steps required for the establishment of such a new standard. It identifies a means by which, through the auspices of ICAO, unnecessary proliferation of standards will be avoided.

Performance Based Navigation Terminology

Two fundamental aspects of any PBN operation are the requirements set out in the appropriate *Navigation Specification* and the *Navigation aid Infrastructure* (both Ground and Space Based) allowing the system to operate.

A *Navigation Specification* is a set of aircraft and air crew requirements needed to support a *navigation application* within a defined *airspace concept.* The *Navigation Specification* defines the performance required of the RNAV system as well as any functional requirements such as the ability to conduct curved path procedures or to fly parallel offset routes

A *navigation specification* that includes a requirement for on-board navigation performance monitoring and alerting is referred to as an *RNP specification* and designated as *RNP X*. One not having such requirements is referred to as an *RNAV specification* and designated as *RNAV X*. For both RNP X and RNAV X, 'X' refers to the lateral navigation accuracy in nautical miles that is expected to be achieved at least 95 per cent of the flight time. An RNAV system capable of achieving the performance requirement of a RNP specification is referred to as an RNP System.

Transition Strategies

Transition to Performance Based Navigation

It is expected that all future RNAV applications will identify the navigation requirements through the use of Performance Specifications rather than defining equipage of navigation aid requirements.

Where operations exist that were defined prior to the publication of this manual, a transition to PBN may not necessarily be undertaken. However where revisions to the functional and operational requirements are made, the development and publication of the revised specification will use the process and description established in this manual.

Transition to RNP specifications

As a result of industry decisions in the 1990s, most modern RNAV systems provide on board performance monitoring and alerting and the navigation specifications developed for use by these systems can therefore be designated RNP.

Many RNAV systems, while offering very high accuracy and possessing many of the functions provided by RNP systems, are not able to provide assurance of their performance. Recognising this and to avoid operators incurring unnecessary expense, where the airspace requirement does not necessitate the use of a RNP system, many new as well as existing navigation requirements will continue to specify RNAV rather than RNP system. It is therefore expected that RNAV and RNP operations will coexist for many years.

However, RNP systems provide improvements on the integrity of operation permitting, inter alia, possibly closer route spacing and can provide sufficient integrity to allow only RNAV systems to be used as for navigating in a specific airspace. The use of RNP systems may therefore offer significant safety, operational and efficiency benefits. Therefore, whilst RNAV and RNP applications will coexist for a number of years, it is expected that there will be a gradual transition to RNP applications as the proportion of aircraft equipped with RNP systems increases and the cost of transition reduces allowing a local or regional business case for the change to be demonstrated.

TABLE OF CONTENTS

ATTACHMENTS TO VOLUME I

FOREWORD

The Performance Based Navigation Manual consists of two volumes:

Volume I: - Concept and Implementation Guidance.

Volume II: - Implementing RNAV and RNP

Organisation and Contents of Volume I

Part A, *The Performance Based Navigation Concept,* contains three chapters:

Chapter 1, *Description of Performance Based Navigation,* explains the PBN concept and lays specific emphasis on the designation of navigation specifications as well as the distinction between RNAV and RNP specifications. This chapter provides the foundation for the rest of the PBN Manual.

Chapter 2, *Concepts of Operation,* provides a context to Performance Based Navigation and explains that PBN does not exist in isolation but rather as an integral component of an airspace concept. This chapter also clarifies that PBN is one of the CNS/ATM enablers in an airspace concept.

Chapter 3, *Stakeholders Uses of Performance Based Navigation,* explains how airspace planners, procedure designers, airworthiness authorities, controllers and pilots use the PBN concept. Written by specialists of these various disciplines, this chapter is intended for the understanding of non-specialists in the various disciplines.

Part B, *Implementation Guidance,* contains five chapters based on three processes aimed at providing practical guidance for the implementation of Performance Based Navigation

Chapter 1, *Introduction to Implementation Processes,* provides an overview of the three implementation processes with a view to encouraging the use of existing navigation specifications when implementing PBN.

Chapter 2, *Process 1: Determine Requirements* outlines steps for a State or Region to determine its strategic and operational requirements for Performance Based Navigation via an Airspace Concept

Chapter 3, *Process 2: Identifying an ICAO Navigation Specification for Implementation* explains how, once the navigation requirements are identified, attempts should be made to use an existing navigation specification to satisfy the requirements identified.

Chapter 4, *Process 3: Planning and Implementation* provides guidance on activities and tasks to be undertaken so as to enable operational implementation.

Chapter 5, *Guidelines for Development of a New Navigation Specification* outlines how a State or Region should progress if it becomes impossible to satisfy an airspace concept using an *existing* navigation specification.

Attachments A & B

Attachment A, *Area Navigation (RNAV) Systems* provides a simple, layman's explanation to RNAV systems, how they operate and what their benefits are. This Attachment is particularly intentioned for air traffic controllers and airspace planners.

Attachment B, *Data Processes* is geared towards anyone involved in the data chain from surveying to packing of the navigation database. This attachment also provides a simple and straightforward explanation of a complex subject.

Specific Remarks

This contents of this Volume are the product of deliberations by ICAO's RNPSORSG and as such, the material it contains has relied to a large extent on the experiences of States which have used RNAV operations. The PBN Concept discussed in Volume I is a notable exception. This concept is new and should be viewed as more than just a remodelling or an extension of the RNP Concept – see Part A, Chapter 1 paragraph 1.1.1. As significantly, this Volume should not be read in isolation. It is an integral part and complementary to Volume II, *Implementing RNAV and RNP.*

In elaborating the PBN concept and developing associated terminology, it became evident to the RNPSORSG that the use of RNAV-related expression could create some complexity. States and international organizations should take particular note of the Explanation of Terms and to Chapter 1, Part A of Volume I.

Attention is drawn to the fact that expressions such as RNP Type and RNP Value that were associated with the RNP Concept (as is the earlier edition of ICAO Doc 9613, formerly titled *Manual on RNP*) are not used under the PBN Concept and are to be deleted in ICAO Material.

History of this Manual

The Special Committee on Future Air Navigation Systems (FANS) identified that the method most commonly used over the years to indicate required navigation capability was to prescribe mandatory carriage of certain equipment. This constrained the optimum application of modern on-board equipment. To overcome this problem, the committee developed the concept of required navigation performance capability (RNPC). FANS defined RNPC as a parameter describing lateral deviations from assigned or selected track as well as along track position fixing accuracy on the basis of an appropriate containment level

The RNPC concept was approved by the ICAO Council and was assigned to the Review of the General Concept of Separation Panel (RGCSP) for further elaboration. The RGCSP, in 1990, noting that capability and performance were distinctively different and that airspace planning is dependent on measured performance rather than designed-in capability, changed RNPC to required navigation performance (RNP).

The RGCSP then developed the concept of RNP further by expanding it to be a statement of the navigation performance necessary for operation within a defined airspace. It was proposed that a specified type of RNP should define the navigation performance of the population of users within the airspace commensurate with the navigation capability within the airspace. RNP types were to be identified by a single accuracy value as envisaged by FANS.

Whilst this was found to be appropriate for application in remote and oceanic areas, the associated guidance for route separation was not sufficient for continental RNAV applications. This resulted from a number of factors that included setting a performance and functional standard for aircraft navigation systems, having to work within the constraints on available airspace, and use of a more robust communication, surveillance and ATM environment. It was also necessitated by practical considerations stemming from the gradual development of RNAV capability together with the need to derive early benefit from installed equipment. This resulted in different specifications of navigation capability with common navigation accuracy. It was also noted that such developments were unlikely to cease as Vertical navigation (3D) and Time (4D) navigation developed and was applied by ATM to increase airspace capacity and efficiency.

The above considerations have presented significant difficulties to those organisations responsible for the early implementation of RNAV operations in continental airspace. In solving these, significant confusion has developed regarding concepts, terminology and definitions. Consequently, a divergence of implementation resulted in a lack of harmonization between RNP applications.

On 3 June 2003, the Commission (163-10) when taking action on recommendations of the fourth meeting of the Global Navigation Satellite System Panel (GNSSP), designated the Required Navigation Performance and Special Operational Requirements Study Group (RNPSORSG) to act as the focal point for addressing several issues related to required navigation performance (RNP).

The RNPSORSG reviewed the ICAO RNP concept, taking into account the experiences of early application as well as current industry trends, stakeholder requirements and existing regional implementations. It developed an agreed understanding of what is now the Performance Based Navigation concept and the relationship between RNP and area navigation (RNAV) system functionality and applications. This will allow global harmonization of existing implementations and create a basis for harmonization of future operations.

Whilst this manual provides the information on the consensus achieved on 2D and approach RNAV applications, The experience of RNP to date leads to the conclusion that as 3D and 4D applications are developed, there will be a need to review the impact such developments have on the Performance Based Navigation concept and to update this manual accordingly

This manual supersedes the RNP Manual (Doc 9613, 2nd Edition). It is applicable to all of the above and consequently affects a number of ICAO Documents including:

ICAO, Annex 11, Rules of the Air and Air Traffic Services

ICAO, Procedures for Air Navigation, Air Traffic Management (PANS-ATM, Doc. 4444- ATM/501)

ICAO, PANS-OPS, Aircraft Operations Volumes I & II,

ICAO, Airspace Planning Methodology for the Determination of Separation Minima (Doc 9689)

ICAO, Air Traffic Services Planning Manual (Doc. 9426-AN/924)

ICAO, Regional Supplementary Procedures for Air Traffic Management

Future Developments of this Volume

[standard text on comments:]

Comments on this manual would be appreciated from all parties involved in the development and implementation of PBN. These comments should be addressed to:

The Secretary General

International Civil Aviation Organization

999 University Street

Montreal, Quebec H3C 5H7

Canada

REFERENCES

Note. – Documents referenced in this manual or affected by Performance Based Navigation

ICAO

ICAO, Annex 4 Aeronautical Charts

ICAO, Annex 6 - Operation of Aircraft, Part I – International Commercial Air Transport – Aeroplanes

ICAO, Annex 6 - Operation of Aircraft, Part II - Int'l General Aviation - Aeroplane

ICAO, Annex 8- Airworthiness of Aircraft;

ICAO, Annex 10 – Aeronautical Telecommunications, Vol. I - Radio Navigation Aids

ICAO, Annex 11, Air Traffic Services;

ICAO, Annex 15, Aeronautical Information Services

ICAO, Annex 17, Security;

ICAO, Procedures for Air Navigation Services, Air Traffic Management (PANS-ATM), Doc. 4444 ATM/501

ICAO, Global Navigation Satellite System (GNSS) Manual, Doc. 9849

ICAO; Manual on Airspace Planning Methodology for the Determination of Separation Minima, Doc. 9689;

ICAO, Safety Management Manual, Doc. 9859.

ICAO, Aircraft Operations, Doc. 8168 Vols. I & II

ICAO, Manual on Testing of Radio Navigation Aids, Doc 8071

ICAO, Circular 311, Assessment of ADS-B to Support Air Traffic Services and Guidelines for Implementation. Draft, First Edition – 2006

OTHER

RTCA, Minimum Operating Performance Standards for GNSS, DO-208;

RTCA, RNP-RNAV Minimum Aviation System Performance Specifications, DO-236(B);

EUROCAE, RNP-RNAV Minimum Aviation System Performance Specifications;ED-75B

RTCA, Standards for Aeronautical Information, DO-201(A)

RTCA, Standards for Processing Aeronautical Data, DO-200A,

ARINC 424

ABBREVIATIONS

ABAS	Airborne based augmentation System
ADS-B	Automated Dependent Surveillance-Broadcast
ADS-C	Automated Dependent Surveillance-Contract
AIP	Aeronautical Information Publication
ANSP	Air Navigation Service Provider
APV	Approach Procedure with Vertical Guidance
ATM	Air Traffic Management
ATS	Air Traffic Services
CDI	Course Deviation Indicator
CDU	Control and Display Unit
CFIT	Controlled Flight Into Terrain
CRC	Cyclic Redundancy Checking
CRM	Collision Risk Modelling
CVSM	Conventional Vertical Separation Minima
DME	Distance Measuring Equipment
EASA	European Aviation Safety Authority
ECAC	European Civil Aviation Conference
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FDE	Fault Detection and Exclusion
FTE	Flight Technical Error
FMS	Flight Management System
FRT	Fixed Radius Transition
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
INS	Inertial Navigation System
IRS	Inertial Reference System
IRU	Inertial Reference Unit
ITRF	International Terrestrial Reference Frame
JAA	Joint Aviation Authorities
MCDU	Multi-Function Control and Display Unit
MEL	Minimum Equipment List
MNPS	Minimum Navigation Performance Specification
NAVAID	Navigation Aid(s)
NSE	Navigation System Error
PBN	Performance Based Navigation
PDE	Path Definition Error
PEE	Positioning Estimation Error
RF	Radius to Fix
RNAV	Area Navigation
RTCA	Radio Technical Commission on Aeronautics
SBAS	Satellite Based Augmentation System
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
TLS	Target Level of Safety
TSE	Total System Error
VOR	Very High Frequency Omni-Range

EXPLANATION OF TERMS

Aircraft-Based Augmentation System (ABAS). An augmentation system that augments and/or integrates the information obtained from the other GNSS elements with information available on board the aircraft.

Note. - The most common form of ABAS is receiver autonomous integrity monitoring (RAIM).

Airspace Concept: An Airspace Concept provides the outline and intended framework of operations within an airspace. An Airspace Concept is essentially a high-level statement of an airspace plan. Airspace Concepts are developed to satisfy explicit t strategic objectives such as improved safety, increased air traffic capacity and mitigation of environmental impact etc. Airspace Concepts include details of the practical organisation of the airspace and its users based on particular CNS/ATM assumptions. e.g. ATS route structure, separation minima, route spacing and obstacle clearance.

Approach procedure with vertical guidance (APV). An instrument procedure which utilizes lateral and vertical guidance but does not meet the requirements established for precision approach and landing operations.

ATS surveillance service. Term used to indicate a service provided directly by means of an ATS surveillance system.

ATS surveillance system. A generic term meaning variously, ADS-B, PSR, SSR or any comparable ground-based system that enables the identification of aircraft.

Note.— A comparable ground-based system is one that has been demonstrated, by comparative assessment or other methodology, to have a level of safety and performance equal to or better than monopulse SSR.

Area navigation (RNAV). 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.

Note.- Area navigation includes performance based navigation as well as other RNAV operations that do not meet the definition of performance based navigation.

Area navigation route. An ATS route established for the use of aircraft capable of employing area navigation.

Cyclic Redundancy Checking (CRC) *A mathematical algorithm applied to the digital expression of data that provides a level of assurance against loss or alteration of data.*

Navigation Aid (NAVAID) Infrastructure. Navaid Infrastructure refers to space-based and or ground-based navigation aids available to meet the requirements in the navigation specification.

Navigation Function. The detailed capability of the navigation system (such as the execution of leg transitions, parallel offset capabilities, holding patterns, navigation databases) required to meet the Airspace Concept.

Note: Navigational functional requirements are one of the drivers for selection of a particular Navigation Specification. Navigation functionalities (functional requirements) for each Navigation Specification can be found in Volume II, Parts B and C.

Navigation Specification. A Navigation Specification is a set of aircraft and air crew requirements needed to support Performance based navigation operations within a defined airspace. There are two kinds of navigation specification:

a) RNAV X. A navigation specification designation that does not include requirements for on-board performance monitoring and alerting.

b) RNP X. A navigation specification designation that includes requirements for on-board performance monitoring and alerting

Note. - For both RNP X and RNAV X, the expression 'X' refers to the lateral navigation accuracy in nautical miles that is expected to be achieved at least 95 per cent of the flight time.

Navigation Application. The application of a navigation specification and the supporting navaid infrastructure, to routes, procedures, and/or defined airspace volume, in accordance with the intended airspace concept.

Note: The navigation application is one element, along with, communication, surveillance and ATM procedures meeting the strategic objectives in a defined airspace concept.

Performance Based Navigation. Performance based navigation specifies system performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in an airspace. Performance requirements are defined in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept.

Mixed Navigation Environment: An environment where different navigation specifications may be applied within the same airspace (e.g. RNP 10 routes and RNP 4 routes in the same airspace) or where operations using conventional navigation are allowed together with RNAV or RNP applications.

Procedural control. Air traffic control service provided by using information derived from sources other than an ATS surveillance system

RNAV Operations. Aircraft operations using an area navigation system for RNAV applications. RNAV operations include the use of area navigation for operations which are not developed in accordance with the PBN Manual.

RNAV System: A navigation system 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. A RNAV system may be included as part of a Flight Management System (FMS).

RNP Route: An ATS Route established for the use of aircraft adhering to a prescribed RNP Specification

RNP System: An area navigation system which supports on-board performance monitoring and alerting.

RNP Operations: Aircraft operations using a RNP System for RNP applications.

Satellite based augmentation system (SBAS). A wide coverage augmentation system in which the user receives augmentation from a satellite-based transmitter.

Standard instrument arrival (STAR). A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced.

Standard instrument departure (SID). A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated ATS route, at PANS-OPS, Vol II, which the en-route phase of a flight commences.

PART A

THE PERFORMANCE BASED NAVIGATION CONCEPT

Chapter 1

DESCRIPTION OF PERFORMANCE BASED NAVIGATION

1.1. INTRODUCTION

1.1.1. General

The Performance Based Navigation (PBN) concept specifies RNAV system performance requirements in terms of accuracy, integrity, availability and functionality needed for the proposed operations in the context of a particular airspace concept. In that context, the PBN concept represents a shift from sensor-based to performance-based navigation. Performance requirements are identified in navigation specifications which also identify the choice of navigation sensors and equipment that may be used to meet the performance requirements. These navigation specifications are defined at a sufficient level of detail to facilitate global harmonization by providing specific implementation guidance for States and operators.

Under PBN, generic navigation requirements are defined based on the operational requirements. Operators are then able to evaluate options in respect of available technologies and navigation services that could allow these requirements to be met. The chosen solution would be the most cost effective for the operator rather than a solution being imposed as part of the operational requirements. Technologies can evolve over time without requiring the operation itself to be revisited as long as the requisite performance is provided by the RNAV system

1.1.2. Benefits

PBN offers a number of advantages over the sensor-specific method of developing airspace and obstacle clearance criteria:

a) Reduction of the cost of maintaining sensor-specific routes and procedures. For example, moving or reassigning a single VOR ground facility can impact dozens of procedures, as that VOR can be used on routes, VOR approaches, as part of missed approaches, etc. Adding new sensor-specific procedures will compound this cost, and the rapid growth in available navigation systems (see below) would soon make system-specific routes and procedures unaffordable.

b) Developing system-specific operations with each new evolution of navigation systems would be cost-prohibitive. The expansion of satellite navigation services is expected to contribute to the continued diversity of RNAV systems in different aircraft. The original Basic GNSS equipment is evolving due to the augmentations of SBAS, GBAS and GRAS, while the introduction of Galileo and modernization of GPS and GLONASS will further improve performance. The use of GNSS/inertial integration is expanding.

c) Allows more efficient use of airspace (route placement, fuel efficiency, noise abatement).

d) Clarifies the way in which RNAV systems are used.

e) Facilitates the operational approval process for operators by making more visible a limited set of navigation specifications intended for global use.

1.1.3. CONTEXT OF PBN

PBN is one of several enablers of an airspace concept. Communications, ATS Surveillance and ATM are also essential elements of an airspace concept. This is demonstrated in Figure 1-1.

The concept of Performance Based Navigation (PBN) relies on the use of an Area Navigation (RNAV) system.

There are two core input components for the application of PBN:

a) the NAVAID Infrastructure

b) the Navigation Specification

Applying these components in the context of the Airspace Concept to ATS routes and Instrument Procedures results in a third component:

c) the Navigation Application

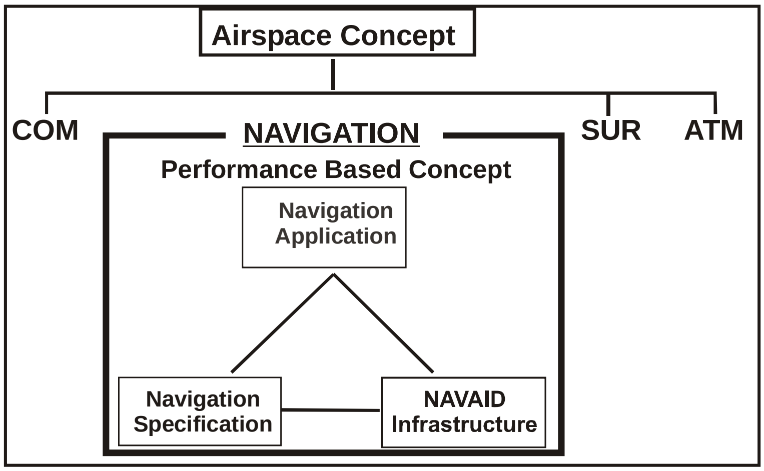


Figure 1-1: Performance Based Navigation Concept

1.1.4. Scope of Performance-Based Navigation

1.1.4.1. Horizontal Performance

Currently PBN is limited to operations with linear horizontal performance requirements. For this reason, operations with angular horizontal performance requirements (i.e. Approach and landing operations with vertical guidance for APV-I and -II GNSS performance levels, as well as ILS/MLS/GNSS precision approach and landing operations) are not considered in this manual. See Figure 1-2.

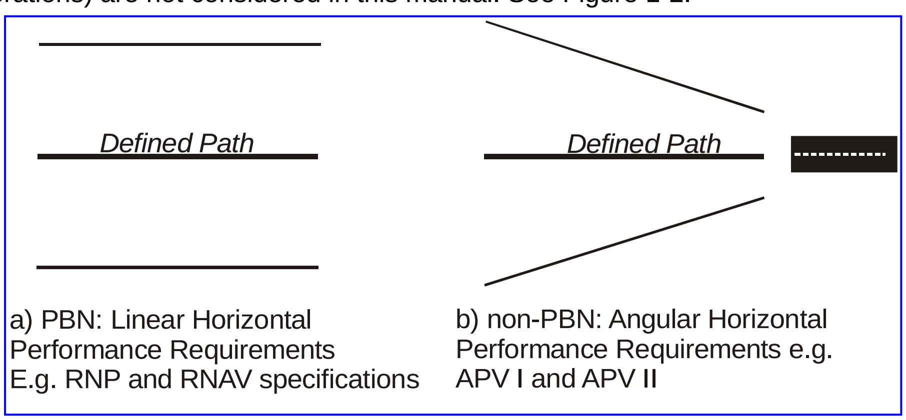


Figure 1-2: Horizontal Performance Requirements for PBN

1.1.4.2. Vertical Performance

Unlike the lateral monitoring and obstacle clearance, for Barometric VNAV systems (see Volume II, Attachment A) there is neither an alerting on vertical position error nor is there a two-times relationship between a 95% required total system accuracy and the performance limit. Therefore this vertical on-board performance monitoring and alerting is not considered vertical RNP.

1.2. NAVIGATION SPECIFICATION

The Navigation Specification is used by a State as a basis for the development of their material for certification and operational approval. A Navigation Specification details what performance is required of the RNAV system in terms of accuracy, integrity, continuity and availability; which navigation functionalities the RNAV system is required to have in order to meet the required performance; which navigation sensors must be integrated into the RNAV system in order to achieve the required performance; which requirements are placed on the flight crew in order to achieve the required performance from the aircraft and the RNAV system. ICAO Navigation specifications are contained in Volume II of this Manual.

A Navigation Specifications is either a *RNP specification* or a *RNAV specification.* A *RNP specification* includes a requirement for on-board self-contained performance monitoring and alerting while a *RNAV specification* does not.

1.2.1. On-board performance monitoring and alerting

On-board performance monitoring and alerting is the main element which determines if the navigation system complies with the necessary safety level associated to a RNP application; it relates to both lateral and longitudinal navigation performance.

On-board performance monitoring and alerting allows the air crew to detect that the RNAV system is not achieving the navigation performance required in the navigation specification. On-board performance monitoring and alerting is concerned with the monitoring of all type of errors which may affect the aircraft ability to follow the desired flight path. A detailed description of on-board performance monitoring and alerting and navigation errors is provided in Part A of Vol. II, and it is defined Vol. II for each RNP specification.

RNP systems provide improvements on the integrity of operation; this may permit closer route spacing and can provide sufficient integrity to allow only RNAV systems to be used as for navigating in a specific airspace. The use of RNP systems may therefore offer significant safety, operational and efficiency benefits.

1.2.2. Navigation Functional Requirements

Both RNAV and RNP specifications include requirements for certain navigation functionalities. At the basic level, these functional requirements may include:

a) Continuous indication of aircraft position relative to track to be displayed to the pilot flying on a navigation display situated in his primary field of view

b) Display of distance and bearing to the active (To) waypoint

c) Display of ground speed or time to the active (To) waypoint

d) Navigation data storage function.

e) Appropriate failure indication of the RNAV system, including the sensors.

More sophisticated RNAV specifications include the requirement for navigation databases (see Attachment B) and the capability to execute data base procedures.

1.2.3. Designation of RNP and RNAV specifications

1.2.3.1. Oceanic, Remote Continental, En Route and Terminal

For oceanic, remote, en route and terminal operations, a *RNP specification* is designated as RNP X e.g. RNP 4. A *RNAV specification* is designated as RNAV X, e.g. RNAV 1. If two navigation specifications share the same value for X, they may be distinguished by use of a prefix. e.g. Advanced-RNP 1 and Basic-RNP 1.

For both RNP and RNAV designations, the suffix ‘X’ corresponds to navigation accuracy in nautical miles; this navigation accuracy is expected to be achieved at least 95% of the time in the horizontal plane by the population of aircraft operating within the airspace. This 95% is the same as Total System Error (TSE), see Volume II, Part A, Chapter 1.

1.2.3.2. Approach

Approach navigation specifications cover all segments of the instrument approach. There are no RNAV specifications, and RNP specifications are designated using RNP as a prefix and an abbreviated textual suffix e.g. RNP APP or RNP AR APP.

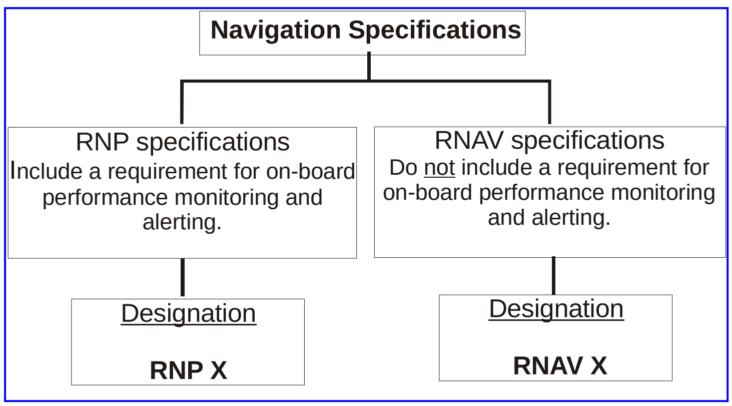


Figure 1-3: Navigation Specifications designations excluding those used on Final Approach

1.2.3.3. Understanding RNAV and RNP designations

In those cases where navigation accuracy is used as part of the designation of a navigation specification, it should be noted that navigation accuracy is only *one* of the many performance requirements included in a navigation specification – see Example 1.

Example 1

A RNAV 1 designation refers to an RNAV specification which includes a requirement for 1 NM navigation accuracy among many other performance requirements. Although the designation RNAV 1 may suggest that 1 NM (lateral) navigation accuracy is the only performance criterion required, this is not the case. Like all navigation specifications, a RNAV 1 specification includes *all* flight crew and airborne navigation system requirements contained in the RNAV 1 specification in Volume II of this Manual.

Designations for navigation specifications are performance based.

A designation should be seen as a coded short-hand for all *the* performance *and* functionality *requirements contained in the particular navigation specification.*

Because specific performance requirements are defined for each navigation specification, an aircraft approved for a RNP specification is not automatically approved for all RNAV specifications. Similarly, an aircraft approved for a RNP or RNAV specification having stringent accuracy requirement (e.g. RNP 0.3 specification) is not automatically approved for a navigation specification having a *less* stringent accuracy requirement (e.g. RNP 4).

1.2.3.4. Flight Planning of RNAV and RNP Designations

Controllers need to know that an aircraft is qualified to operate along an ATS route, on a procedure or in an airspace. ATC is notified of an aircraft's approval status in the ATC Flight Plan. How this notification is achieved is explained in PANS-ATM, ICAO Doc. 4444.

1.2.3.5. Accommodating inconsistent RNP designations

The existing RNP 10 designation is inconsistent with the above between RNP and RNAV specifications. RNP 10 does not include requirements for on-board performance monitoring and alerting. For purposes of consistency, RNP 10 is referred to as RNAV 10 in this Manual. Renaming current RNP 10 routes, operational approvals etc. to a RNAV 10 designation are an extensive and expensive task, which is not cost effective. New operational approvals will continue to be designated RNP 10, and any charting annotations will be for RNP 10.

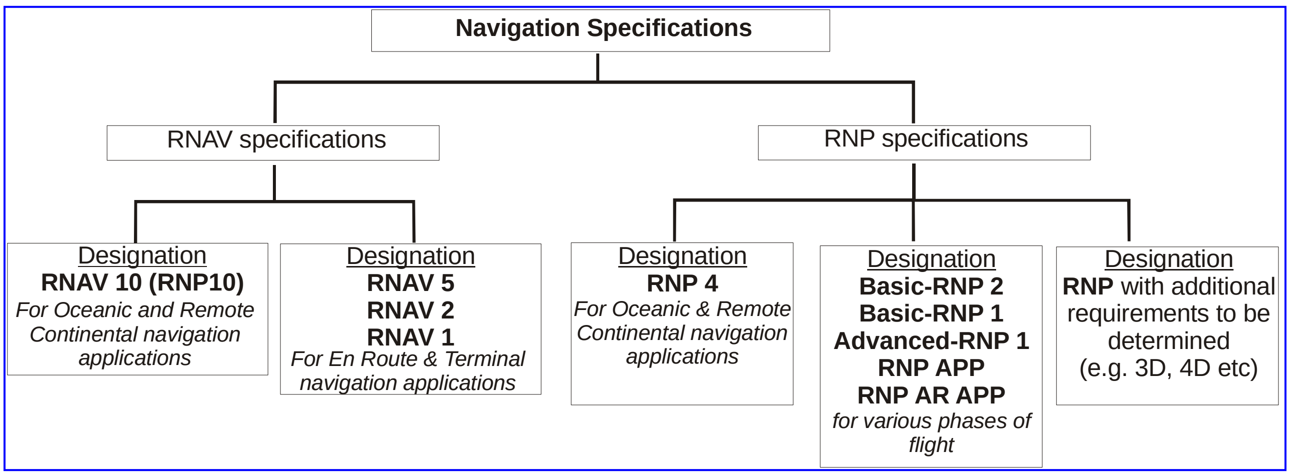


Figure 1-4: Accommodating existing and future designations

The United States and member States of the European Civil Aviation Conference (ECAC) currently use regional RNAV specifications with different designators. The US applications (RNAV Types A & B) and European applications (P-RNAV and B-RNAV) will continue to be used only within these States. Over time, US and European RNAV applications will migrate towards the international navigation specifications of RNAV 1 and RNAV 5.

1.2.3.6. MNPS

Aircraft operating in the North Atlantic MNPS airspace are required to meet a Minimum Navigation Performance Specification (MNPS). The MNPS specification has intentionally been excluded from the above designation scheme because of its mandatory nature and because future MNPS implementations are not envisaged. The requirements for MNPS are set out in ICAO Nat Doc 001, Consolidated Guidance and Information Material concerning Air Navigation in the North Atlantic Region' (available at http://www/nat-pco.org).

1.2.3.7. Future RNP designations

It is possible that RNP specifications for future airspace concepts may require additional functionality without changing the navigation accuracy requirement. Examples of such future navigation specifications may include requirements for vertical navigation and time-based (longitudinal) capability. The designation of such specifications will need to be addressed in future developments of this manual.

1.3. NAVAID INFRASTRUCTURE

The NAVAID Infrastructure refers to ground- or space-based navigation aids. Ground-based Navaids include DME, VOR, and space-based Navaids includes GPS, Glonass and, in the future, Galileo.

1.4. NAVIGATION APPLICATIONS

A Navigation Application is the application of a *navigation specification* and associated *NAVAID infrastructure* to ATS routes, instrument approach procedures and or defined airspace volume in accordance with the airspace concept. A *RNAV Application* is supported by a *RNAV specification*; a *RNP Application* is supported by a *RNP specification*.

This can be illustrated by expanding, in Example 2, the example used previously on page A-1-4.

Example 2

The RNAV 1 specification in Volume II of this Manual, shows, that any combination of the following navigation sensors meets the performance requirements for this navigation specification: GNSS or DME/DME/IRU or DME/DME. Which combination of sensors is needed to satisfy the performance requirements for a RNAV 1 specification in a particular State is not only dependent on the on-board capability. A limited available NAVAID Infrastructure in the State may lead the authorities to impose requirements for specific navigation sensors for a RNAV 1 specification in that State.

As such, State A's AIP could stipulate GNSS as a requirement for its RNAV 1 specification (because State A only has GNSS available in its NAVAID Infrastructure); State B's AIP could stipulate requirements for DME/DME for its RNAV 1 specification; State C's AIP could require DME/DME/IRU for its RNAV 1 specification (because States B & C) only has DME available in its NAVAID Infrastructure). The use of each of these navigation specifications would, at implementation, be a RNAV 1 application. This means that aircraft operators wishing to operate in both States A, B & C would therefore need to be equipped with GNSS, and DME/DME/IRU. Notably, aircraft equipped only with GNSS and approved for the RNAV 1 specification in State A would not be approved to operate in State B or C. This is illustrated in Figure 1-5.

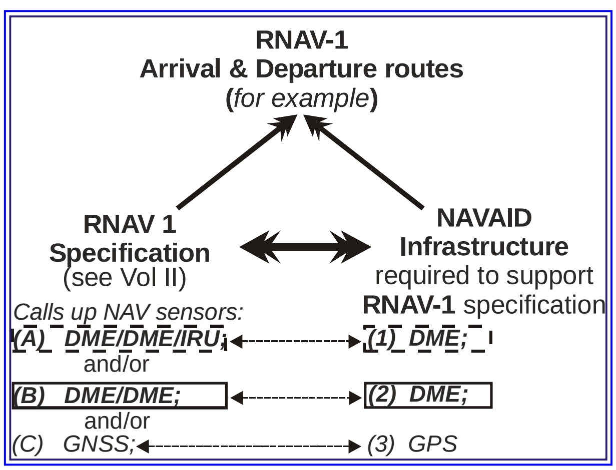


Figure 1-5: RNAV 1 in State A, State B & State C

It can be seen that that the designation of the navigation specification is mirrored in the designation of the associated navigation application.

1.5. FUTURE DEVELOPMENTS

From a Performance Based Navigation perspective, it is likely that navigation applications will progress from 2D to 3D/4D, although timescales and operational requirements are currently difficult to determine. To these ends, on-board performance monitoring and alerting is still to be developed in the vertical plane (Vertical RNP) and on-going work is aimed at harmonising longitudinal and linear performance requirements. It is also possible that angular performance requirements associated with PBN may be included in the scope of PBN in the future.

Increasingly, the development of airspace concepts will need to ensure the coherent integration of Navigation, Communication and ATS Surveillance enablers as more reliance is placed on GNSS.

CHAPTER 2
AIRSPACE CONCEPTS

2.1. INTRODUCTION

This chapter explains the airspace concept and its relationship to navigation applications. This builds on the Performance-Based navigation concept described in the previous chapter.

2.2. THE AIRSPACE CONCEPT

An Airspace Concept may be viewed as general vision or master plan for a particular airspace. Based on particular principles, an airspace concept is geared towards specific objectives. Airspace concepts need to include a certain level of detail if changes are to be introduced within an airspace. Details could explain, for example, airspace organisation and management and the roles to be played by various stakeholders and airspace users. Airspace Concepts may also describe the different roles and responsibilities, mechanisms used and the relationships between people and machines.

Strategic objectives drive the general vision of the airspace concept. These objectives are usually identified by airspace users, air traffic management (ATM), airports as well as environmental and government policy. It is the function of the airspace concept and the concept of operations to respond to these requirements. The strategic objectives which most commonly drive airspace concepts are Safety, Capacity (and Efficiency) and the Environment. As Examples 1 and 2 below suggest, strategic objectives can result in changes being introduced to the airspace concept.

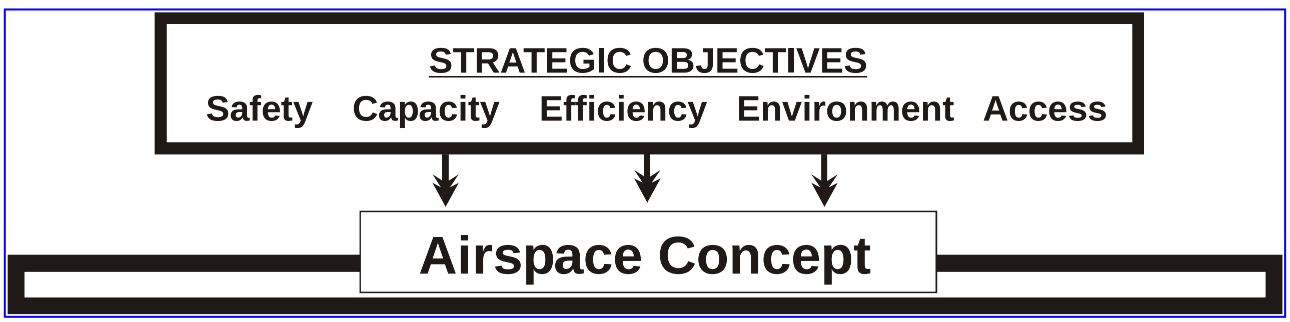


Figure 2-1: Strategic Objectives to Airspace Concept

Example 1

Safety: The design of RNP instrument procedures could be a way of increasing safety (by reducing Controlled Flights into Terrain (CFIT));

Capacity: Planning the addition of an extra runway to enhance airport is a sign of capacity triggering a change to the airspace concept (new SIDs and STAR required);

Efficiency: A user requirement to optimise flight profiles on departure and arrival could make flights more efficient in terms of fuel burn;

Environment: Requirements for noise preferential routes or continuous descent approaches (CDA) are environmental drivers for change.

Access: A requirement to provide a RNP approach with lower minima than supported by conventional procedures, to ensure continued access to the airport in periods during bad weather.

2.2.1. Airspace Concepts & Navigation Applications

This cascade effect from Strategic Objectives to the Airspace Concept puts requirements on various enablers such as Communication, Navigation, ATS Surveillance, Air Traffic Management and Flight Operations. *Navigation Functional Requirements* – now within a Performance Based Navigation context - need to be identified, *see Part B, Chapter 2 of this Volume*. These navigation functionalities are formalised in a *navigation specification* which, together with a *NAVAID Infrastructure*, supports a particular *navigation application.* As part of an airspace concept, navigation applications also have a relationship to Communication, ATS Surveillance, ATM, ATC tools and Flight operations. The Airspace Concept is therefore a coherent whole.

The above approach is top-down: it starts at the generic level (*What* are the strategic objectives? *What* airspace concept is required?), with a view to identifying specific requirements i.e. how CNS/ATM will satisfy this concept and its concept of operations.

The role to be played by each enabler in the overall concept is identified. No 'enabler' can be developed in isolation i.e. Communication, ATS Surveillance and Navigation enablers should form a coherent whole. This can be illustrated by using an example.

Example
Although GNSS is associated primarily with navigation, GNSS is also the backbone of ADS-B surveillance applications. As such, GNSS positioning and track keeping functions are no longer 'confined' to being a navigation enabler to an airspace concept. GNSS in this case, is also an ATS Surveillance enabler. The same is true of data-link communications: data is used by ATS Surveillance system (in ADS-B, for example) and Navigation.

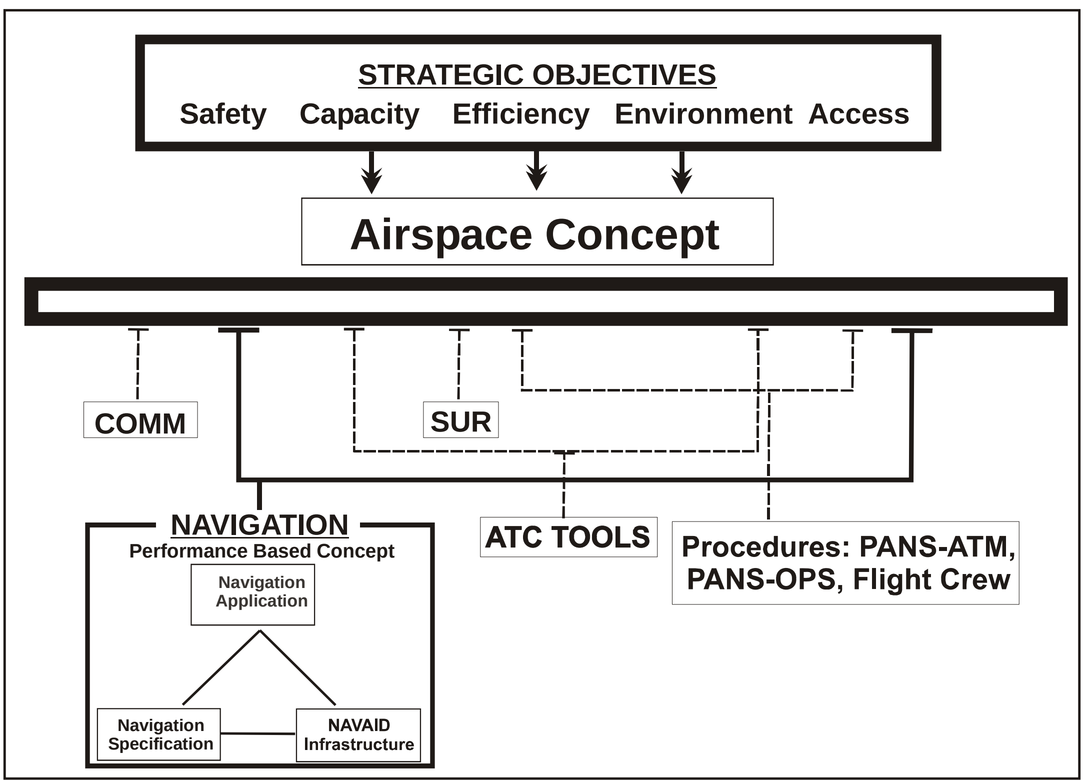


Figure 2-2: Relationship: Performance Based Navigation and Airspace Concept

2.3. AIRSPACE CONCEPTS BY AREA OF OPERATION

2.3.1. Oceanic and Remote Continental

Oceanic and Remote continental airspace concepts are currently served by two RNAV applications, RNAV 10) and RNP 4 (see paragraph 1.2.3.1 on page A-1-4). Both these navigation applications rely primarily on GNSS to support the navigation element of the airspace concept. In the case of the RNAV 10 application, no form of ATS Surveillance service is required. In the case of the RNP 4 application, ADS contract (ADS-C) is used.

Note. – RNAV 10 retains the RNP 10 designation See paragraph 1.2.3.5 in the previous chapter.

2.3.2. Continental En Route

Continental En Route airspace concepts are currently supported by RNAV applications. RNAV 5 is used in the Middle East (MID) and European Region (EUR) but as of publication date of this Manual, it is designated as B-RNAV (Basic R-NAV. – see the closing remarks of paragraph 1.2.3.5 on page A-1-5). In the United States, an RNAV 2 application supports an En Route continental airspace concept. As of publication date of this Manual it is termed US RNAV Type A. At present, Continental RNAV applications support airspace concepts which include radar surveillance and direct controller pilot communication (voice).

2.3.3. Terminal Airspace: Arrival and Departure

Existing Terminal Airspace concepts, which include arrival and departure, are supported by RNAV applications. These are currently used in the European Region (EUR), the United States. The European Terminal Airspace RNAV application is known as known as P-RNAV (Precision RNAV). As of publication of this Manual, the US Terminal Airspace Application is known as US RNAV Type B. As shown in Volume II, although the RNAV 1 specification shares a common navigation accuracy with P-RNAV and US RNAV Type B, neither of the regional navigation specifications satisfy the full the requirements of the RNAV 1 specification shown in Volume II. In future, more RNP applications are expected to be used in terminal airspace.

2.3.4. Approach

Approach concepts cover all segments of the instrument approach i.e. initial, intermediate, final and missed approach. They will increasingly call for RNP specifications requiring a navigation accuracy of 0.3 NM to 0.1 NM or lower. Typically, two sorts of RNP applications are characteristic of this phase of flight: those replacing existing instrument procedures based on different technologies and those developed to enhance airport access in demanding environments. The relevant RNP specifications covered in Volume II of this Manual are RNP APP and RNP AR APP.

CHAPTER 3

STAKEHOLDER USES OF PERFORMANCE BASED NAVIGATION

3.1. INTRODUCTION

Various stakeholders are involved in the development of the airspace concept and the navigation application. These stakeholders are the airspace planners, procedure designers, aircraft manufacturers as well as pilots and controllers and each has a different role and responsibilities.

Stakeholder of Performance Based Navigation use the concept at different stages:

- at a *strategic level*, airspace planners and procedure designers 'translate 'the PBN *concept* into the reality of route spacing, aircraft separation minima and procedure design;
- also a *strategic level*, but after the airspace planners and procedure designers have completed their work, airworthiness and regulatory authorities ensure that aircraft and aircrew satisfy the operating requirements of the intended implementation;
- at a *tactical level*, controllers and pilots use the PBN concept in real-time operations. They rely on the 'preparatory' work completed at a more strategic level by other stakeholders.

Stakeholders of the PBN concept use the concept at different stages and in different ways. While it can generally be said that *all* stakeholders use *all* the elements of the PBN concept, each stakeholder tends to focus on a particular part of the PBN concept. This is depicted in Figure 3-1.

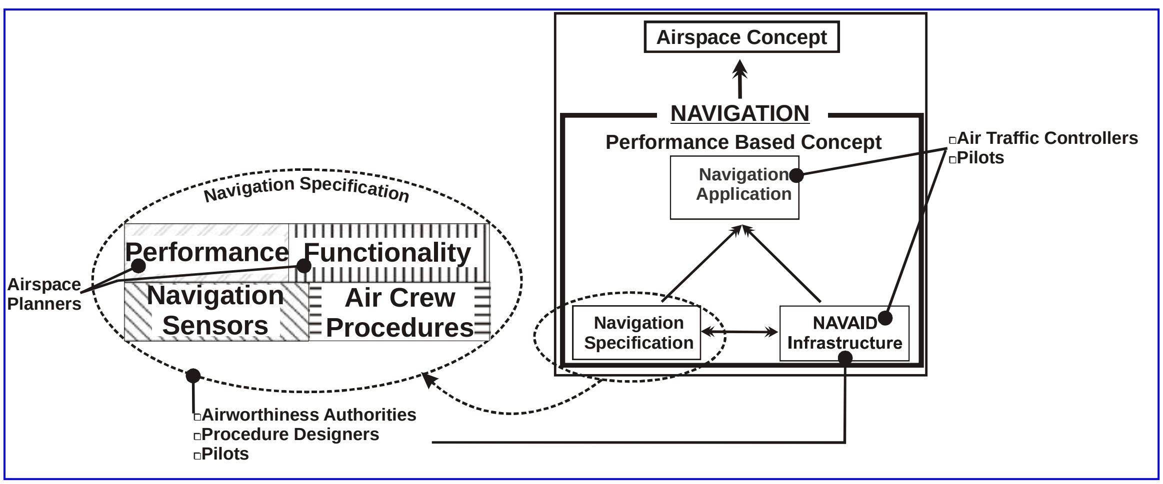


Figure 3-1: PBN Elements and specific points of interest of various stakeholders.

Airspace planners, for example, focus more on the navigation system performance required by the *navigation specification*. While they are interested to know how the required performance of accuracy, integrity, continuity and availability are to be achieved, they use the required performance of the navigation specification to determine route spacing and separation minima.

Procedure designers design instrument flight procedures in accordance with obstacle clearance criteria associated with a particular *navigation specification*. Unlike airspace planners, procedure designers focus on the entire navigation specification (performance, functionality and the navigation sensors of the navigation specification) as well as flight crew procedures. These specialists are also particularly interested in the NAVAID Infrastructure because of coverage issues related to the design of instrument flight procedures.

For their part, the State of the Operator must ensure that the aircraft are properly certified and approved to operate in accordance with the *navigation specification* prescribed for operations in an airspace, along an ATS route or instrument approach procedure. In so doing, State of the Operator are cognisant of the *navigation application* because this provides a context to the *navigation specification*.

To a large extent, the *navigation specification* can therefore be considered an anchor point for these three PBN stakeholders. This does not mean that stakeholders consider the navigation specification in isolation, but that it is their primary focus.

The position is slightly different for pilots and controllers. As end-users of the PBN concept, controllers and pilots are more involved in the navigation application which includes the navigation specification and the NAVAID Infrastructure. If, for example, a particular separation minima (the navigation application) is based on a particular navigation aid, controllers will need to know that the aircraft is equipped with a particular navigation sensor (detailed in the navigation specification) and that the NAVAID Infrastructure is available. For their part, pilots operate along a route designed and placed by the Procedure designer and airspace planner while the controller ensures that separation is maintained between aircraft operating on these routes.

Safety

All users of the PBN concept are concerned with safety. Airspace planners and procedure designers, as well as aircraft manufacturers and ANSPs, need to ensure that their part of the airspace concept meets the pertinent safety requirements. States of the Operator specify requirements for on-board equipment and need then to be satisfied that these requirements are actually being met by the manufacturers. Other authorities specify requirements for safety at airspace concept level. These requirements are used as a basis for airspace and procedure design and, again, the authorities need to be satisfied that their requirements are being met.

Demonstrating that safety requirements are being met is achieved in different ways by different stakeholders. The means used to demonstrate the safety of an airspace concept is not the same used to demonstrate that safety requirements at aircraft level are being met. When all safety requirements have been satisfied, air traffic controllers and pilots need to ensure that they adhere to their respective procedures in order to ensure the safety of operations.

3.2. AIRSPACE PLANNING

The determination of separation minima and route spacing for use by aircraft is a major element of airspace planning. The *Manual on Airspace Planning Methodology for the Determination of separation Minima, ICAO Doc. 9689* is a key reference document planners should consult.

Separation minima and route spacing can generally be described as being a function of three factors: navigation performance, aircraft's exposure to risk and the mitigation measures which are available to reduce risk – see Figure 3-2, below. Aircraft-to-aircraft separation and ATS route spacing are not exactly the same. As such, the degree of complexity of the 'equation' depicted graphically in Figure 3-2 and Figure 3-3 depends on whether separation between two aircraft or route spacing criteria are being determined.

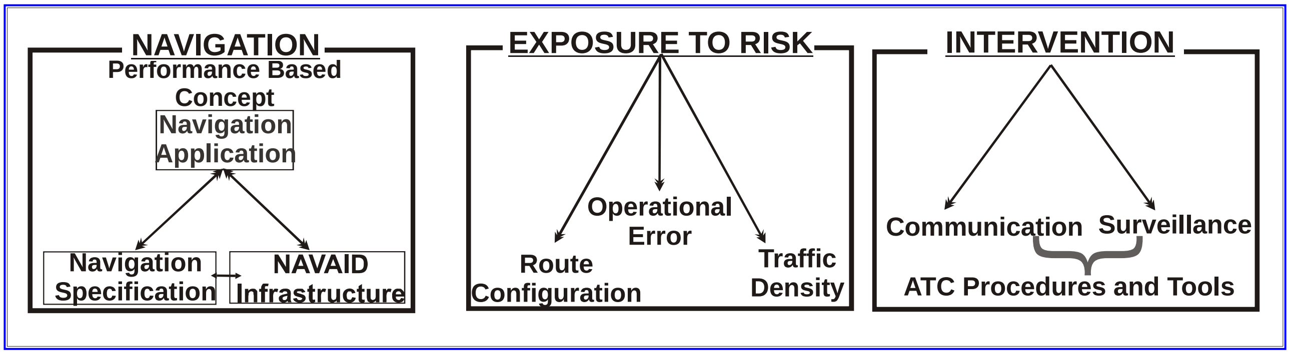
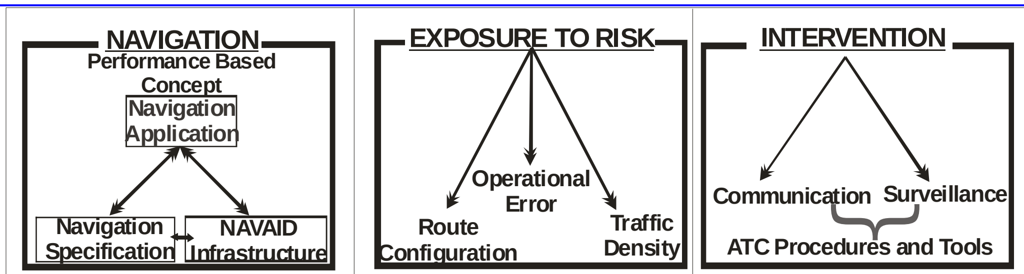


Figure 3-2: Generic model used to determine separation and ATS Route spacing

Aircraft to aircraft *separation,* for example, is usually applied between two aircraft and as a consequence, the traffic density part of the Risk is usually considered to be a single aircraft pair. For route spacing purposes this is not the case: the traffic density is determined by the volume of air traffic operating along the spaced ATS routes. This means that if aircraft in an airspace are all capable of the same navigation performance, one could expect the separation minima between a single aircraft pair to be less than the spacing required parallel ATS routes, for example.

The complexity of determining route spacing and separation minima is affected by the availability of ATS Surveillance service and the type of communication used. If an ATS Surveillance service is available, this means that risk can be mitigated by including requirements for ATC intervention. These inter-relationships are reflected in Figure 3-3 for separation and route spacing.



PBN	NAVIGATION	EXPOSURE TO RISK	INTERVENTION
Determination of **separation minima** *(1)* for tactical use *without* ATC Surveillance	✓	✓ (2)	✗
Determination of **separation minima** *(1)* for tactical use *with* ATC Surveillance	✗	✗ (2) & (3)	✓
Determination of **Route Spacing** *without* ATC Surveillance	✓	✓	✗
Determination of **Route Spacing** *with* ATC Surveillance	✓	✓	✓

✓Relevant; ✗largely irrelevant; ***(1)****In context, separation minima based on Navaid or Navigation Sensor or PBN;* ***(2)*** *traffic density = single aircraft pair;* ***(3)*** *separation minima determined as a function of performance of ATC surveillance system.*

Figure 3-3: Factors affecting the Determination of Separation and Route Spacing

Impact of PBN on airspace planning

When separation and route spacing are determined using a conventional, sensor-based approach, the *navigation performance* data used to determine the separation minima or route spacing depends on the accuracy of the raw data from specific navigation aids such as VOR, DME or NDB. In contrast, PBN requires a RNAV system which integrates received raw navigation data to provide a positioning and navigation solution. In determining separation minima and route spacing in a PBN context, this integrated navigation performance 'output' is used.

It has been explained in Chapter 1 that the navigation performance required from the RNAV system is described as part of the navigation specifications. To determine separation and route spacing, airspace planners fully exploit that part of the navigation specification which prescribes the performance required from the RNAV system. Airspace planners do not ignore the remainder of the navigation specification, but they make most use of the required performance viz. accuracy, integrity, availability and continuity to determine route spacing and separation minima.

Chapter 1 also explains that are two types of Navigation Specifications: RNAV specifications and RNP specifications, and that the distinctive feature of RNP is a requirement for on-board performance monitoring and alerting. It is expected, for example, that the separation minima and route spacing derived from a RNP 1 specification will be smaller than those derived for a RNAV 1 specification though the extent of this improvement has yet to be assessed.

In airspace procedurally controlled airspace, separation and route spacing based on RNP specifications are expected to provide a greater benefit than those based on RNAV specifications. This is because the on-board performance monitoring and alerting function could alleviate the absence of ATS Surveillance service by providing an alternative means of risk mitigation.

Reference: Manual on Airspace Planning Methodology for the Determination of separation Minima, ICAO Doc. 9689.

3.3. INSTRUMENT FLIGHT PROCEDURES DESIGN

3.3.1. Introduction

Instrument flight procedure design deals with the construction of routes, arrivals, departures and approach procedures. These procedures consist of a series of predetermined manoeuvres by reference to flight instruments with specified protection from obstacles.

Each State is responsible to ensure that all published instrument flight procedures in their airspace can be flown safely by the relevant aircraft. Safety is not only accomplished by application of the technical criteria in PANS-OPS and associated ICAO provisions, but also requires measures that control the quality of the process used to apply that criteria, which may include regulation, air traffic monitoring, ground validation and flight validation. These measures must ensure the quality and safety of the procedure design product through review, verification, coordination, and validation at appropriate points in the process, so that corrections can be made at the earliest opportunity in the process.

The following paragraphs regarding instrument flight procedure design describe conventional procedure design and sensor dependent RNAV procedure design, their disadvantages and the issues that led up to PBN.

3.3.2. Non-RNAV: Conventional procedure design

Conventional procedure design is applicable to non-RNAV applications when aircraft are navigating based on direct signals from ground radio navigation aids. The big disadvantage of this type of navigation is that the routes are dependent on the location of the navigation beacons (See figure 3-4), often resulting in longer routes, as optimal arrival and departure routes are impracticable due to siting and cost constraints on installing ground-based radio navigation aids. Additionally, obstacle protection areas are comparatively large and the navigation system error increases as a function of the aircraft's distance from the navigation aid.

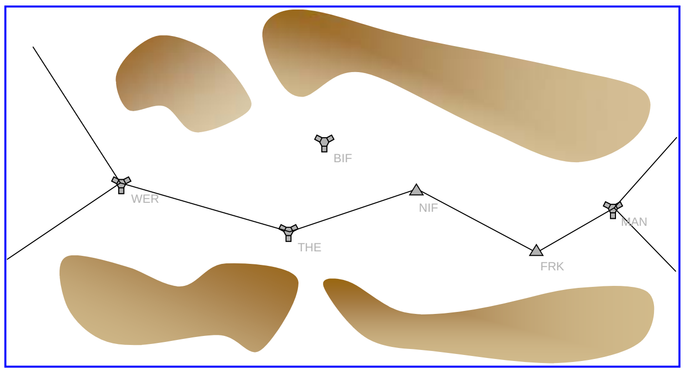


Figure 3-4: Conventional instrument flight procedure design

3.3.3. Introduction of Sensor-Specific RNAV procedure design

Initially, RNAV was introduced using sensor-specific design criteria. A fundamental breakthrough with RNAV was the creation of fixes defined by name, latitude and longitude. RNAV fixes allowed the design of routes to be less dependent on the location of navaids and the designs could better accommodate airspace planning requirements (see figure 3-5). The flexibility in route design varied by the specific radio navigation system involved, such as DME/VOR or GNSS. Additional benefits included the ability to store the routes in a navigation database, reducing pilot workload and resulting in more consistent flying of the nominal track as compared to cases where the non-RNAV procedure design was based on heading, timing, or DME arcs. As RNAV navigation is accomplished using an aircraft navigation database, a big change for the designer is the increased need for quality assurance in the procedure design process.

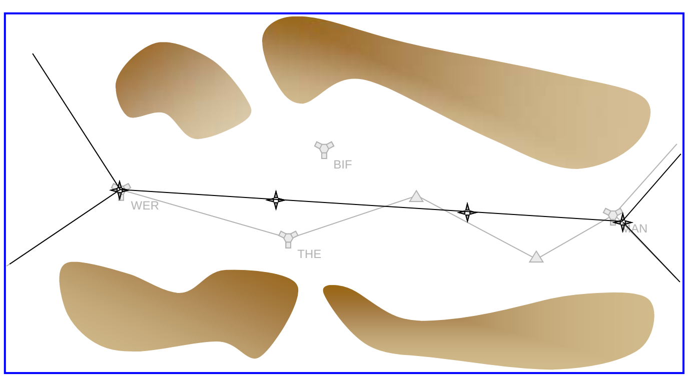


Figure 3-5: RNAV procedure design

Despite these advantages, RNAV had a number of issues and characteristics that needed to be considered. Among these were the sometimes wide variations in flight performance and flight paths of aircraft, as well as the inability to predict the behaviour of navigation computers in all situations. This resulted in large obstacle assessment areas, and as a consequence not much benefit was achieved in terms of reduction of the obstacle protection area.

As experience in RNAV operations grew, other important differences and characteristics were discovered.. Aircraft RNAV equipment, functionalities and system configurations ranged from the simple to the complex. There was no guidance for the designer as to what criteria to apply for the aircraft fleet for which the instrument flight procedures are being designed. Some of the system behaviour was the result of the development of RNAV systems that would fly database procedures derived from ATC instructions. This attempt to mimic ATC instructions resulted in many different ways to describe and define an aircraft flight path, resulting in observed variety of flight performance. Furthermore, the progress in aircraft and navigation technology caused an array of different types of procedures, each of which require different equipment, imposing unnecessary costs on the airlines.

3.3.4. RNP procedure design (pre-PBN)

RNP procedures were introduced in PANS-OPS (applicable in 1998). These RNP procedures were the predecessor of the current PBN concept, whereby the performance for operation on the route is defined in lieu of simply identifying a required radio navigation system. However, due to insufficient description of the navigation performance and operational requirements, there was little perceived difference between RNAV and RNP. In addition, the inclusion of conventional flight elements such as fly-over procedures, variability in flight paths, and added airspace buffer resulted in no significant advantages being achieved in designs. As a result there was a lack of benefits to the user community and little or no implementation.

3.3.5. PBN procedure design

With PBN, RNAV is transformed into a performance based environment in which the navigation performance characteristics of the aircraft are well specified and the problems described above for the original RNAV and RNP criteria can be resolved. The performance based descriptions address various aircraft characteristics that were causing variations in flight trajectories, leading to more repeatable, reliable and predictable flight tracking, and smaller obstacle assessment areas. An example of the advantage of PBN RNP design compared to RNAV design is shown in Figure 3-6.

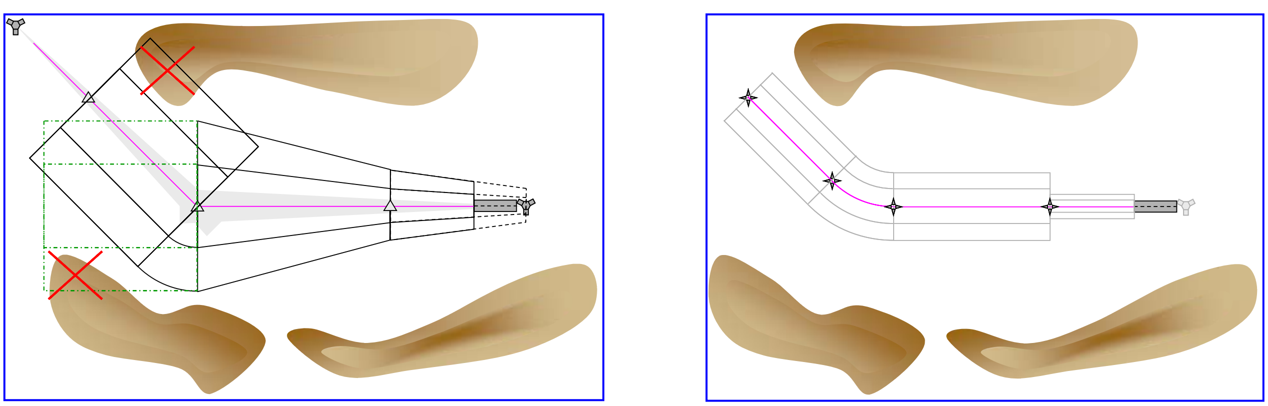


Figure 3-6: Comparison between RNAV (left) and RNP (right) procedure design

The main change for the designer will be that he/she will not be designing for a specific sensor but according to a navigation specification (e.g. RNAV 1). The selection of the appropriate navigation specification is based on the airspace requirements, the available navaid infrastructure, and the equipage and operational capability of aircraft expected to use the route. For example, where an airspace requirement is for RNAV-1 or RNAV-2, the available navigation infrastructure would have to be basic GNSS or DME/DME, and aircraft would be required to utilize either to conduct operations. However, until specific PBN procedure design criteria are defined, the criteria for Basic GNSS and DME/DME would be applied. Volume II of this Manual provides a more explicit and complete navigation specification for the aircraft and operator as compared to PANS-OPS Volume I. Together, the procedure design, along with qualified aircraft and operators result in greater reliability, repeatability and predictability of the aircraft flight path. It should be understood, that no matter what infrastructure is provided, the designer may still apply the same general design rules in fix and path placement. However, adjustments may result based upon the associated obstacle clearance or separation criteria.

Integration of the aircraft and operational criteria in this Manual will enable procedure design criteria to be updated. A first effort to create such criteria is for the RNP AR APP navigation specification. In this case the design criteria takes full account of the aircraft capabilities and are fully integrated with the aircraft approval and qualification requirements. The tightly integrated relationship between aircraft, operational and procedure design criteria for RNP AR approaches warrants closer examination of aircraft qualification and operator approval such that special authorization is required. This additional requirement will incur cost to the airlines and will make these types of procedures only cost beneficial in cases where other procedure design criteria and solutions will not fit.

Reference: PANS-OPS Volumes I & II; RNP AR Manual (tbd) and The Quality Assurance Manual (tbd)

3.4. AIRWORTHINESS & OPERATIONAL APPROVAL

3.4.1. General

Aircraft should be equipped with a RNAV system able to support the desired navigation application. RNAV system and aircraft operations shall be compliant with regulatory material that reflects the navigation specification developed for a particular navigation application (see Chapter 1).

The navigation specification details the flight crew and aircraft requirements needed to support this navigation application. This specification includes the level of navigation performance, functional capabilities, and operational considerations required for the RNAV system. The RNAV system installation should be certified in accordance with ICAO Annex 8 and operational procedures should respect Aircraft Flight Manual (AFM) limitations, if any.

The RNAV system should be operated in accordance with recommended practices described in ICAO Annex 6 and Doc 8168 PANS-OPS Volume I. Flight crew and/or operator should respect operational limitations required to support the navigation application, if any.

All assumptions related to the navigation application are listed in the navigation specification. Review of these assumptions is necessary when proceeding to the airworthiness and operational approval process.

Operator and Flight crew are responsible for checking that the installed RNAV system is operated in areas where the airspace concept and the Navaid infrastructure described in the navigation specification is fulfilled. To ease this process, certification and/or operational documentation should clearly identify compliance with the related navigation specification.

3.4.2. Airworthiness Approval Process

The Airworthiness approval process assures that each item of the RNAV equipment installed is of a kind and design appropriate to its intended function and that the installation functions properly under foreseeable operating conditions. Additionally, the airworthiness approval process identifies any installation limitations that need to be considered for operational approval. Such limitations and other information relevant to the approval of the RNAV system installation are documented in the AFM, or AFM Supplement as applicable. Information may also be repeated and expanded upon in other documents such as Pilot Operating Handbooks (POHs) or Flight Crew Operating Manuals (FCOMs). The Airworthiness approval process is well established among States of Operators and a normal process will reference the intended function as defined in the navigation specification to be applied.

3.4.2.1. Approval of RNAV systems for RNAV-X operation.

The RNAV system installed should be compliant with a set of basic performance requirement described in the “navigation specification” which defines accuracy, integrity and continuity criteria.

The RNAV system installed should be compliant with a set of specific functional requirements described in the navigation specification.

For a multi-sensor RNAV system, an assessment should be conducted to establish which sensors are compliant with the performance requirement described in the navigation specification.

The RNAV system installed should have a navigation data base and should support each specific path terminator as required by the navigation specification.

Note: For certain navigation applications, a navigation data base may be optional

The navigation specification generally indicates if a single or a dual installation is necessary to fulfil availability and/or continuity requirements. The airspace concept and Navaid infrastructure are key elements to decide if single or dual installation is necessary.

3.4.2.2. Approval of RNAV systems for RNP-X operation

The RNAV system installed should be compliant with a set of basic RNP performance requirement described in the navigation specification. The RNAV system should include an on board performance monitoring and alerting function.

The RNAV system installed should be compliant with a set of specific functional requirement described in the navigation specification.

For a multi-sensor RNAV system, an assessment should be conducted to establish sensors which are compliant with the RNP performance requirement described in the RNP specification.

The RNAV system installed should have a navigation data base and should support path terminator as required by the navigation specification

3.4.3. Operational Approval

The aeroplane must be equipped with an RNAV system enabling the flight crew to navigate in accordance with operational criteria defined in the navigation specification.

The state of the operator is the authority responsible for approval of flight operations.

The authority must be satisfied that operational programmes are adequate. Training programmes and operations manuals should be evaluated.

3.4.3.1. General RNAV approval process

The operational approval process assumes first that the corresponding installation/airworthiness approval has been granted.

During operation, crew should respect AFM limitations if any.

Normal procedures are provided in the navigation specification and detailed necessary crew action to be conducted during the Pre-flight planning, prior to commencing the procedure and during the procedure.

Abnormal procedures are provided in the navigation specification. These procedures should detail crew action in case of on-board RNAV system failure and in case of system inability to maintain the prescribed performance of the on board monitoring and alerting function.

The Operator should have in place a system for investigation events affecting the safety of operations to determine its origin (coded procedure, accuracy problem, etc)

Minimum equipment list (MEL) should identify the minimum equipment necessary to satisfy the navigation application.

3.4.3.2. Flight Crew training

Each pilot must receive appropriate training, briefing and guidance material in order to safely conduct the operation.

3.4.3.3. Navigation database management

Any specific requirement regarding the navigation database should be provided in the navigation specification particularly if the navigation data base integrity should demonstrate compliance with DO 200A/EUROCAE ED 76 (data quality assurance process).

Note: This demonstration may be documented with a Letter Of Acceptance (LOA), or other equivalent means as accepted by the State.

3.5. FLIGHT CREW AND AIR TRAFFIC OPERATIONS

Pilots and air traffic controllers are the end-users of Performance Based Navigation. Each has their own expectations of how the use and capability of the RNAV system affects their ways of working.

Pilots need to know about PBN operations is whether the aircraft and flight crew are qualified to operate in an airspace, on a procedure or along an ATS Route. For their part controllers assume that the flight crew and aircraft are suitably qualified for PBN operations. A basic understanding of how RNAV systems work as well as their advantages and limitations is necessary for both controllers and pilots in that it allows the advantages and limitations of these systems to be understood.

For pilots, one of the main advantages of using a RNAV system is that the navigation function is performed by highly accurate and sophisticated on-board equipment allowing a reduction of cockpit workload and, in some cases, increased safety. In controller terms, the main advantage of aircraft using a RNAV system is that ATS routes can be straightened as it is not necessary for routes to pass over locations marked by conventional Navaid. Another advantage is that RNAV-based arrival and departure routes can complement, and even replace radar vectoring, thereby reducing Approach and Departure controller workload. Consequently, parallel ATS route networks are usually a distinctive characteristic of airspace in which RNAV or RNP applications are used. These parallel track systems can be uni-directional or bi-directional and can, on occasion, cater for parallel routes requiring a different navigation specification for operation along each route e.g. a RNP 4 route alongside a parallel RNP 10 route. Similarly, RNAV SIDs, STARs or instrument procedures feature extensively in some Terminal Airspaces. From an obstacle clearance perspective, the use of RNP applications may allow or increase access to an airport in terrain rich environments where such access was not previously possible or limited.

ANSPs sometimes assume that because all aircraft operating in an airspace are required to be approved to the same level of performance, that all the aircraft will systematically provide entirely or exactly repeatable and predictable track keeping performance. This is not an accurate assumption because the different algorithms used in different FMS and the different ways of coding data used in the navigation data base can affect the way an aircraft performs on the turn. The exception is where Radius to Fix (RF) leg type or Fixed-Radius Transitions (FRT) are used.

Flight crew procedures

Flight crew procedures complement the technical contents of the navigation specification. Flight crew procedures are usually embodied in the company operating manual. These procedures could include, for example, that the flight crew notify ATC of contingencies (equipment failures, weather conditions) that affect the aircraft's ability to maintain navigation accuracy. These procedures would also require the flight crew to state their intentions, coordinate a plan of action and obtain a revised ATC clearance in such instances. At a regional level, established contingency procedures should be made available so as to permit the flight crew to follow such established procedures in the event that it is not possible to notify ATC of their difficulties.

ATS Procedures

ATS procedures are needed for use in airspace utilizing RNAV and RNP applications. Examples include procedures to enable the use of the parallel offset on-board functionality (see Attachment A) or to enable the transition between airspaces having different performance and functionality requirements (i.e. different navigation specifications). Detailed planning is required to accommodate such a transition. Examples of situations to be catered for include:

a) determining the specific points where the traffic will be directed as it transits from airspace requiring a navigation specification with less stringent performance and functional requirements to an airspace requiring a navigation specification having more stringent performance and functional requirements;

b) coordinating efforts with relevant parties in order to obtain a regional agreement detailing the required responsibilities.

Air traffic controllers should take appropriate action to provide increased separation, as well as to coordinate with other ATC units as appropriate, when informed that the flight is not able to maintain the prescribed level of navigation performance.

PART B

IMPLEMENTATION GUIDANCE

CHAPTER 1

INTRODUCTION TO IMPLEMENTATION PROCESSES

1.1. INTRODUCTION

The objective of this Part is to provide guidance for implementing RNAV or RNP applications in a given Region, State or group of States. Part B builds upon the general PBN concept described in part A of this volume, and provides a framework for using the ICAO Navigation Specifications published in Volume II of this manual.

1.2. PROCESS OVERVIEW

Three processes are provided to assist States in the implementation of PBN. They are used in sequence.

- Process 1 – Determine Requirements
- Process 2 – Identifying ICAO Navigation Specification for Implementation
- Process 3 – Planning and Implementation

Process 1 outlines steps for a State or Region to determine its strategic and operational requirements for Performance Based Navigation via an Airspace Concept. Fleet equipage, and CNS/ATM infrastructure the State or Region will have available for implementation are assessed, and navigation functional requirements are identified.

Process 2 describes how a Region or State determines if implementation of an ICAO Navigation Specification from Volume II achieves the objectives of the Airspace Concept, provides the required navigation functions, and can be supported by the fleet equipage and CNS/ATM infrastructure that have been identified from Process 1. Process 2 might lead to the need to review the airspace concept and required navigation functions identified in Process 1 identify tradeoffs that would allow a better fit with a particular Navigation Specification in Volume II.

Process 3 provides a hands-on guide to planning and implementation, so that the navigation requirement may be turned into an implementation reality.

1.3. DEVELOPMENT OF A NEW NAVIGATION SPECIFICATION

The above three processes are designed to enhance the application of harmonised global standards, and avoid proliferation of local/regional standards. Development of a new Navigation Specification would be considered in those very exceptional cases where

a) a State or Region has determined that it is not possible to use an existing ICAO navigation specification to satisfy its intended Airspace Concept and

b) it is not possible to change elements of the proposed Airspace Concept so that an existing ICAO navigation specification can be used.

Chapter 5 of this Part provides guidance for the ICAO-coordinated development of a new Navigation Specification. Such a development is an extensive and rigorous exercise in airworthiness and flight operations development. It should be expected to be a very complex and lengthy effort leading to a globally harmonized specification.

CHAPTER 2

PROCESS 1: DETERMINE REQUIREMENTS

2.1. INTRODUCTION

The goal of Process 1 is formulation of the Airspace Concept and assessment of the existing fleet equipage and CNS/ATM infrastructure, with the overall aim of identifying the navigation functional requirements necessary to meet the Airspace Concept. A summary of Process 1 is provided at the end of this chapter in Figure 2-1

2.2. INPUT TO PROCESS 1

The input to start this process is the strategic objectives and operational requirements stemming from airspace users (military/civil, air carrier/business/general aviation, IFR/VFR operations), and ATM requirements (e.g. airspace planners, ATC). Policy directives such as those stemming from political decisions concerning environmental mitigation can also be inputs.

The process should consider the needs of the airspace user community in a broad context i.e. IFR, VFR, military and civil aviation, (air carrier, business and general aviation). Consideration should be given to both domestic and international user requirements.

The overall safety, capacity and efficiency requirements of an implementation should be balanced. An analysis of all requirements, and tradeoffs among competing requirements, will need to be made. Primary and alternate means of meeting requirements should be considered. Methods for communicating to airspace users the requirements and availability (and outages) of services need to be identified as well. Detailed planning also needs to be undertaken for the transition to the new airspace concept.

2.3. STEPS IN PROCESS 1

2.3.1. Step 1 – Formulate Airspace Concept

An Airspace Concept is only useful if it is defined in sufficient detail so that supporting navigation functions can be identified. The elaboration of the Airspace Concept is therefore best undertaken by a multi-disciplinary team as opposed to a single specialisation (see also Part A, chapter 3 of this Volume). This team should be expected to be made up of air traffic controllers and airspace planners (from the ANSP), pilots, procedure design specialists, avionics specialists, flight standards and airworthiness regulators, and airspace users. Together, this team would develop in the Airspace Concept the broad directions provided by the strategic objectives.

Factors that would be detailed include

a) airspace organisation and management (i.e. ATS route placement, SIDs/STARs, ATC sectorisation);

b) Separation minima and route spacing;

c) instrument approach procedure options;

d) how ATC is to operate the airspace;

e) expected operations by flight crew

Insets 1 to 4 provide expanded information for planners' consideration:

Inset 1 - Airspace User Requirements

Airspace Concept developers should consider the needs of the airspace user community in a broad context i.e. IFR, VFR, military and civil aviation, (air carrier, business and general aviation). Consideration should be given to both domestic and international user requirements.

The overall safety, capacity and efficiency requirements of an implementation should be balanced. An analysis of all requirements, and tradeoffs among competing requirements, will need to be made. Primary and alternate means of meeting requirements should be considered. Methods for communicating to airspace users the requirements and availability (and outages) of services need to be identified as well. Detailed planning also needs to be undertaken for the transition to the new airspace concept.

Inset 2 - Airspace Requirements

In order to identify the airspace requirements, it is necessary to:

a) Gather and analyze data on current and expected traffic growth within and surrounding the specific airspace.

b) Understand the traffic flows, volume of traffic, and the composition of air traffic both in the airspace under consideration and adjoining airspace

   i) It is important to consider transition airspace and procedures for integrating operations across airspace boundaries and national borders.

c) Define the required ATS Route spacing prior to design of the airspace, route or procedure. ATS Route spacing must be based on the overall safety, capacity and efficiency requirements of the airspace concept.

   i) The surveillance and communications infrastructure, as well as navigation infrastructure, available in the airspace must be assessed.

   ii) ATS Route and other procedure design criteria should be adopted from existing ICAO material to the maximum extent possible.

   iii) Identify the minimum navigation functions needed to support the operational requirement and compare with the equipage of the aircraft fleets operating in the subject airspace

Airspace requirements may identify a need for on-board performance monitoring and alerting by, for example specifying a need for closely spaced parallel routes (i.e. routes with consistent route spacing on both straight and turning segments). These types of requirements need to be carefully noted in that they directly determine the required navigation functions discussed at paragraph **Error! Reference source**

Inset 3 - Approach Requirements

As a general principle, approach requirements should seek to take advantage of existing aircraft capabilities as much as possible. In addition, designers should use existing procedure design criteria s to minimize the cost of operator approvals and harmonize implementation across national boundaries.

In addition to the above considerations, the designer will need to determine which type(s) of approaches are required in order to meet the needs of the airspace. Considerations include:

a) Straight in or curved Approach

b) Straight in or curved Missed Approach

c) Single or multiple runways

- Parallel or converging multiple runways
- Independent or Dependent runway approaches

d) Need for backup approach procedures (for example, if a local GPS outage occurs, what is available for approach guidance?)

Inset 2 - Other requirements

In designing the airspace concept (route or procedure) the designers should identify

- Environmental factors requiring consideration and accommodation
- Any expected impacts to Flight Plan submission or processing

2.3.2. Step 2 – Assessment of existing fleet capability and available Navaid Infrastructure

Planners must understand the capability of the aircraft that will be flying in the airspace, to determine what implementation is feasible for the users. Understanding what NAVAID infrastructure is available is essential to determining if a Navigation Specification can be supported. The following considerations should be taken into account.

Assessing Aircraft Fleet Capability

Aircraft fleets are not homogenous in terms of RNAV system capability. This is because up to five generations of aircraft are active in any large fleet such as those operating in Europe, North America and the Far East. As such, the airspace has to accommodate aircraft operating with technology dating from the 1970s alongside aircraft manufactured in the 1980s, 1990s and since 2000. Often, it is not cost effective to retrofit an old aircraft. Sometimes, it is even impossible to do so.

Since most States will need to support a mixed-equipage traffic environment for a significant time period, the airspace designer must know the characteristics and level of equipage of the fleet operating in the airspace. Questions that might be asked include -

- Are sufficient aircraft equipped with GNSS capability? Can failures of GNSS be mitigated by other means of navigation (e.g. DME based RNAV, conventional navigation or ATS surveillance service?)

- Do all IFR approved aircraft carry VOR and DME equipment, and is that equipment integrated into the RNAV system? Even so, when there are insufficient Navaids available to provide adequate signal coverage, can the gaps in coverage be accommodated by reliance on aircraft inertial systems?

Care must be taken to pay attention to accommodating various types of users whose equipage may be mixed. That said, air traffic control requirements must also be addressed for operations if a mixed RNAV performance environment (or mixed RNAV and conventional environment) is decided upon. Experience suggests that handling traffic of mixed navigation equipage can, depending on the level of mixed equipment and operations, adversely affect capacity in an airspace and place an unsuitable workload on controllers.

Assessing Navaid Infrastructure

States currently provide a network of ground-based Navaids to support en route, terminal and approach operations. The use of RNAV routes and approaches is expanding, allowing operators to take advantage of onboard systems.

The introduction of satellite navigation based on the Global Navigation Satellite System (GNSS) has brought RNAV within reach of all operators, and makes it possible to consider a full transition to RNAV-based en route and terminal operations. However, such a transition can be expected to take a number of years. In the meantime, most States can be expected to identify a need to maintain some ground-based Navaids either providing an alternative input to RNAV systems or supporting a reversionary conventional navigation environment.

Factors determining the scope of a ground Navaids replacement programme: the rate at which aircraft operators equip with GNSS avionics; the extent of the requirement to retain some ground Navaids for users not equipped with GNSS, or as backup to GNSS (e.g., as partial mitigation to the potential hazard posed by interference with GNSS signals.) the existence and age of the existing NAVAID infrastructure.

In respect of the last point it is important that implementing an RNAV application does not in itself become the cause for installing new NAVAID infrastructure. The introduction of RNAV applications could result in being able to move some existing Navaids (e.g. DMEs relocated when they no longer have to be co-located with VOR). However, it is not the case that GNSS-based RNAV can only be implemented if there is a reversionary backup of ground Navaids.

2.3.3. Step 3– Assessment of existing ATS surveillance system and communications infrastucture and ATM System

An air traffic system is the sum of the CNS/ATM capabilities available. PBN is only the navigation component of CNS/ATM. It cannot be safely and successfully implemented without due consideration of the communication and ATS surveillance infrastructure available to support the operation. For example, an RNAV-1 route will require different ATS Route spacing in a radar, or a non-radar, environment. The availability of communications between the aircraft and air traffic service provider may impact the level of air traffic intervention capability needed for safe operations.

ATS Surveillance Infrastructure

States currently provide primary and/or secondary surveillance radars to support en route, terminal and approach operations. Newer ATS surveillance systems, such as Automatic Dependent Surveillance-Broadcast (ADS-B), can be expected to play an increasing role, particularly in existing procedurally controlled environments. However, the dependence of ADS on the navigation solution has to be considered when undertaking the overall evaluation of the operation – see ICAO Circular 311.

Without robust ATS surveillance systems, RNAV route spacing is large. Implementation of RNP in such environments can compensate to a certain extent for the lack of ATS surveillance coverage.

Communication Infrastructure

States currently provide voice communication services through VHF and HF radio. VHF service in particular is widely available and is expected to be maintained (with or without augmentation by data link communications).

ATM Systems

The evolution of a State's ATM system to meet the needs of PBN implementation must be considered. If separation s are reduced and this affects the alert limits of conflict detection tools, or if different separation s are used for different route types or aircraft capabilities, this must be considered in the ATM system evolution. If required time of arrival is included in an airspace concept, the automation system will need to be designed to accommodate this. This same consideration applies with use of equipment classifications (flight plan suffixes), controller merging and spacing tools, and any other air traffic control automation features that enable or maximize the benefits of RNAV and RNP.

2.3.4. Step 4– Identify necessary navigation functional requirements

It should be noted that the decision on the choice of an ICAO RNAV or RNP navigation specification is not only determined by the need for aircraft performance monitoring and alerting, but may also be determined by the need for specific functional requirements (e.g. leg transitions/path terminators, parallel offset capabilities, holding patterns, navigation databases). See attachment A of this volume.

The proposed navigation functional requirements also need to consider:

a) Complexity of RNAV procedures envisaged. The number of waypoints needed to define the procedure. The spacing between waypoints and the need to define how a turn is executed.

b) Whether the procedures envisaged aim simply to connect with the en-route operations and can be restricted to operations above MSA/MRA or are the procedures going to provide guidance to and from the ground.

The next stage is ***Process 2***, where the effort is made to identify the appropriate ICAO Navigation Specification for implementation.

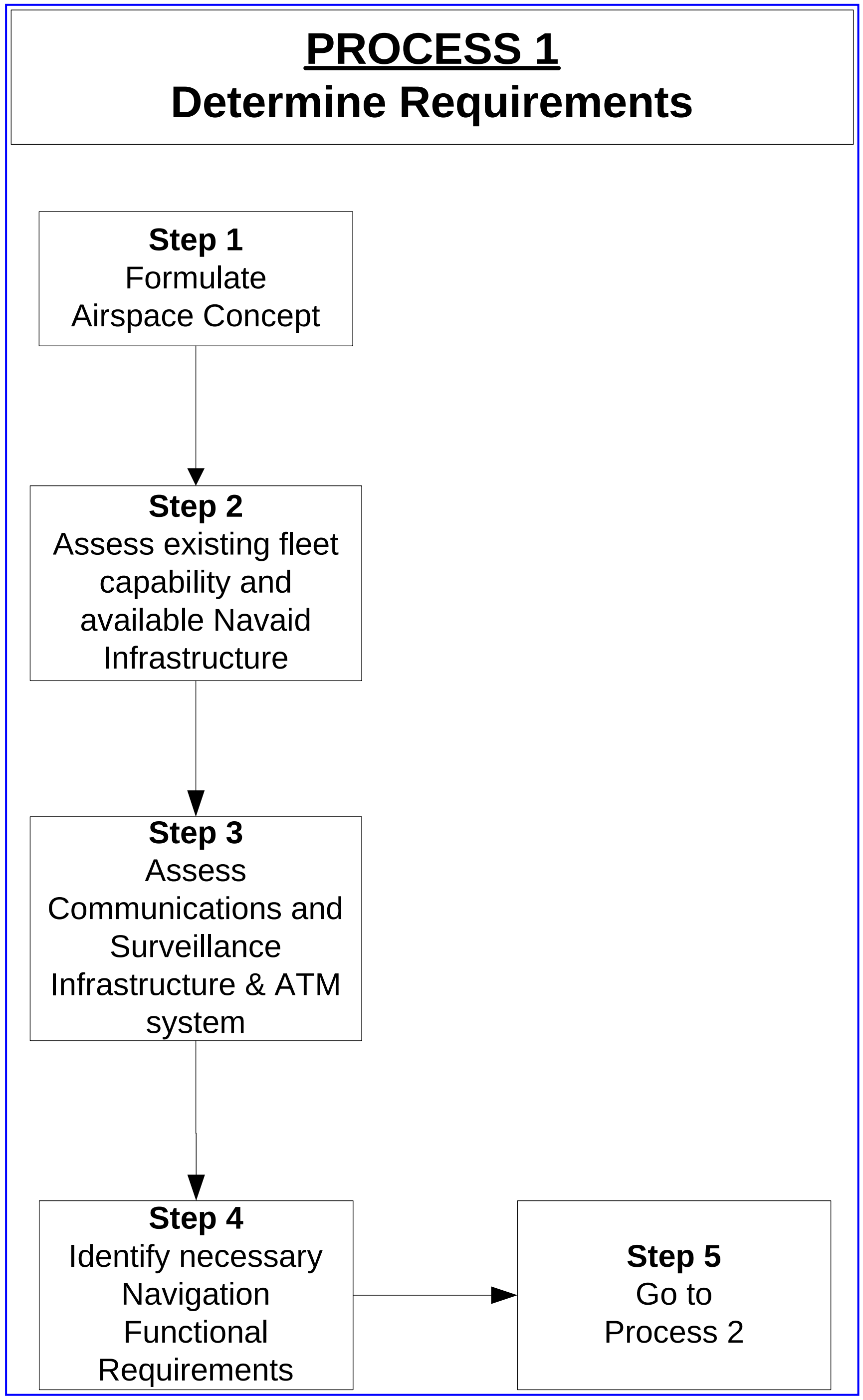


Figure 2-1: Summary of Process 1

CHAPTER 3

PROCESS 2: IDENTIFYING ICAO NAVIGATION SPECIFICATION FOR IMPLEMENTATION

3.1. INTRODUCTION

The goal of Process 2 is the identification of the ICAO Navigation Specification that will support the Airspace Concept and navigation functional requirements as defined in Process 1. A summary of Process 2 is provided at the end of this chapter in Figure 3-1.

3.2. INPUT TO PROCESS 2

The navigation functional requirements, fleet capability, and CNS/ATM capabilities will have been identified in Process 1. These will provide the specific context against which the planners will evaluate their ability to meet the requirements of a particular ICAO navigation specification.

3.3. STEPS IN PROCESS 2

3.3.1. Step 1 – Review ICAO Navigation Specifications in Volume II

a) The first step in Process 2 is aimed at finding a potential match between the requirements identified from Process 1 and those contained in one or more of the ICAO Navigation Specifications in Vol II of this Manual.

b) In reviewing one or more possible ICAO Navigation Specifications, planners will need to

   i) Assess the ability of the existing aircraft fleet and available NAVAID infrastructure to meet the requirements of a particular ICAO Navigation Specification.

   ii) Following the above, planners will need to assess the capabilities of their communications and ATS surveillance infrastructure and ATM system to support implementation of this particular ICAO navigation specification.

Examples of some questions to be considered when comparing the output from with Process 1 with the ICAO Navigation Specifications can be found in Inset 5.

Inset 5 – Examples of questions to be considered when comparing the output from with Process 1 with the ICAO Navigation Specifications

Is the anticipated route structure (from Airspace Concept) compatible? Consider the spacing between individual routes and the existence of multiple routes.

Are the RNAV systems designed to operate with the same NAVAID infrastructure?

Is the available NAVAID infrastructure (assessed in Process 1) the same as the navaid Infrastructure associated with the ICAO Navigation Specification?

3.3.2. Step 2 – Identify Appropriate ICAO Navigation Specification to Apply in the Specific CNS/ATM environment

If planners determine that a particular ICAO Navigation Specification in Vol II can be supported by the fleet equipage, NAVAID infrastructure, and communication, ATS surveillance and ATM capabilities available in the State, proceed to Process 3, Planning and Implementation.

If an ICAO Navigation Specification cannot be supported, continue with Process 2, Step 3.

3.3.3. Step 3 – Identify Tradeoffs with airspace concept and navigation functional requirements if needed

This step is followed when an exact match between a particular ICAO Navigation Specification and the fleet equipage, NAVAID infrastructure, and communication, ATS Surveillance and ATM capabilities available in the State can not be made. It is aimed at changing either the Airspace Concept or navigation functional requirements, in order to select an ICAO navigation specification. For example, operational requirements reflected in the Airspace Concept could be reduced, or alternate means identified to achieve a similar (if not identical) operational result.

Note: Implementation of ICAO Navigation Specifications can improve safety by establishing uniform aircraft and navigation requirements across varying regions. Navigation specifications are also significant sources for cost control to operators. Navigation specifications have associated aircraft requirements, NAVAID infrastructure expectations, and route spacing requirements.

Planners should revisit the Airspace Concept and required navigation functions identified in Process 1 to determine what tradeoffs can be made, so as to implement a particular ICAO Navigation Specification. The following are reasons which could explain the lack of a match:

a) The original analysis of the navigation functional requirements (from Process 1) did not correctly identify all functions required for the Airspace Concept. This could be because a functional capability was omitted or because it was unnecessarily identified. Reasons could include the omission of the TMA leg types for RNAV in terminal airspace or failure to require Fixed Radius Transitions where closely spaced parallel tracks are to be implemented in en route applications.

b) the navigation functional requirements identified in Process 1 were defined around existing fleet capability operating in the airspace on the expectation that this capability would be appropriate for the Airspace Concept. If use of this fleet capability remains the target, then it will be necessary to change the Airspace Concept.

Example:

Trade off of a Navigation Functional Requirement

As an example of a trade off, if the only difference between the ICAO Navigation Specification and the navigation functional requirements identified in Process 1 is a requirement for parallel offset capability, it might be possible to adjust the functional requirement. An alternative to parallel offset capability in a continental airspace could be the creation of radar vectoring areas in which aircraft could be vectored off track, to facilitate climb and descent of overtaking traffic.

In most instances it will be possible to make sufficient tradeoffs in the original Airspace Concept or required navigation functions from Process 1, such that an ICAO Navigation Specification can then be selected. Once tradeoffs have been made that will allow selection of an ICAO Navigation Specification, proceed to Process 3, Planning and Implementation.

However, if in the rare case that a State determines that it is impossible to make trade-offs in its Airspace Concept and/or navigational functional requirements, the State would have to develop a new Navigation Specification. See chapter 5.

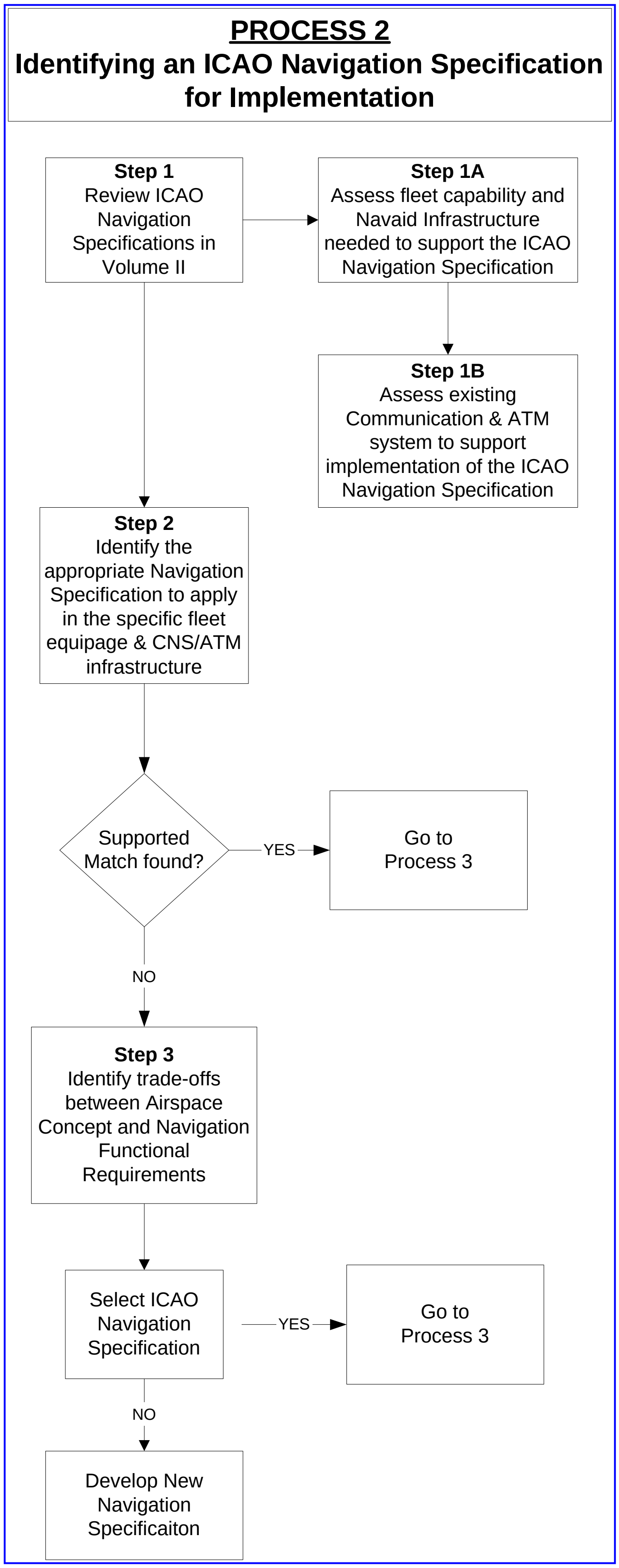


Figure 3-1: Summary of Process 2

CHAPTER 4

PROCESS 3: PLANNING AND IMPLEMENTATION

4.1. INTRODUCTION

The process described in this chapter is concerned with planning and implementing Performance-Based Navigation. It follows upon completion of Process 1 and 2. See Inset 6 for detailed discussion of some important considerations planners should keep in mind when framing the implementation plan. A summary of Process three is provided at the end of this chapter in Figure 4-1.

Inset 6 - Implementation Considerations

In applying one of the ICAO navigation specifications for Oceanic, Remote Continental and en route operations as described in Volume II, consideration should be given to the need for regional or multi-regional agreement. This is because connectivity and continuity with operations in adjoining airspace need to be considered to maximise benefits. For Terminal and Approach operations, the implementation of an ICAO Navigation Specification in Volume II is more likely to occur on a single State basis. Some TMAs are adjacent to national borders for which multinational agreement would likely be required.

Where compliance with an ICAO navigation specification is prescribed for operation in an airspace or ATS routes, these requirements are to be indicated in the State's Aeronautical Information Publication.

The decision to mandate a requirement for one or more ICAO RNAV or RNP specifications should only be considered after several factors have been taken into account. These include but are not limited to –

(a) the operational requirements of the airspace users (civil/military; IFR operations) as well as those of ANSPs

(b) regulatory requirements at both international and national level;

(c) the proportion of the aircraft population currently capable of meeting the specified requirements, and the cost to be incurred by operators that need to equip aircraft to meet the requirements of the navigation specification.

(d) the benefits in terms of safety, capacity, improved access to airspace/airports or environment to be derived from implementing the airspace concept;

(e) the impact on operators in terms of additional flight crew training

(f) the impact on flight crew in terms of workload;

(g) the impact on air traffic services in terms of controller workload and required facilities, (including automation and flight plan processing changes) . Particular attention must be given to possible workload and efficiency impacts of operating mixed navigation environments. See Inset 7 following Step 7 for further discussion of mixed equipage.

4.2. INPUTS TO PROCESS 3

The navigation functional requirements, fleet capability, and CNS/ATM capabilities will have been identified in Process 1. The ICAO Navigation Specification(s) will have been selected in Process 2. Possible additional Region or State requirements for implementation should be identified and incorporated.

4.3. STEPS IN PROCESS 3

4.3.1. Step 1 – Formulate Safety Plan

The first step in Process 3 is the formulation of a safety plan for the PBN implementation. Guidance for formulating a Safety Plan can be found in ICAO Doc 9859*, Safety Management Manual.*

Depending on the nature of the implementation, this could be a Regional or State safety plan. Normally, such a plan would be developed together with an ANSP safety bureau to the satisfaction of the Regulatory Authority. This safety plan details how the safety assessment is to be achieved for the RNAV or RNP implementation.

4.3.2. Step 2 – Validate Airspace Concept for Safety

Validation of an airspace concept involves completing a Safety Assessment. From this assessment, additional safety requirements may be identified which need to be fed back into the airspace concept prior to implementation.

Four validation means are traditionally used to validate an airspace concept:

a) airspace modelling;

b) fast-time simulation (FTS);

c) real-time simulation (RTS);

d) live ATC trials

For simple airspace changes it may be unnecessary to use all of the above validation means for any one implementation. For complex airspace changes, however, FTS and RTS can provide essential feedback on safety (and efficiency) issues and their use is encouraged. Application of new navigation specifications can range from simple through major changes to the airspace concept. All four types of validation are briefly discussed below.

Airspace modelling

Airspace modelling is a beneficial first step because it provides some understanding of how the proposed implementation will work, yet does not require the participation of controllers or pilots. Airspace models are computer based, so it is possible to make changes quickly and effectively to ATS routes, holding patterns, airspace structures or sectorisation to identify the most beneficial scenarios (i.e. those that are worth carrying forward to more sophisticated types of validation). Using a computer-based airspace model can make it easier to identify non-viable operating scenarios so that unnecessary expense and effort is not wasted on more advanced validation phases. The main role of the airspace model is to eliminate non-viable airspace scenarios and to support the qualitative assessment of further concept development.

Fast-Time Simulation (FTS)

Following the computer-based airspace modelling phase, it can be useful to run a fast-time simulation (FTS). A more sophisticated assessment than airspace modellers[1], FTS return more precise and realistic results, while still not requiring the active participation of controllers or pilots. They are demanding in terms of data collection and input; preparation of an FTS can be time consuming.

[1] Some airspace modellers are incorporated in fast-time simulators.

Real-Time Simulation (RTS)

The most realistic way to validate an airspace concept is to subject the viable scenarios to real-time simulation (RTS). These simulators realistically replicate ATM operations and require the active participation of proficient controllers and simulated or “pseudo”- pilots. In some cases, sophisticated RTS can be linked to multi-cockpit simulators so that realistic flight performance is used during the simulation. One of the difficulties that can be encountered with real time simulation is that the navigation performance of the aircraft is too perfect. ‘Aircraft’ in RTS may operate with a navigation precision that is unrealistic, given realities of weather, individual aircraft performance, etc. In such cases, error rates from live operations are analysed and these can be scripted into the RTS.

Live ATC Trials

Live ATC trials – which of necessity involve live flight trials – are most generally used to verify operating practices or procedures whose subtleties are such that FTS and RTS do not satisfy the validation requirements. Importantly, however, procedures need to be designed prior to using these trials, which is why Step 3 would precede any Live ATC trials.

4.3.3. Step 3 – Procedure Design

A total system approach to the implementation of the Airspace Concept means that the procedure design process is an integral element. Therefore, the procedure designer is a key member of the Airspace Concept development team.

Procedure designers need to ensure that the procedures can be coded in ARINC 424 format. Currently, this is one of the major challenges facing procedure designers. Many are not familiar with either the path and terminators used to code RNAV systems or the functional capabilities of different RNAV systems (see Attachment A of this Volume). Many of the difficulties can be overcome, however, if close co-operation exists between procedure designers and data houses that provide the coded data to the navigation data-base providers.

Once these procedures have been validated and flight inspected (see steps 4 and 6), they are published in the national AIP along with any changes to routes, holding areas, or airspace structures.

The complexity involved in data processing for the RNAV system data base means that in most instances, a lead period of two AIRAC cycles is used – see Volume I, Attachment B, Section 3 for more details.

4.3.4. Step 4 – Procedure Validation

The development of an RNAV or RNP instrument flight procedure or ATS route follows a series of steps from the origination of data through survey to the final publication of the procedure and subsequent coding of it for use in an airborne navigation database (see Attachment B of this Volume). At each step there should be quality control procedures in place to ensure that the necessary levels of accuracy and integrity are achieved and maintained.

Before an RNAV or RNP route or procedure is published, as part of the safety assurance process it must be checked to

a) establish that the track definition is correct,

b) the obstacle clearance is sufficient, and

c) the Navaid coverage is adequate.

These checks should consist of software tools allowing the flyability of the procedure to be confirmed for a range of aircraft and environmental conditions (wind/temperature etc). The verification of the flyability of an RNAV or RNP procedure can include independent assessments by procedure designers and other experts using specialist software or full flight simulators. Flyability tests using flight inspection aircraft can be considered but it must be born in mind that this only proves that the particular aircraft used for the test can execute the procedure correctly. The size and speed of flight test aircraft can seldom fully represent the performance of a fully loaded B747 or A340 and therefore simulation is considered the most appropriate way to carry out the flyability test. Tools that are available to confirm appropriate Navaid coverage use terrain data (typically DTED level 1 being required).

4.3.5. Step 5 – Implementation Decision

It is usually during the various validation processes described above that it becomes evident whether the proposed design can be implemented. The decision whether or not to go ahead with implementation needs to be made at a pre-determined point in the life-cycle of a project.

The decision of whether to go ahead with implementation will be based on certain deciding factors. These include

a) whether the ATS route/procedure design meets air traffic and flight operations needs;

b) whether safety and navigation performance requirements have been satisfied;

c) pilot and controller training requirements; and

d) whether changes to flight plan processing, automation, AIP publications are needed to support the implementation

If all implementation criteria are satisfied, the project team needs to plan for execution of the implementation, not only as regards their ‘own’ airspace and ANSP, but in co-operation with any affected parties which may include ANSPs in an adjacent State.

4.3.6. Step 6 – Flight Inspection

Flight Inspection of Navaids involves use of test aircraft which are specially equipped to gauge the coverage of the NAVAID infrastructure required to support the procedures, arrival and departure routes designed by the procedure design specialist. Flight Inspection can also be used to confirm the validity of the terrain and obstruction data used to construct the procedure.

Output from the above procedures phase may require the draft procedures designed by the procedure design specialist to be refined and improved. ICAO Doc 8071*, Manual on Testing of Radio Navigation Aids*, provides general guidance on the extent of testing and inspection normally carried out to ensure that radio navigation systems meet the SARPs in ICAO Annex 10, Volume 1.

4.3.7. Step 7 –ATC System Considerations

The new Airspace Concept may require changes to the ATC system interfaces and display to ensure controllers have the necessary information on aircraft capabilities. Considerations arising from mixed equipage scenarios are discussed in Inset 7. Such changes could include, for example,

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

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

c) Required changes to the ATC situation display

d) Required changes to ATC support tools

e) There may be a requirement for changes to ANSP methods for issuing NOTAMS.

Inset 7 – Mixed Navigation Environments

A mixed navigation environment introduces some complexity for ATS. From an ATC workload and associated automation system perspective, the system needs to include the capability of filtering different navigation specifications from the ATC flight plan and conveying relevant information to controllers. For air traffic control, particularly under procedural control, different separation minima and route spacing are applied as a direct consequence of the navigation specification.

Mixed navigation environments usually occur in one of three scenarios:

a) One RNAV or one RNP application has been implemented (but not as a mandate), and conventional navigation is retained. An example of this would be if RNAV 1 were the declared RNAV specification for a Terminal Airspace, with the availability also of procedures based on conventional navigation, for those aircraft not RNAV 1 approved.

b) A 'mixed-mandate' is used within an airspace volume – usually en route or oceanic/remote procedural operations. For example, it is mandatory to be approved to a RNAV 1 specification for operation along one set of routes, and Basic RNP 1 along another set of routes within the same airspace;

c) A mix of RNAV or RNP applications is implemented in airspace, but there is no mandate for operators to be able to perform them. Here again, conventional navigation could be authorised for aircraft that are not approved to any of the navigation specifications.

Mixed navigation environments can potentially have a negative impact on ATC workload, particularly in dense En Route or Terminal area operations. The acceptability of a mixed navigation environment to ATC is also dependent on the complexity of the ATS route or SID and STAR route structure and upon availability and functionality of ATC support tools. The increased ATC workload normally resulting from mixed mode operations has sometimes resulted in the need to limit mixed-mode operations to a maximum of two types where there is one main level of capability. In some cases ATC has only been able to accept a mixed environment where 90% of the traffic are approved to the required navigation specification; whereas in other instances, a 70% rate has been workable.

For these reasons, it is crucial that operations in a mixed navigation environment be properly assessed in order to determine the viability of such operations.

4.3.8. Step 8 – Awareness and Training Material

The introduction of PBN can involve considerable investment in terms of training, education and awareness material for both flight crew and controllers. In many States, training packages and computer based training have been effectively used for some aspects of education and training. ICAO provides additional training material and seminars. Each Navigation Specification in Volume II, Parts B and C addresses the education and training appropriate for flight crew and controllers.

4.3.9. Step 9 – Establishing Operational Implementation Date

Once a State has established a publication date in accordance with an AIRAC cycle, a sufficient additional time period (e.g. two weeks) should be allocated for the operational implementation date, to ensure ground and airborne system data is properly loaded and validated in databases.

4.3.10. Step 10 – Post Implementation Review

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

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

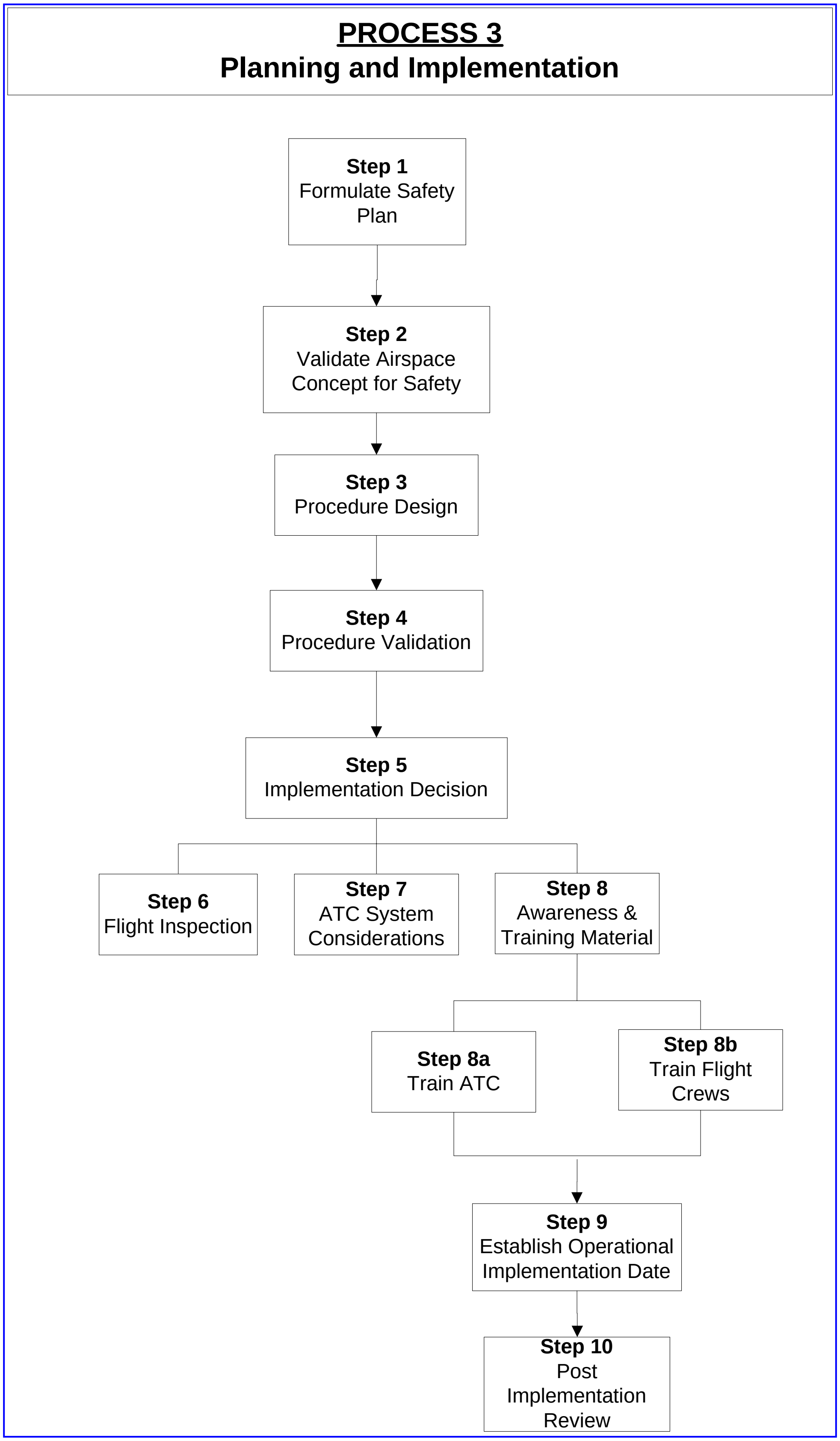


Figure 4-1: Summary of Process 3

CHAPTER 5

GUIDELINES FOR DEVELOPMENT OF A NEW NAVIGATION SPECIFICATION

5.1. INTRODUCTION

In most instances it will be possible to use an existing ICAO Navigation Specification from Volume II to satisfy the navigation requirements for a State or Region's planned Airspace Concept. In the rare case that a State is not able to complete Process 2 and select an ICAO Navigation Specification, the State would have to develop a new Navigation Specification. In order to avoid proliferation of regional standards, a new Navigation Specification would be subject to ICAO review, and ultimately be available for global application. The guidelines in this chapter address this situation.

Development of a new Navigation Specification should only be undertaken if it becomes impossible to make acceptable trade-offs between the defined Airspace Concept, and navigational functional requirements that can be supported by a standard ICAO Navigation Specification.

It should be recognized that development of a new Navigation Specification involves a rigorous evaluation of navigation equipment and its operation. This will require an even greater involvement of airworthiness authorities than the high demands already placed on them in Process 2.

A considerable amount of the preparatory work for development of a new Navigation Specification would initially be undertaken as part of Processes 1 and 2. However, the State or Region concerned is starting from a clean sheet and has therefore to undertake a full analysis at every step. Revisiting the work done in Process 1 and 2 may need to be accomplished in whole or part.

5.2. STEPS FOR DEVELOPING A NEW NAVIGATION SPECIFICATION

5.2.1. Step 1 – Feasibility Assessment and Business Case

When developing a new navigation specification, the question of the feasibility of establishing a new navigation specification that can realistically be met by aircraft manufacturers and operators, and achieving cost effective implementation of that navigation specification, is particularly important. It is necessary to undertake a feasibility assessment and to develop a business case.

The business case assesses the benefits to be derived from proposed Airspace Concept and the cost of meeting the new Navigation Specification. The cost information will be derived from the proposed functions included in the planned new navigation specification, together with estimates of installation and certification costs.

It has also to be understood that the timescales from initial definition of the requirement to it being available in new RNAV or FMS systems can be in excess of 5-7 years. To develop from this point to one where the majority of the aircraft fleet operating in a given airspace by natural (non-mandated) upgrading of the RNAV equipment can be in excess of 15 years. Thus development of a new Navigation Specification normally involves using navigation functional requirements already provided by manufacturers without the existence of certification or operational approval.

Outline of new Navigation Specification

The outline is a product of the business case and has to take due account of the functional requirements needed to meet the Airspace Concept. It has to be produced with sufficient detail to enable aircraft manufacturers to prepare cost estimates for the upgrades to RNAV systems (including RNP systems) needed to provide the required functions of the new navigation specification.

5.2.2. Step 2 - Development of Navigation Specification

Contact should be made early with ICAO, identifying the Airspace Concept that is to be introduced and the foreseen need for a new Navigation Specification. The role of ICAO in this process will be to support the State/Region in a detailed review of its requirements, to ensure subsequent global acceptability of the new navigation specification.

Starting from the Airspace Concept developers identified at the beginning of their PBN implementation efforts, it will then be necessary to elaborate the detailed requirements against which the aircraft and its operation will ultimately be approved. In its co-ordinating role, ICAO will be able to identify if other States or Regions are in the process of developing a new Navigation Specification with similar operational and/or navigation functions. In this situation, ICAO will seek to support a multi-State or Multiregional development of a new harmonised Navigation Specification. Once the new Navigation Specification is complete, it will ultimately be incorporated into Volume II of this Manual.

Although the Airspace Concept and Navigation functional requirements developed in Process 1 form the starting point of the development of a new Navigation Specification, it is likely that these will need iterative refinement, in order to align them with the details of the new navigation specification as it is being developed.

5.2.3. Step 4 – Identification and development of associated ICAO provisions

The development of a new navigation specification may require the development of new ICAO provisions, for example procedure design (PANS-OPS) criteria or ATM procedures. While these tasks are formally carried out by ICAO Panels, the Region(s) or State(s) would be expected to identify changes that need to be introduced to enable the new navigation specification and applications.

5.2.4. Step 5 – Safety Assessment

In accordance with the provisions included in Annex 11 and PANS-ATM, a full safety assessment on the new navigation specification should be completed – see ICAO *Safety Management Manual*, Doc 9859. This safety assessment is undertaken once the new Navigation Specification is sufficiently mature.

See Volume II, Part A, Chapter 2 on Safety Assessment for a more detailed discussion of the necessary elements of safety assessment and risk modelling.

5.2.5. Step 6- Follow up

Where the above evaluation leads to the conclusion that the proposed new Navigation specification can be applied in the ATM environment, the State or Region will be required to formally notify ICAO of the proposed application. ICAO will take action to include the new Navigation Specification to Volume II of this Manual.

On completion of the new Navigation Specification development, the State or Region would then continue with Process 3, Planning and Implementation.

ATTACHMENTS TO VOLUME I

Attachment A

AREA NAVIGATION (RNAV) SYSTEMS

1 BACKGROUND

1.1 RNAV is defined as "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." This removes the restriction imposed on conventional routes and procedures where the aircraft must overfly referenced navigation aids, thereby permitting operational flexibility and efficiency.

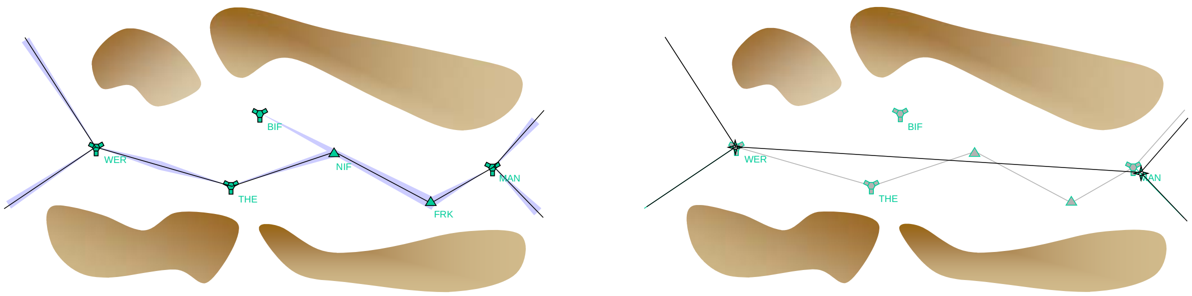
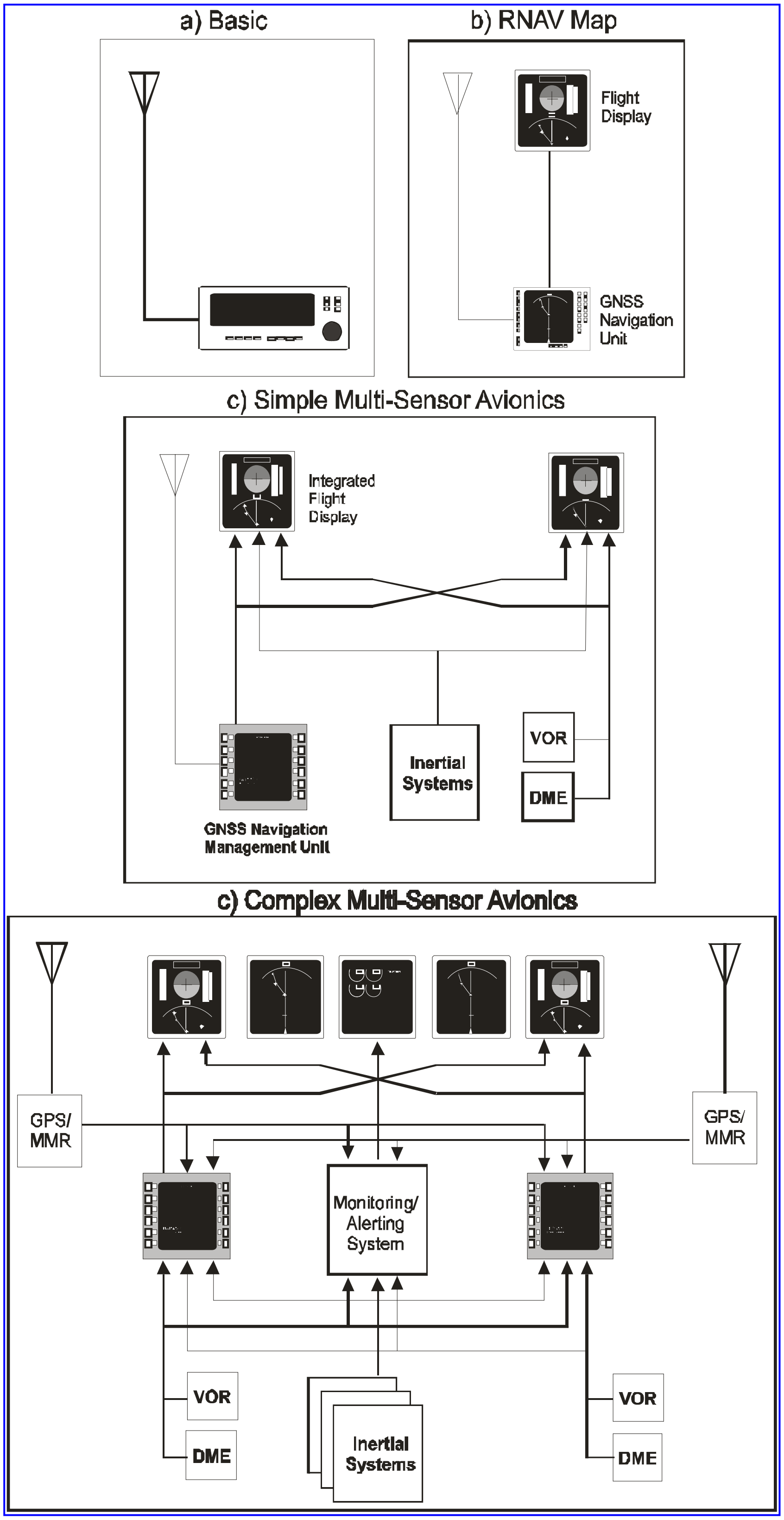


Figure A- 1: Navigation by conventional Navigation compared to RNAV

1.2 Differences in the types of aircraft systems capabilities, features, and functions have resulted in a degree of uncertainty and confusion regarding how aircraft perform RNAV operations. This attachment provides information to aid in understanding RNAV systems.

1.3 All RNAV systems are not the same. They range from single sensor based systems to systems with multiple types of navigation sensors, as illustrated in Figure A-2.

1.4 The RNAV system may also be connected with other systems, such as auto throttle and autopilot/flight director, allowing more automated flight operation and performance management. In spite of the differences in architecture and equipment, the basic types of functions contained in the RNAV equipment are common. The descriptions contained in this section address a system capable of both lateral and vertical navigation. Vertical navigation is not a requirement in all navigation applications.



1 *Figure A-2: RNAV Systems – from Basic to Complex*

2 RNAV SYSTEM - BASIC FUNCTIONS

2.1 RNAV systems are designed to provide a given level of accuracy, with repeatable and predictable path definition, appropriate to the application. The RNAV System typically integrates information from sensors such as air data, inertial reference, radio navigation, satellite navigation, together with inputs from internal data bases and crew-entered data to perform the following functions (see Figure A-3):

- Navigation
- Flight Plan Management
- Guidance and Control
- Display and System Control

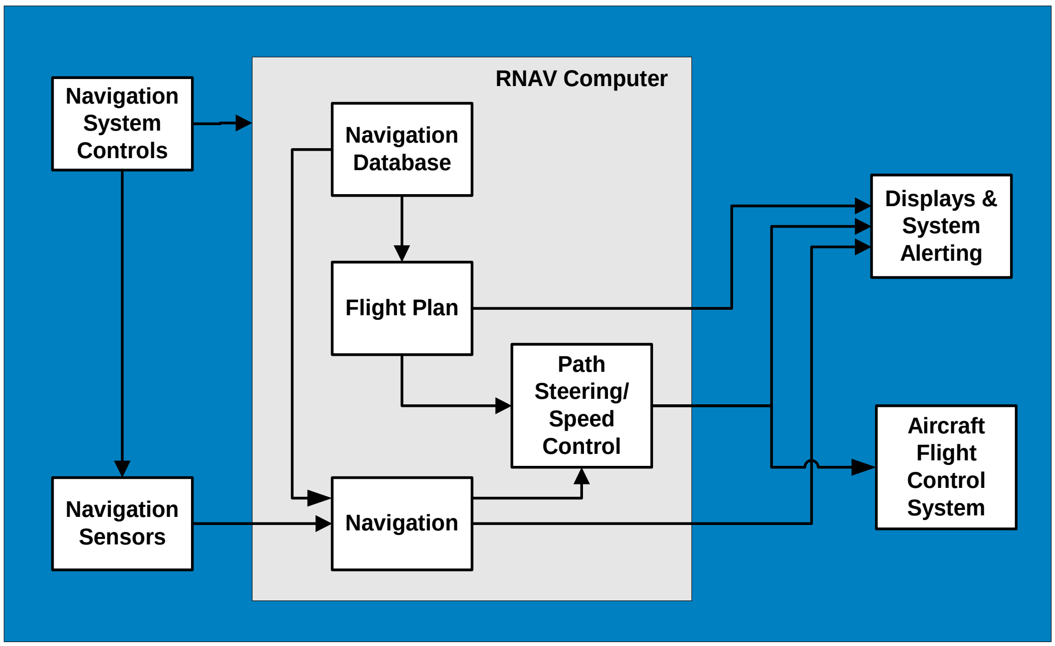


Figure A-3: Basic RNAV System Functions

Navigation

2.2 The navigation function computes data that can include aircraft position, velocity, track angle, vertical flight path angle, drift angle, magnetic variation, barometric-corrected altitude, and wind direction and magnitude. It may also perform automatic radio tuning as well as supporting manual tuning.

2.3 While navigation can be based upon a single type of navigation sensor such as GNSS, many systems are multi-sensor RNAV systems. Such systems use a variety of navigation sensors including GNSS, DME, VOR and IRS to compute position and velocity of the aircraft. While the implementation may vary, the system will typically base its calculations on the most accurate positioning sensor available.

2.4 The RNAV system performs checks on its sensor data before it is used. GNSS data is usually subjected to rigorous integrity and accuracy checks prior to being accepted for navigation position and velocity computation. DME and VOR data are typically subjected to a series of reasonableness checks prior to being accepted for FMC radio updating. This difference in rigour is due to the capabilities and features designed into the navigation sensor technology and equipment. For multi-sensor RNAV systems, if neither GNSS nor DME/VOR radio data are available for calculating position/velocity, then the system will automatically select its lowest priority sensor, e.g. IRS if available. For single sensor systems, sensor failure may lead to a dead reckoning mode of operation.

2.5 As the aircraft progresses along its flight path, the RNAV system uses its current estimate of the aircraft's position and its internal data base to automatically tune the ground stations to obtain the most accurate radio position.

2.6 Lateral and vertical guidance is supplied to display instruments and in many cases, to an automatic flight guidance system. Navigation data is displayed on the primary flight instruments. In its most advanced form, this display consists of an electronic map with an aircraft symbol, planned flight path, and ground facilities of interest, such as navaids and airports.

Navigation Database

2.7 The RNAV system is expected to access a navigation database, if available. The Navigation Data Base contains pre-stored information on navaid locations, waypoints, ATS routes and terminal procedures, and related information. The RNAV system will use such information for flight planning and may also conduct cross checks between sensor information and the data base.

Flight Planning

2.8 The Flight Planning function performs the creation and assembly of the lateral and vertical flight plan used by the guidance function. A key aspect of the flight plan is the specification of flight plan waypoints using latitude and longitude, without reference to the location of any ground navigation aids.

2.9 More advanced RNAV systems include a capability for performance management where aerodynamic and propulsion models are used to compute vertical flight profiles matched to the aircraft and able to satisfy the constraints imposed by Air Traffic Control. A performance management function can be complex, utilizing fuel flow, total fuel, flap position, engine data and limits, altitude, airspeed, Mach, temperature, vertical speed, progress along the flight plan and pilot inputs.

2.10 RNAV systems routinely provide flight progress information for the waypoints enroute, for terminal and approach procedures, and the origin and destination. The information includes estimated time or arrival, and distance to go, useful in tactical and planning coordination with ATC.

Guidance and Control

2.11 An RNAV system provides lateral guidance, and in many cases vertical guidance as well. The lateral guidance function compares the aircraft's position generated by the navigation function with the desired lateral flight path and generates steering commands used to fly the aircraft along the desired path. Geodesic or great circle paths joining the flight plan waypoints, typically known as "legs", and circular transition arcs between these legs are calculated by the RNAV system. The flight path error is computed by comparing the aircraft's present position and direction with the reference path. Roll steering commands to track the reference path are based upon the path error. These steering commands are output to a flight guidance system, which either controls the aircraft directly or generates commands for the flight director. The vertical guidance function, where included, is used to control the aircraft along the vertical profile within constraints imposed by the flight plan. The outputs of the vertical guidance function are typically pitch commands to a display and/or flight guidance system, and thrust or speed commands to displays and/or an autothrust function.

Display and System Control

2.12 Display and system controls provide the means for system initialization, flight planning, path deviations, progress monitoring, active guidance control and presentation of navigation data for flight crew situational awareness.

3 RNP SYSTEM - BASIC FUNCTIONS

3.1 An RNP system is an RNAV system whose functionalities support on-board performance monitoring and alerting. Current specific requirements include:

- Capability to follow a desired ground track with reliability, repeatability and predictability, including curved paths.
- Where vertical profiles are included for vertical guidance, use of vertical angles or specified altitude constraints to define a desired vertical path.

3.2 The performance monitoring and alerting capability may be provided in different forms depending on the system installation, architecture and configurations, including:

- Display and indication of both the required and the estimated navigation system performance
- Monitoring of the system performance and alerting the crew when RNP is exceeded
- Cross track deviation displays scaled to RNP, in conjunction with separate monitoring and alerting for navigation integrity

3.3 An RNP system utilizes its navigation sensors, system architecture and modes of operation to satisfy the RNP requirements. It must perform the integrity and reasonableness checks of the sensors and data, and may provide a means to deselect specific types of navigation aids to prevent reversion to an inadequate sensor. RNP requirements may limit the modes of operation of the aircraft e.g. for low RNP where flight technical error is a significant factor, manual flight by the crew may not be allowed. Dual system/sensor installations may also be required depending on the intended operation or need.

4 SPECIFIC FUNCTIONS

4.1 Performance-based flight operations are based on the ability to assure reliable, repeatable and predictable flight paths for improved capacity and efficiency in planned operations. The implementation of performance-based flight operations requires not only the basic functions, but also specific functions to achieve improved procedures, airspace and air traffic operations. The system capabilities for established fixed radius paths, holding and offsets fall into this category.

Fixed Radius Paths

4.1.1 Fixed Radius Paths (FRP): The FRPs take two forms. One is the radius to fix (RF) leg type. The RF leg is one of the leg types described 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. The RNP system supporting this leg type provides the ability to anticipate the turn in and out of this path, along with any bank angle, to assure flyability and repeatability.

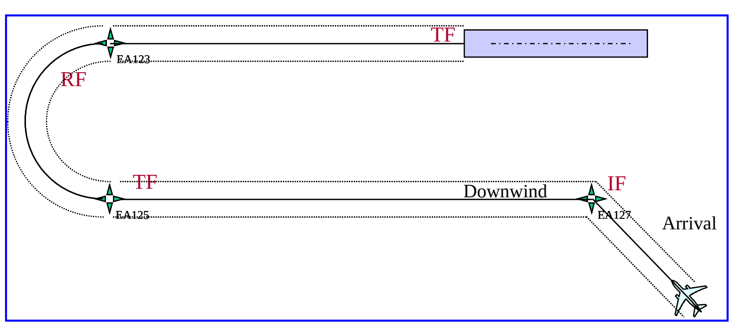


Figure A-4: RF Leg

Another form of the FRP is intended to fit with enroute procedures. Due to the technicalities of how the procedure data is defined, it falls upon the RNP system to create the fixed radius turn (also called a fixed radius transition) between two route segments.

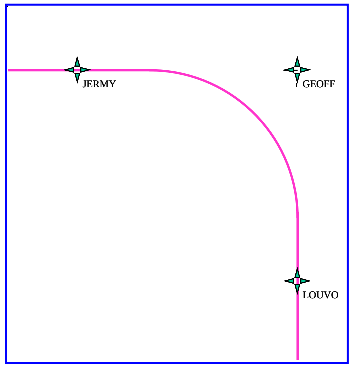
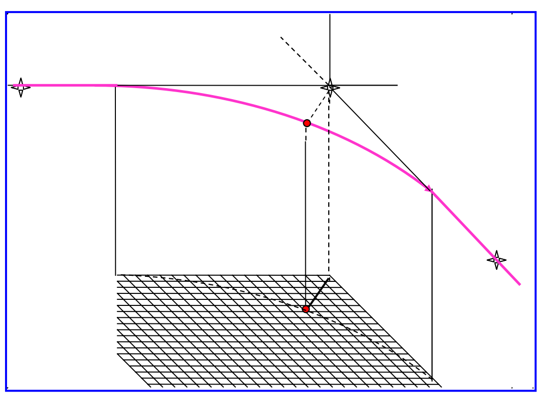


Figure A-5: Fixed Radius Transition

These turns have two possible radii, 22.5 NM for high altitude routes (above FL195) and 15 NM for low altitude routes. Using such path elements in an RNAV ATS route enables improvement in airspace usage through closely spaced parallel routes.

Fly-By Turns

4.1.2 Fly-by turns are a key characteristic of an RNAV flight path. The RNAV system uses information on aircraft speed, bank angle, wind, and track angle change, to calculate a flight path turn that smoothly transitions from one path segment to the next. However, because the parameters affecting the turn radius can vary from one plane to another, as well as due to changing conditions in speed and wind, the turn initiation point and turn area can vary.



Holding Pattern

4.1.3 The RNAV system facilitates the holding pattern specification by allowing definition of the inbound course to the holding waypoint, turn direction and leg time or distance on the straight segments, as well as the ability to plan the exit from the hold. For RNP systems, further improvement in holding is available. These RNP improvements include fly-by entry into the hold and minimizing the necessary protected airspace on the non-holding side of the holding pattern, consistent with the RNP limits provided. Where RNP is applied, a maximum of RNP 1 is suggested since less stringent values adversely affect airspace usage and design.

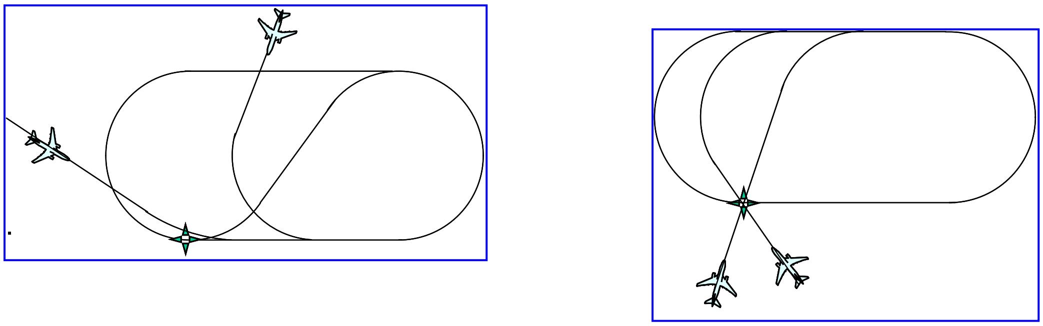


Figure A-6: RNP Holding Pattern Entries

Offset Flight Path

4.1.4 RNAV systems may provide the capability for the flight crew to specify a lateral offset from a defined route. Generally, lateral offsets can be specified in increments of 1 NM up to 20 NM. When a lateral offset is activated in the RNAV system, the RNAV aircraft will depart the defined route and typically intercept the offset at a 45 degree or less angle. When the offset is cancelled, the aircraft returns to the defined route in a similar manner. Such offsets can be used both strategically i.e. fixed offset for the length of the route, or tactically, i.e. temporarily. Most RNAV systems discontinue offsets in the terminal area or at the beginning of an approach procedure, at a RNAV hold, or course changes of 90 degrees or greater. The amount of variability in these types of RNAV operations should be considered as operational implementation proceeds.

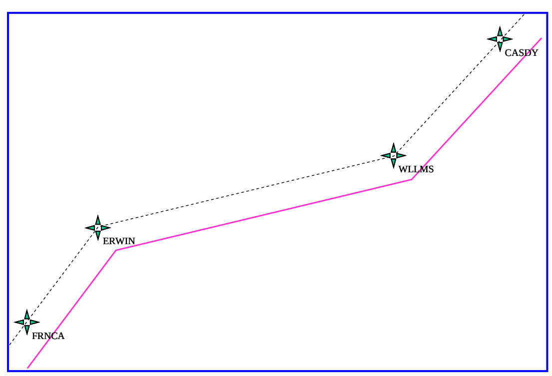


Figure A-7: Offset Flight Path.

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Attachment B

DATA PROCESSES

1 AERONAUTICAL DATA

1.1. All RNAV applications use aeronautical data to define, inter alia, ground-based navaids, runways, gates, waypoints and the route/procedure to be flown. The safety of the application is contingent upon the accuracy, resolution and integrity of this data. The accuracy of the data depends upon the processes applied during the data origination. The resolution depends upon the processes applied at the point of origination and during the subsequent data processing, including the publication by the State. The integrity of the data depends upon the entire aeronautical data chain from the point of origination to the point of use.

1.2 An aeronautical data chain is a conceptual representation of the path that a set, or element of aeronautical data takes from origination to end use. A number of different aeronautical data chains may contribute to a collection of data that is used by an RNAV application. The main components of the chain are illustrated below and include data originators, data collators, data publishers, database suppliers, data packers and data users.

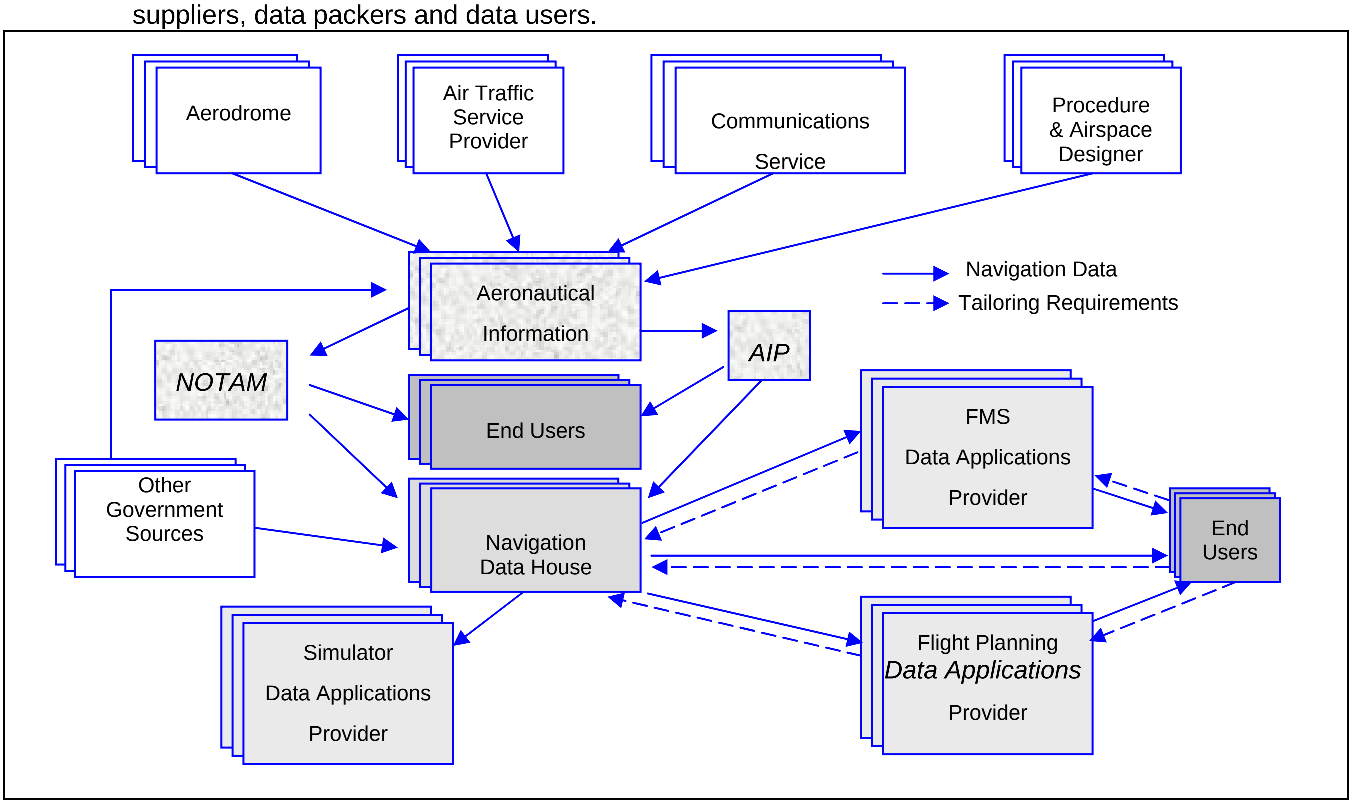


Figure B-1: The Data Chain

2 DATA ACCURACY AND INTEGRITY

2.1 The accuracy, resolution and integrity requirements of individual data items processed by the aeronautical data chain are detailed in ICAO SARPs for AIS (Annex 15), which requires each Contracting State to take all necessary measures to ensure that the aeronautical information/data it provides is adequate, of required quality (accuracy, resolution and integrity) and provided in a timely manner for the entire territory that the State is responsible for.

2.2 Each Contracting State is also required to introduce a properly organized quality system in conformance with the ISO 9000 series of quality standards. Additional guidance is provided in RTCA/EUROCAE document DO-200A/ED76, entitled ‘Standards for Processing Aeronautical Data’.

3 PROVISION OF AERONAUTICAL DATA

3.1 It is incumbent upon the national aviation authority in each State to arrange for the timely provision of required aeronautical information to the AIS by each of the State services associated with aircraft operations. Information provided under the AIRAC system must be distributed at least 42 days prior to the effective date and major changes should be published at least 56 days prior to the effective date.

3.2 The processing cycle for the airborne navigation databases requires that the database is delivered to the end user at least 7 days before the effective date. The RNAV system provider requires at least 8 days to pack the data prior to delivery to the end user and the navigation data houses generally exercise a cut-off 20 days prior to the effective date in order to ensure that the subsequent milestones are met. Data supplied after the 20 day cut-off will generally not be included in the database for the next cycle. The timeline is illustrated in the following diagram.

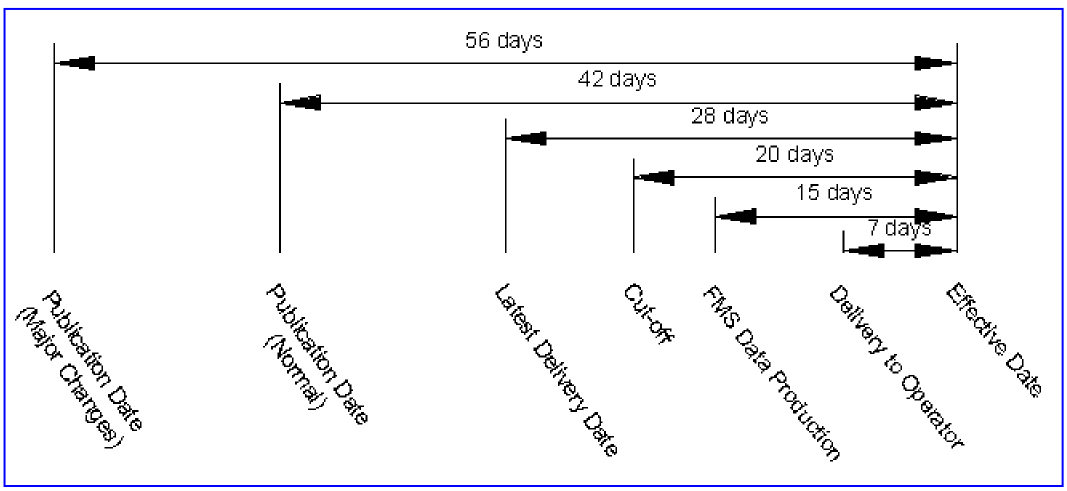


Figure B-2: Data processing time-line

3.3 The quality of data obtained from another link in the aeronautical data chain must be either validated to the required level or guaranteed through an assurance of data quality from that supllier. In most cases, there is no benchmark against which the quality of such data can be validated and the need to obtain assurance of the data quality will generally flow back through the system until it reaches the originator of each data element. Consequently, reliance must be placed upon the use of appropriate procedures at every point along the aeronautical data chain.

3.4 Navigation data may originate from survey observations, from equipment specifications/settings or from the airspace and procedure design process. Whatever the source, the generation and the subsequent processing of the data must take account of the following:

a) All co-ordinate data must be referenced to the World Geodetic System 84.

b) All surveys must be based upon the International Terrestrial Reference Frame.

c) All data must be traceable to source.

d) Equipment used for survey must be adequately calibrated.

e) Software tools used for survey, procedure design or airspace design must be suitably qualified.

f) Standard criteria and algorithms must be used in all designs.

g) Surveyors and designers must be properly trained.

h) Comprehensive verification and validation routines must be used by all data originators.

i) Where necessary, procedures must be subjected to flight inspection prior to publication.

j) Aeronautical navigation data must be published in a standard format, with an appropriate level of detail and to the required resolution.

k) All data originators and data processors must implement a Quality Management Process which includes:

  i) A requirement to maintain quality records

  ii) A procedure for managing feedback and error reporting from users and other processors in the data chain.

4 ALTERING AERONAUTICAL DATA

4.1 A data processor or data user shall not alter any data without informing the originator of the change and receiving concurrence. Altered data shall not be transmitted to a user if the originator rejects the alteration. Records shall be kept of all alterations and shall be made available on request.

4.2 Wherever possible, data handling processes should be automated and human intervention should be kept to a minimum. Integrity-checking devices such as Cyclical Redundancy Checking (CRC) algorithms should be used wherever possible throughout the navigation data chain.

RNP SPECIAL OPERATIONAL REQUIREMENTS STUDY GROUP (RNPSORSG)

PERFORMANCE BASED NAVIGATION MANUAL

VOLUME II

- IMPLEMENTING RNAV AND RNP-

Version:	Working Draft 4.1
Date	27 October 2006
Access:	Restricted **RNPSORSG SASP; OCP; OPS/P; NSP;**

TABLE OF CONTENTS

ATTACHMENTS

Attachment A: Baro VNAV

FOREWORD

The Performance Based Navigation Manual consists of two volumes:

Volume I: - Concept and Implementation Guidance.

Volume II: - RNAV and RNP Applications

Volume II is comprised of three Parts:

Part A, General

Part B, *RNAV Specifications,* contains three chapters that describe how to implement RNAV 10, RNAV 5 and RNAV 1& 2 respectively.

Part C, *RNP Specifications,* contains six chapters that describe how to implement RNP 4, RNP 2, RNP 1; RNP 0.3, RNP 0.3-0.1

Attachment A - *Barometric VNAV.*

All of the chapters in Parts B & C are intended for the use of airworthiness authorities, ANSPs, airspace planners and PANS-OPS specialists.

These chapter follows the same structure –

- Introduction
- Using RNAV X (or RNP X) specification
- General Considerations for development of RNAV X (or RNP X) specification
- Navigation Specification
- References
- Attachments

Specific Remarks

This contents of this Volume are the product of deliberations by ICAO's RNPSORSG and as such, the material it contains has relied to a large extent on the experiences of States which have used RNAV operations. This Volume should not be read in isolation. It is an integral part and complementary to Volume I, *Concept and Implementation Guidance.*

History of this Manual

For the history of this Manual, see Volume I, Foreword.

Future Developments of this Volume

[standard text on comments:]

Comments on this manual would be appreciated from all parties involved in the development and implementation of PBN. These comments should be addressed to:

The Secretary General
International Civil Aviation Organization
999 University Street
Montreal, Quebec H3C 5H7
Canada

REFERENCES

Note. – Documents referenced in this manual or affected by Performance Based Navigation

ICAO

ICAO, Annex 4 Aeronautical Charts

ICAO, Annex 6 - Operation of Aircraft, Part I – International Commercial Air Transport – Aeroplanes

ICAO, Annex 6 - Operation of Aircraft, Part II - Int'l General Aviation - Aeroplane

ICAO, Annex 8- Airworthiness of Aircraft;

ICAO, Annex 10 – Aeronautical Telecommunications, Vol. I - Radio Navigation Aids

ICAO, Annex 11, Air Traffic Services;

ICAO, Annex 15, Aeronautical Information Services

ICAO, Annex 17, Security;

ICAO, Procedures for Air Navigation Services, Air Traffic Management (PANS-ATM), Doc. 4444 ATM/501

ICAO, Global Navigation Satellite System (GNSS) Manual, Doc. 9849

ICAO; Manual on Airspace Planning Methodology for the Determination of Separation Minima, Doc. 9689;

ICAO, Safety Management Manual, Doc. 9859.

ICAO, Aircraft Operations, Doc. 8168 Vols. I & II

RTCA & EUROCAE

RTCA, Minimum Operating Performance Standards for GNSS, DO-208;

RTCA, RNP-RNAV Minimum Aviation System Performance Specifications, DO-236(B);

EUROCAE, RNP-RNAV Minimum Aviation System Performance Specifications;ED-75B

RTCA, Standards for Aeronautical Information, DO-201(A)

EUROCAE, …..[ED-7*]

RTCA, Standards for Processing Aeronautical Data, DO-200A,

EUROCAE, …..[ED-7*]

ABBREVIATIONS

ABAS	Airborne based augmentation System
ADS-B	Automated Dependent Surveillance-Broadcast
ADS-C	Automated Dependent Surveillance-Contract
AIP	Aeronautical Information Publication
ANSP	Air Navigation Service Provider
ATM	Air Traffic Management
ATS	Air Traffic Services
CDI	Course Deviation Indicator
CDU	Control and Display Unit
CFIT	Controlled Flight Into Terrain
CRC	Cyclic Redundancy Checking
CRM	Collision Risk Modelling
CVSM	Conventional Vertical Separation Minima
DME	Distance Measuring Equipment
EASA	European Aviation Safety Authority
ECAC	European Civil Aviation Conference
EUROCAE	European Organization for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
FAA	Federal Aviation Administration
FDE	Fault Detection and Exclusion
FTE	Flight Technical Error
FMS	Flight Management System
FRT	Fixed Radius Transition
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
INS	Inertial Navigation System
IRS	Inertial Reference System
IRU	Inertial Reference Unit
ITRF	International Terrestrial Reference Frame
JAA	Joint Aviation Authorities
MCDU	Multi-Function Control and Display Unit
MEL	Minimum Equipment List
MNPS	Minimum Navigation Performance Specification
NAVAID	Navigation Aid(s)
NSE	Navigation System Error
PBN	Performance Based Navigation
PDE	Path Definition Error
PEE	Positioning Estimation Error
RF	Radius to Fix
RNAV	Area Navigation
RTCA	Radio Technical Commission on Aeronautics
SBAS	Satellite Based Augmentation System
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
TLS	Target Level of Safety
TSE	Total System Error
VOR	Very high Frequency Omni-Range

EXPLANATION OF TERMS

Aircraft-Based Augmentation System (ABAS). An augmentation system that augments and/or integrates the information obtained from the other GNSS elements with information available on board the aircraft.

Note. - The most common form of ABAS is receiver autonomous integrity monitoring (RAIM).

Airspace Concept: An Airspace Concept provides the outline and intended framework of operations within an airspace. An Airspace Concept is essentially a high-level statement of an airspace plan. Airspace Concepts are developed to satisfy explicit strategic objectives such as improved safety, increased air traffic capacity and mitigation of environmental impact etc. Airspace Concepts include details of the practical organisation of the airspace and its users based on particular CNS/ATM assumptions. e.g. ATS route structure, separation minima, route spacing and obstacle clearance.

ATS surveillance service. Term used to indicate a service provided directly by means of an ATS surveillance system.

ATS surveillance system. A generic term meaning variously, ADS-B, PSR, SSR or any comparable ground-based system that enables the identification of aircraft.

Note.— A comparable ground-based system is one that has been demonstrated, by comparative assessment or other methodology, to have a level of safety and performance equal to or better than monopulse SSR.

Area navigation (RNAV). 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.

Note.- Area navigation includes performance based navigation as well as other RNAV operations that do not meet the definition of performance based navigation.

Area navigation route. An ATS route established for the use of aircraft capable of employing area navigation.

Critical DME. A DME facility that, when unavailable, results in a navigation service which is insufficient for DME/DME or DME/DME/IRU based operations along a specific route or procedure. These services are defined based on the minimum charted requirements for that procedure: see paragraph X of each Navigation Specification . (is this an ICAO definition?)

Navigation Aid (NAVAID) Infrastructure. Navaid Infrastructure refers to space-based and or ground-based navigation aids available to meet the requirements in the navigation specification.

Navigation Specification. A Navigation Specification is a set of aircraft and air crew requirements needed to support Performance based navigation operations within a defined airspace. There are two kinds of navigation specification:

a) RNAV X. A navigation specification designation that does not include requirements for on-board performance monitoring and alerting.

b) RNP X. A navigation specification designation that includes requirements for on-board performance monitoring and alerting

Note. - For both RNP X and RNAV X, the expression ’X’ refers to the lateral navigation accuracy in nautical miles that is expected to be achieved at least 95 per cent of the flight time.

Navigation Application. The application of a navigation specification and the supporting NAVAID infrastructure, to routes, procedures, and/or defined airspace volume, in accordance with the intended airspace concept.

Note: The navigation application is one element, along with, communication, surveillance and ATM procedures meeting the strategic objectives in a defined airspace concept.

Performance Based Navigation. Performance based navigation specifies system performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in an airspace. Performance requirements are defined in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept.

Procedural control. Air traffic control service provided by using information derived from sources other than an ATS surveillance system

Receiver Autonomous Integrity Monitoring (RAIM): A technique whereby a GNSS receiver processor determines the integrity of the GNSS navigation signals using only GPS signals or GPS signals augmented with altitude. This determination is achieved by a consistency check among redundant pseudorange measurements. At least one additional satellite needs to be available with the correct geometry over and above that needed for the position estimation for the receiver to perform the RAIM function.

RNAV Operations. Aircraft operations using an area navigation system for RNAV applications. RNAV operations include the use of area navigation for operations which are not developed in accordance with the PBN Manual.

RNAV System: A navigation system 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. A RNAV system may be included as part of a Flight Management System (FMS).

RNP Route: An ATS Route established for the use of aircraft adhering to a prescribed RNP Specification

RNP System: An area navigation system which supports on-board performance monitoring and alerting.

RNP Operations: Aircraft operations using a RNP System for RNP applications.

Satellite based augmentation system (SBAS). A wide coverage augmentation system in which the user receives augmentation from a satellite-based transmitter.

Standard instrument arrival (STAR). A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced.

Standard instrument departure (SID). A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated ATS route, at PANS-OPS, Vol II, which the en-route phase of a flight commences.

PART A

– GENERAL –

CHAPTER 1

INTRODUCTION

1.1. PBN CONCEPT REVIEW

The Performance Based Navigation concept is made up of three inter-related elements: the navigation specification, the NAVAID infrastructure, and the navigation application.

Navigation specifications are used by States as a basis for certification and operational Approval. Navigation specifications describe in detail, the requirements placed on the area navigation system for operation along a particular route, procedure or within an airspace where approval against the navigation specification is prescribed. The requirements placed on the area navigation system include:

a) the performance being required of the area navigation system in terms of accuracy, integrity, continuity and availability;

b) the functions that need to be available in the area navigation system so as to achieve the required performance

c) the navigation sensors, integrated into the area navigation system, that may be used to achieve the required performance;

d) flight crew and other procedures needed to achieve the performance being required of the area navigation system.

The NAVAID infrastructure relates to space or ground-based NAVAIDs that are called up in each navigation specification.

Navigation specifications which require on-board performance monitoring and alerting are termed RNP specifications. Those that do not require on-board performance monitoring and alerting are known as RNAV specifications.

A navigation application is the application of a *navigation specification* and associated *NAVAID infrastructure* to ATS routes, instrument approach procedures and or defined airspace volume in accordance with the airspace concept. Examples of how the navigation specification and NAVAID infrastructure may be used together in a navigation application include RNAV or RNP SIDs and STARs; RNAV or RNP ATS Routes and RNP Approach Procedures.

Note. – A detailed explanation of the PBN concept is presented at Volume I, Part A, Chapter 1.

1.2. USE AND SCOPE OF NAVIGATION SPECIFICATIONS

Most of the ICAO navigation specifications contained in this Volume were originally developed for Regional use to respond to the operational requirements of specific airspace concepts. Some of the applications of these navigation specifications are used in airspace concepts for Oceanic or Remote Continental Airspace. Others are used in airspace concepts for Continental or Terminal Airspace.

Proliferation of Regional or State navigation specifications is avoided by publishing these ICAO navigation specifications, to allow Regions and States to use *existing* ICAO navigation specifications rather than developing new ones.

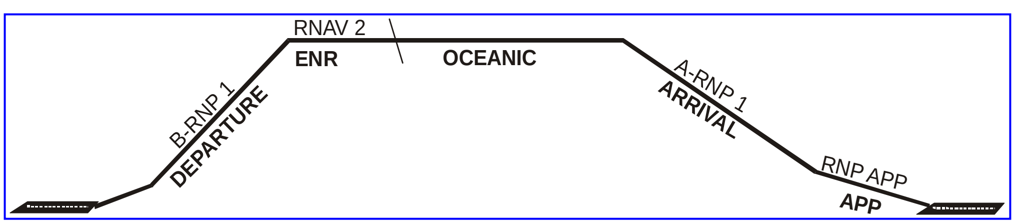
Table 1-1: Application of Navigation Specification by Flight Phase

FLIGHT PHASE → / NAVIGATION SPECIFICATION ↓	En Route OCEANIC /REMOTE	En Route Continental	ARR	APPROACH				DEP
				Initial	Interm.	Final	MISSED	
RNAV 10	10							
RNAV 5		5	5					
RNAV 2		2	2					2
RNAV 1		1	1	1	1		1[b]	1
RNP 4	4							
RNP 2*	2	2	2					
Basic-RNP 1			1[a,c]	1[a]	1[a]		1[ab]	1[a,c]
Advanced-RNP 1*		1	1	1	1		1[b]	1
RNP APP				1	1	0.3	1	
RNP AR APP				1-0.1	1-0.1	0.3 – 0.1	1-0.1	

Notes:
The numbers given in the table refer to the 95% accuracy requirements
** denotes that the navigation application will not be included in Ed. 1 of the PBN Manual;*
1a means that the navigation application is limited to use on STARs and SIDs only;
1b means that the area of application can only be used after the initial climb of a missed approach phase
1c means that beyond 30 NM from the airport reference point (ARP), the accuracy value for alerting becomes 2 NM

The above table shows the navigation specifications and their associated navigation accuracies published in Parts B and C of this Volume. It demonstrates, for example, that the designation of an oceanic/remote, en route or terminal navigation specification includes an indication of the required navigation accuracy, and that the designation of navigation specifications used on Final Approach is different.

Most important, the above table shows that for any particular PBN operation, it is possible that a sequence of RNAV and RNP applications is used. A flight may commence in an airspace using a Basic RNP 1 SID, transit through En Route then Oceanic airspace requiring RNAV 2 and RNP 4, respectively, and culminate with Terminal and Approach operations requiring Advanced RNP 1 and RNP AR APP.



Figre 1-1: Example of an Application of RNAV and RNP Specifications to ATS Routes and Instrument Procedures

While

Table 1-1 identifies for example in the Approach and Missed approach phases of flight, a number of instances where different Navigation Specifications can be applied on the same phases of flight providing identical Total System Errors (TSE), this does not imply that all of the specifications provide identical functional capability. As a result, in the design of the procedures, it is important to call up only that capability which is provided by the appropriate Navigation Specification and that the procedure is appropriately identified.

The entire procedure that is to be flown by the RNAV system is to be coded into the data base and it shall be possible for the pilot to ensure that the system is capable of meeting the operational requirement for the whole procedure

1.2.1. Scope of ICAO Navigation Specifications

The ICAO navigation specifications (i.e. those included in this volume) do not address all requirements that may be specified for operation in a particular airspace, route or in a particular area. Such additional requirements are specified in other documents such as operating rules, aeronautical information publications (AIPs) and the ICAO Regional Supplementary Procedures (Doc 7030). While operational approval primarily relates to the navigation requirements of the airspace, operators and flight crew are still required to take account of all operational documents relating to the airspace that are required by the appropriate State authority before conducting flights into that airspace. Furthermore, it is incumbent upon States to undertake a safety assessment in accordance with the provisions contained in Annex 11 and PANS-ATM, Chapter 2.

1.2.2. Navigation Specifications and the Approval process

A Navigation Specification found in this Manual does not in itself constitute regulatory guidance material against which either the aircraft or the operator will be assessed and approved. OEMs manufacture their products against an airworthiness basis containing the basic code for the aircraft type and the relevant guidance material held in Advisory Material. Operators will be approved against their National Operating Rules. The Navigation Specification provides the technical and operational criteria. Therefore, with RNAV-2/RNAV-1, for example, there is still a need to have the instruments for approval. This could be either through a dedicated approval document or through recognition that existing regional RNAV implementation certification documents (TGL No. 10 and AC 90-100) can be applied with the necessary differences, to satisfy the objectives set out in the PBN Navigation Specification.

CHAPTER 2

ON-BOARD PERFORMANCE MONITORING AND ALERTING

2.1. INTRODUCTION

This chapter addresses the requirements associated with on board performance monitoring and alerting for RNP. In order to do this the chapter first provides an overview of the error sources associated with RNAV systems.

2.2. NAVIGATION ERROR COMPONENTS AND ALERTING

2.2.1. Lateral Navigation

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 in the context of on-board performance monitoring and alerting are Path Definition Error (PDE), Flight Technical Error (FTE), (also known as Path Steering Error – PSE) and Navigation System Error (NSE) (also known as Position Estimation Error, PEE). If the distribution of these errors can be assumed to be Gaussian, then the Total System Error (TSE) is also Gaussian with a standard deviation equal to the Route Sum Square (RSS) of the standard deviations of these three errors.

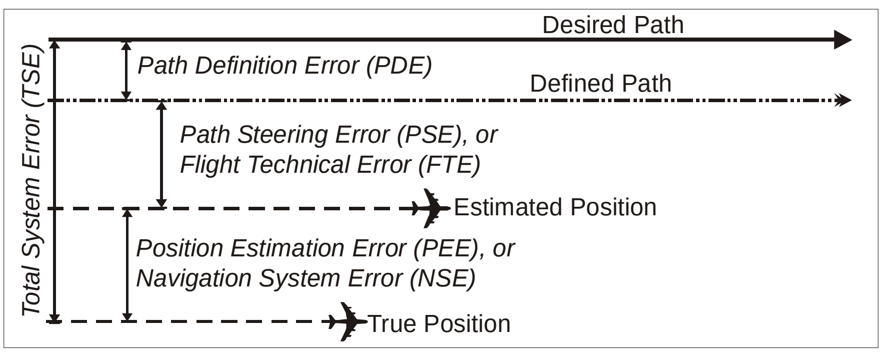


Figure 2-1: Lateral Navigation Errors

a) 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. Use of an RNAV system for navigation presupposes that a defined path representing the intended track is loaded into the navigation database. The only time a path cannot be defined is where a turn is to be affected using a fly-by or fly-over waypoint (see Attachment A for a full explanation). This means that in such cases PDE cannot be established and neither can FTE. In contrast, when a Radius to Fix (RF) leg transition or Fixed Radius Transition (FRT) are used, as with some RNP specifications (see below), a path can be defined and therefore PDE and FTE can be determined.

b) FTE relates to the air crew or autopilot's ability to follow the *defined path* or track. Significantly, with RNP Specifications, FTE can be *monitored* by the autopilot or air crew procedures and the extent to which these procedures need to be supported by other means depends, for example, on the phase of flight and the type of operations. Such monitoring support could be provided by a map display.

Note. – FTE is sometimes referred to as Path Steering Error (PSE)

c) NSE refers to the difference between the aircraft's estimated position and actual position. Note. – NSE is sometimes referred to as Positioning Estimation Error (PEE)

2.2.2. Longitudinal Navigation

Unlike lateral navigation, the inability to achieve the required longitudinal accuracy is only due to the Navigation System Error (NSE) (also known as Position Estimation Error, PEE). The longitudinal accuracy affects position reporting (e.g., "10 NM to ABC") and procedure design (e.g., minimum segment altitudes where the aircraft can begin descent once crossing a fix). For advanced 4-dimensional applications where the aircraft must cross a given fix at a specified time, it is expected that additional requirements will be necessary..

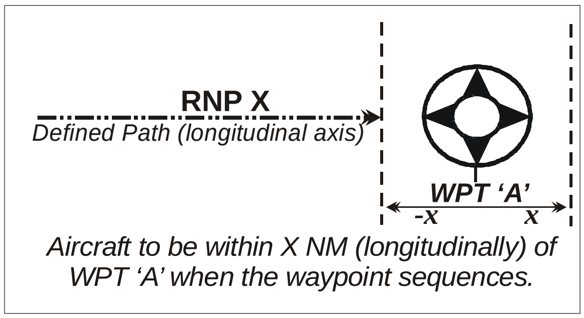


Figure 2-2: Longitudinal Navigation Errors

2.3. ROLE OF ON-BOARD PERFORMANCE MONITORING AND ALERTING

On-board performance monitoring and alerting allows the air crew to detect whether or not the RNAV system is not achieving the navigation performance required in the navigation specification. On-board performance monitoring and alerting relates to both lateral and longitudinal navigation performance.

On-board performance monitoring and alerting is concerned with the performance of the area navigation system.

- 'on-board' explicitly means that the performance monitoring and alerting is affected on board the aircraft and not elsewhere e.g. using a ground-based route adherence monitor or ATC surveillance. The monitoring element of on-board performance monitoring and alerting relates to FTE, NSE and PDE.
- 'monitoring' refers to the monitoring of the aircraft's performance as regards it's ability to determine it's true position and/or to follow the desired path.
- 'alerting' is also related to aircraft positioning: if the aircraft's navigation system does not perform well enough, this will be alerted to the air crew.

The monitoring and alerting requirement could be satisfied by -

a) an airborne navigation system having a NSE monitoring and alerting algorithm (e.g RAIM or FDE algorithm) plus a lateral navigation display indicator (e.g CDI) enabling the crew to monitor the FTE. In this case, on the assumption that PDE is negligible, the requirement is satisfied because NSE and FTE are monitored leading to a TSE monitoring.

Or

b) by an airborne navigation system having a TSE monitoring and alerting algorithm.

The net effect of the above is evident in TSE and can be illustrated in tabular form as shown in Table 1-2.

Table 2-1: Effect of On-board performance monitoring and alerting on TSE

	RNAV Specification	RNP Specifications	
		RNP X Specification not requiring RF or FRT	*RNP X specification* requiring RF, FRT
NSE *(Monitoring and Alerting)*	NSE only observed by pilot cross checks; No alerting on position error	Alerting on position error performance	
FTE *(Monitoring)*	Controlled by on board system or crew procedure.	Controlled by on board system or crew procedure supported, where necessary by a map display, for example.	
PDE *(Monitoring)*	Generally negligible; the desired path is not defined on fly-by and fly over turns.		Generally negligible; path defined on RF and FRT.
NET EFFECT ON **TSE**	TSE not bounded. In addition, the wide variation in turn performance results in need for extra protection on turns.	TSE bounded but extra protection of the route needed on turns;	TSE bounded; no extra protection of the route needed on turns if turns defined by RF or FRT.

Notice that the above table also reflects that RNP X specifications which do not require RF or FRT, have much in common with RNAV specifications as regards PDE since the desired path is not defined. This results in the need to provide additional protected airspace on the turn.

The PBN concept uses the term on-board performance monitoring and alerting in preference to the term containment. This is to avoid confusion between existing uses of containment in various documents by different areas of expertise. For example:

a) Containment has referred to the region within which the aircraft will remain 95% of the time. The associated terms have been *containment value* and *containment distance* and the related airspace protection on either side of a RNAV ATS route.

b) Within the industry standards of RTCA/DO-236() and EUROCAE/ED-75, containment referred to the region that the aircraft will remain when there is no alert (0.99999 probability), and defines a requirement for how often an alert occurs (0.9999). The associated terms are *containment limit, containment integrity, containment continuity,* and *containment region.*

c) Within PANS-OPS material, containment has referred to the region used to define the obstacle clearance, and the aircraft is expected to remain within or above that surface (regardless of alerting) with very high probability. The associated terms have been *containment area, airspace containment, obstacle clearance containment* and related obstacle protection areas.

The previous ICAO expressions of *containment value* and *containment distance* have been replaced by the *navigation accuracy* of TSE.

2.3.1. Performance Monitoring and Alerting Requirements for RNP

The performance monitoring and alerting requirements for RNP 4, RNP 2, RNP 1 and RNP 0.3 have common terminology and application. Each of these RNP navigation specifications includes requirements for the following characteristics:

a) *Accuracy*: The accuracy requirement defines the 95% TSE for those dimensions where an accuracy requirement is defined. The accuracy requirement is harmonized with the RNAV navigation specifications and is always equal to the accuracy value. A unique aspect of the RNP navigation specifications is that the accuracy is one of the performance characteristics that is monitored, as described in the next paragraph.

b) *Performance Monitoring*: The aircraft, or aircraft and pilot in combination, is required to monitor the TSE, and to provide an alert if the accuracy requirement is not met or if the probability that the TSE exceeds two-times the accuracy value is larger than 10^{-5}.

c) *Aircraft Failures*: Failure of the aircraft equipment is considered within airworthiness regulations. Failures are categorized by the severity of their effect, and the system must be designed to reduce the likelihood of the failure or mitigate its effect. Both malfunction (equipment operating but not providing appropriate output) and loss of function (equipment ceases to function) are addressed. Oceanic and remote operations include a requirement for dual systems since the operational effect of loss of function is greater than in domestic operations. The requirements on aircraft failure characteristics are not unique to RNP navigation specifications.

d) *Signal-in-Space Failures*: Signal-in-space characteristics of navigation signals are addressed in Annex 10 and are the responsibility of the ANSP. However, GNSS signals are unique in that a portion of the responsibility for monitoring GNSS satellite signals is allocated to the aircraft. .

Of these requirements, the one that is truly unique to RNP navigation specifications is the performance monitoring requirement. The net effect of RNP navigation specifications is to provide bounding of the TSE distribution. Path definition error is undefined on fly-by and fly-over turns. For all other cases where path definition error is defined, it is assumed to be negligible. This reduces the monitoring requirement to the other two components of TSE, i.e. FTE and NSE. It is assumed that FTE is an ergodic[1] stochastic process within a given flight control mode. As a result, the FTE distribution is constant over time within a given flight control mode. However, in contrast, the NSE distribution varies over time due to a number of changing characteristics, most notably:

a) Selected navigation sensors: which navigation sensors are being used to estimate position, such as GNSS or DME/DME

b) The relative geometry of the aircraft position to the supporting aids: All radio NAVAIDs have this basic variability, although the specific characteristics change. GNSS performance is affected by the relative geometry of the satellites as compared to the aircraft (lines of position should be well distributed in space to support good resolution in space and time). DME/DME navigation solutions are affected by the inclusion angle between the two DMEs at the aircraft (90 degrees being optimal) and the distance to the DMEs since the aircraft transponder can have increasing range errors with increasing distance.

c) Inertial reference units have error characteristics that increase with the time since being updated.

2.3.1.1. Application of Performance Monitoring and Alerting to Aircraft

Although the TSE can change significantly with time for a number of reasons, including those above, the RNP navigation specifications provide assurance that the TSE distribution remains suitable to the operation. This results from two requirements associated with the TSE distribution, namely:

a) The requirement that the TSE remains equal to or less than the required accuracy for 95% of the flight time; and

b) The probability that the TSE of each aircraft exceeds the specified TSE limit without annunciation is less than 10^{-5}.

Typically, the 10^{-5} TSE requirement provides the greater restriction on the performance. For example, with any system that has TSE with a Normal distribution of cross-track error, the 10^{-5} monitoring requirement constrains the standard deviation to be 2×(accuracy value)/4.45 = accuracy value/2.23, while the 95% requirement would have allowed the standard deviation to be as large as the accuracy value/1.96.

It is important to understand that whilst these characteristics define minimum *requirements* that must be met, they do not define the actual TSE distribution. The actual TSE distribution may be expected to be typically better than the requirement, but there must be evidence on the actual margin by which this is the case.

In applying the performance monitoring requirement to aircraft, there can be significant variability in how individual errors are managed:

[1] An ergodic process is one in which every sequence or sizable sample is equally representative of the whole. It is realised that this is not necessarily true all of the operations envisaged by RNAV and RNP systems especially where manual operation is involved, but when averaged over a large number of operations this assumption becomes valid.

a) Some systems monitor the actual cross-track and along-track errors individually, whereas others monitor the radial NSE to simplify the monitoring and eliminate dependency on the aircraft track, e.g. based on typical elliptical 2-D error distributions.
b) Some systems include the FTE in the monitor, by taking the current value of FTE as a bias on the TSE distribution.
c) For Basic GNSS systems, the accuracy and 10^{-5} requirements are met as a by-product of the ABAS requirements that have been defined in equipment standards and the FTE distribution for standardized course deviation indicator (CDI) displays.

It is important that performance monitoring is not regarded as error monitoring. A performance monitoring alert will be issued when the system cannot guarantee, with sufficient integrity, that the position meets the accuracy requirement. When such an alert is issued, the most likely reason is the loss of capability to validate the position data (insufficient satellites being a potential reason). For such a situation, the position of the aircraft at that time is the exact same position indicated on the pilot display. Assuming the desired track has been flown correctly, the FTE would be within the required limits and therefore it is not appropriate to think of TSE prior to the alert as being close to twice the accuracy value: instead, it is simply that the likelihood of the TSE exceeding twice the accuracy value just prior to the alert is approximately 10^{-5}. Conversely, it cannot be assumed that simply because there is no alert the TSE is less than twice the accuracy value: the TSE can be larger. An example is for those aircraft that account for FTE based on a fixed error distribution: for such systems, if the FTE grows large, no alert is issued by the system even when the TSE is many times larger than the accuracy value. For this reason, the operational procedures to monitor FTE are important.

2.3.1.2. Application of Performance Monitoring and Alerting to Risk Evaluations

The performance monitoring and alerting requirements for RNP 4, RNP 2, RNP 1 and RNP 0.3 do not obviate the need for safety assessments to determine the separation minima and obstacle clearance criteria for these routes using a risk metric such as collisions per hour or excursions outside the obstacle clearance area during an approach. Since the relationship between level of collision risk, accuracy and route spacing or obstacle clearance is generally fairly complex, it is not appropriate to simply assume that the appropriate route spacing (track-to-track) is four-times the accuracy value, or to assume that the obstacle clearance is two-times the accuracy value. Very simplistically, the risk of collision between aircraft or between aircraft and obstacles depends on the probability of the loss of separation in the dimension under consideration and the exposure to that loss of separation. The exposure may be evaluated over time (e.g., the time it takes to conduct an approach operation) or over the number of risk events (e.g., the number of aircraft that will be passed in an hour).

The safety assessment may use the performance monitoring and alerting requirement to provide a bounding of the TSE distribution in each dimension, the resulting bounding of distribution will need to be validated. In addition, one needs to be aware of the scope of these bounding distributions as they do not cover human error, for example. Moreover, navigation database errors are not covered by the PBN-based navigation specifications, see Parts B and C of this Volume. It is well known that blunder errors are a major source of errors in navigation and, as precision increases through application of GNSS become the most significant source of risk. These have traditionally been taken into account in safety assessments for the determination of separation minima by the ICAO RGCSP/SASP.

Although the determination of obstacle clearance criteria by the ICAO OCP is traditionally based on the fault-free case, it has repeatedly been found that with modern navigation methods based on GNSS, integrity and continuity of service are of critical importance to the resulting level of safety. Deviations resulting from a mixture of fault-free performance and some (but not all) failures where these deviations are not annunciated have become apparent. Thus, considerable care is necessary with respect to the precise scope of the pertinent safety assessments.

In conducting a safety assessment, States may elect to take into account that the ensemble distribution (of all aircraft operating on the route or procedure) will have a TSE *better* than the bounding distribution allowed by the performance monitoring and alerting requirements. However, in doing so, there must be evidence as to the actual performance being achieved.

2.3.1.3. Application of Performance Monitoring and Alerting for RNP AR APP

The performance monitoring and alerting requirements for RNP AR APP include many of the same characteristics as for RNP 4, RNP 2, RNP 1 and RNP 0.3. However, in the case of RNP AR APP these requirements can be tighter and a number of additional requirements are applied to more tightly monitor or control each error source. There are basically two ways to determine obstacle clearance through analysis. One way is to derive obstacle clearance from the target level of safety, given pre-defined aircraft requirements and operational mitigations. The other way is to derive aircraft requirements and operational mitigations from the target level of safety, given pre-defined obstacle clearance criteria. It is of vital importance in understanding the methodology applied for RNP AR that the latter way was followed, i.e. the obstacle clearance for RNP AR APP operations was first established to have a total width of four-times the accuracy value (± two-times the accuracy value centred on the path) after which aircraft requirements and operational mitigations were then developed to satisfy the target level of safety.

In the case of GNSS, the signal in space requirement for RNP AR APP is not set based on the *NSE*: instead, it is described in terms of the *TSE* to ensure an acceptable risk that the aircraft will go outside the obstacle clearance area. The aircraft failure requirements are more constraining, and tighter performance monitoring and alerting requirements are defined for many of the individual error sources.

2.3.1.4. Performance monitoring and alerting requirements: Sample RNP 1 values

a) Accuracy: the lateral TSE shall be equal to or better than 1 NM for 95% of the total flight time.

b) Performance Monitoring and Alerting: The RNAV System, or the RNAV System and pilot in combination, shall provide an alert if the accuracy requirement is not met, or if the probability that the TSE exceeds 2 NM is greater than 10^{-5}.

c) Aircraft Failures: Malfunction of the aircraft navigation equipment is considered a major failure condition under airworthiness regulations (i.e., 10^{-5} per hour). Loss of function is considered a minor failure condition if the operator can revert to a different navigation system and proceed to a suitable airport.

d) Signal-in-Space: If using GNSS, the system shall provide an alert if the probability of signal-in-space errors causing a lateral position error greater than 2 NM exceeds 10^{-7} per hour.

CHAPTER 3

SAFETY ASSESSMENT CONSIDERATIONS

3.1. SAFETY ASSESSMENT CONSIDERATIONS

3.1.1. Introduction

Parts B and C of this Volume contains navigation specifications which are applied in an Airspace Concept. When applying a navigation specification, a number of safety considerations have to be assessed.

Planners should consult these key reference documents:

- ICAO Document 9859, *Safety Management Manual*, Chapter 13, provides guidance on performing safety assessments.
- ICAO Document 9689, *Manual on Airspace Planning Methodology for the Determination of Separation Minima*, provides information on means for quantifying the effect separation minima have on air traffic safety.
- ICAO Document 8168, Volume II, *PANS OPS* provides design criteria for ATS routes and procedures.
- ICAO Doc 4444, *PANS ATM* provides separation minima.

The following provides an overview of some of the performance characteristics that need to be considered in the Safety Assessment. A table providing cross-references to safety assessment references for the navigation specifications in Parts B and C of this volume concludes this section on safety assessment.

3.1.2. Aircraft Performance

Normal performance: Lateral accuracy is addressed in the individual navigation specifications in chapters B and C of this volume. Lateral accuracy is expressed in terms of a nautical mile value, either side of a desired track centreline. The aircraft is expected to be within that lateral value of the desired track centreline for 95% of the time. Longitudinal accuracy is also defined as the accuracy of distance reporting or fix location.

Non-Normal Errors: Navigation specifications in chapter B do not define aircraft performance in cases of non-normal errors. Non-normal errors include RNAV system failures, as well as “blunder” type errors such as selection of the wrong route. Navigation specifications in chapter C address some non-normal errors through the on-board performance monitoring and alerting requirements, including aircraft and signal-in-space failure conditions. Blunder errors are not included in the on-board performance monitoring and alerting requirements, and must be handled through crew procedure and training, detection through surveillance or additional separation.

3.1.3. System failures

The safety assessment must consider aircraft having single navigation systems, where allowed in the particular navigation specification. The impact of failure of single systems must be considered. Potential mitigations are identified by considering both the nature of the aircraft system failure and the available CNS ATM environment.

In a surveillance environment, one aircraft with a navigation system failure could normally be handled successfully by ATC. Where there is no surveillance, it is necessary to consider two situations: 1) the complete failure of the RNAV system; and 2) the potential that an aircraft's navigation system has an unreported position error. In either case, mitigations will need to be identified and incorporated into the operating procedures for the implementation.

Potential mitigations will depend upon the ATM environment. For example, in the case of complete navigation system failure on an aircraft, where the Navigation Application is implemented in a low traffic environment, with no intent for future implementation of closely spaced tracks, then autonomous navigation capability (inertial or dead reckoning) may provide a sufficient reversion. In cases where there is a plan to implement closely spaced routes, a potential mitigation could be increased aircraft separation to enable safe operation in a procedural environment. In the case of an aircraft with unreported position errors in a non-surveillance environment, RNP navigation specifications address this through the requirements for on-board performance monitoring and alerting.

3.1.4. Infrastructure

3.1.4.1. Failure of Navigation Aid environment

The impact of failure of the NAVAID environment depends upon the NAVAIDs being employed for the operation. For most ground-based NAVAIDs, the number of aircraft using a given aid is normally small. Depending on the number of NAVAIDs available, the loss of a single VOR or DME facility may not result in the loss of position fixing capability. The NAVAID infrastructure environment and the degree of redundancy of NAVAIDs will need to be specifically studied. Inertial navigation capability should also be considered for mitigation of a sparsely populated ground based NAVAID infrastructure.

Where GNSS is planned to be the main or sole positioning source, consideration needs to be given to the impact of loss of navigation capability, not to just a single aircraft, but to a predetermined population of aircraft in a specified airspace. Where ATS surveillance is proposed as the mitigation, consideration has to be given to the acceptability of the resulting ATC workload, in the event of a possibly near-simultaneous loss of navigation capability by a number of aircraft. The likelihood of GNSS outage should be considered in the evaluation.

If it is considered that the likelihood of an outage is unacceptable and the ATC workload would not be acceptable, and therefore that reliance only on ATS surveillance is an unacceptable mitigation solution, another mitigation could be an aircraft requirement for carriage of an alternative navigation capability. An example could be the requirement for the carriage of inertial navigation capability allowing continued operation for an extended period. Other potential mitigations, depending on the navigation specification being implemented, could be a requirement for either the availability of an alternative terrestrial NAVAID input to the RNAV system.

3.1.5. ATS Surveillance and Communication

Along with considering the aircraft performance requirements of the navigation specification planned for implementation, and the available NAVAID infrastructure (both for primary and reversionary navigation capability), the contributions of ATS surveillance and communications to achieve the TLS for a desired route spacing, must be considered. ATS surveillance and communications can be examined to determine what mitigation to navigation errors they can be expected to provide.

The availability of ATS surveillance along the route is a major element in determining if the desired route spacing for the planned navigation implementation (i.e, the Navigation Application) will support the TLS. The amount of redundancy in the ATS surveillance capability must also be considered.

With the exception of Navigation Specifications implemented in oceanic or continental remote airspace, where HF, SATCOM and/or CPDLC can be encountered, the ATS communications requirement is VHF voice. In some States, UHF voice to support military operations is also available. In addition to accounting for the availability of communications, consideration of the reception strength of the communications (strong or weak signal) should be included.

The effectiveness of ATC intervention in the event of an aircraft not following the route centre line must be considered. In particular, controller workload in a busy environment, can delay ATC recognition of unacceptable route centreline deviation beyond the point where the TLS is maintained.

Table 2-1: Navigation Specification Safety Assessment References

Navigation Specification	Safety Assessment References	Notes
RNAV 10 (note: retains designation of RNP 10 in implementation)	(1) ICAO Regional Supplementary Procedures (Doc 7030/4, MID/ASIA/PAC RAC) (2) ICAO Manual on Airspace Planning Methodology for the Determination of Separation Minima (Doc 9689-AN/953) (3) ICAO Procedures for Air Navigation Services, Air Traffic Management (Doc 4444 PANS ATM/501)	
RNAV 5	EUROCONTROL B-RNAV Route Spacing Study ICAO EUR DOC 001, RNAV	
RNAV 2	To be developed	
RNAV 1	EUROCONTROL Safety Assessment of P-RNAV Route Spacing and Aircraft Separation	
RNP 4	(1) ICAO Regional Supplementary Procedures (Doc 7030/4, APAC-S 02/8-MID/ASIA/PAC/RAC) (2) ICAO Manual on Airspace Planning Methodology for the Determination of Separation Minima (Doc 9689-AN/953) (3) ICAO Procedures for Air Navigation Services, Air Traffic Management (Doc 4444 PANS ATM/501)	
RNP 2	To be developed	Navigation specification in development for inclusion in PBN Manual 2d edition
Basic RNP 1	ICAO Doc 8168, PANS OPS, Volume II,	
Advanced RNP 1	To be developed	Navigation specification in development for inclusion in PBN Manual 2d edition
RNP APP	(1) ICAO Doc 8168, PANS OPS, Volume II, (2) ICAO Doc 9613, Vol II,	
RNP AR APP	ICAO Doc 9613, Vol II	

PART B

– IMPLEMENTING RNAV –

CHAPTER 1

IMPLEMENTING RNAV 10 (RNP 10)

1.1. INTRODUCTION

1.1.1. Background

This chapter addresses the implementation of RNAV 10 to support 50 NM lateral and the 50 NM longitudinal distance-based separation minima in oceanic or remote area airspace. This guidance has been titled RNAV 10 for consistency with the other chapters in the PGN Manual. This designation and this version of the material do not change any requirements, and does not affect operators who obtained RNP 10 authorization under ICAO Doc 9613 Appendix E. Recognizing the extent of existing airspace designations and operational approvals using the designation RNP 10, it is anticipated that any new airspace designations or aircraft approvals will continue to use the designation RNP 10.

1.1.2. Purpose

This material provides guidance to States for implementing RNP 10 routes and developing an RNP 10 operational approval process. This material includes guidance on airworthiness, operational issues. The information enables an operator to be approved as capable of meeting the navigation element requirements for RNP 10 operations. It also provides a means by which an operator can lengthen any navigation time limit associated with the RNP 10 approval.

This guidance material does *not* address details of the communications or ATS Surveillance requirements that may be specified for operation on a particular route or in a particular area. These requirements are specified in other documents such as aeronautical information publications (AIPs) and the ICAO *Regional Supplementary Procedures* (Doc 7030). RNP 10 operational approval primarily relates to the navigation requirements of the airspace, operators and flight crew are still required to take account of all operational documents relating to the airspace that are required by the appropriate State authority before conducting flights into that airspace.

1.2. ANSP CONSIDERATIONS

1.2.1. Navaid Infrastructure

RNP 10 was developed for operations in oceanic and remote areas and does not require any ground-based NAVAID infrastructure or assessment.

1.2.2. Communication and ATS Surveillance

This guidance material does *not* address communications or ATS Surveillance requirements that may be specified for operation on a particular route or in a particular area. These requirements are specified in other documents such as aeronautical information publications (AIPs) and the ICAO *Regional Supplementary Procedures* (Doc 7030).

1.2.3. Obstacle Clearance and Route Spacing

Detailed guidance on obstacle clearance is provided in PANS-OPS (Doc 8168, Volume II). The general criteria in Part 1 and Part 3 apply, together with the en-route criteria from Doc 8168, Volume II, Part III, Section 1, Chapter 7 (10NM) and Section 3, Chapter 8.

The rationale for having chosen the RNP 10 value was to support reduced lateral and longitudinal separation minima for application in oceanic and remote areas where the availability of navigation aids, communications and surveillance is limited.

The minimum route spacing where RNP 10 is utilised is 50 NM.

1.2.4. Additional Considerations

Guidance in this chapter does not supersede appropriate State operating requirements for equipage.

1.2.5. Publication

The AIP should clearly indicate the navigation application is RNP 10.

The route should identify minimum segment altitude requirements.

The navigation data published in the State AIP for the routes and supporting navigation aids must meet the requirements of ICAO Annex 15.

All routes must be based upon WGS 84 coordinates

1.2.6. Controller Training

Air Traffic controllers who will provide separation services based on RNP 10 must have completed training in the following areas:

a) RNP 10 lateral separation;

b) RNP 10 longitudinal separation;

c) RNAV systems and navigation sensors including GNSS;

d) RNP 10 operational approvals processes;

e) RNP 10 related phraseology.

1.2.7. Status Monitoring

The NAVAID infrastructure to support radio navigation updating prior to entry in RNP 10 airspace should be monitored and maintained and timely warnings of outages (NOTAM) should be issued.

1.2.8. ATS System Monitoring

Demonstrated navigation accuracy provides one of the primary parameters for determining the lateral route spacing and separation minima necessary for traffic operating on a given route. Accordingly, lateral and longitudinal navigation errors are monitored (i.e. through monitoring programmes which use *Oceanic Navigation Error Reports*, *Oceanic Altitude Deviation Reports* or *Navigation Error Reports*) and then investigated to prevent their reoccurrence. Radar observations of each aircraft's proximity to track and altitude, before coming into coverage of short-range navaids at the end of the oceanic route segment, are typically noted by ATS facilities.

If an observation indicates an aircraft is not within the established limit, the reason for the apparent deviation from track or altitude may need to be determined and steps taken to prevent a recurrence. Additionally, it is a condition of the approval that pilots/operators notify the relevant regulatory authority of any lateral navigational errors of 27.8 km (15 NM) or more, longitudinal navigational errors of 18.5 km (10 NM) or more, longitudinal navigational errors or three minutes or more variation between the aircraft's estimated time of arrival at a reporting point and its actual time of arrival, or navigation system failures.

1.3. NAVIGATION SPECIFICATION

1.3.1. Background

This section identifies the airworthiness and operational requirements for RNP 10 operations. Operational compliance with these requirements must be addressed through national operational regulations, and may require a specific operational approval in some cases. For example, certain operational regulation requires operators to apply to their national authority (State of registry) for operational approval.

This chapter addresses only the lateral part of the navigation system.

The United States Department of Transportation published FAA Order 8400.12 — Required Navigation Performance 10 (RNP 10) Operational Approval on 24 January 1997. Based on the comments received from operators, States, and aviation regulatory authorities, a new version, 8400.12A, was published on 9 February 1998. The Civil Aviation Safety Authority (CASA) of Australia, in coordination with the United States, used FAA Order 8400.12A (as amended) to develop Civil Aviation Advisory Publication (CAAP) RNP 10-1, detailing the approval process for Australian operators. This has since been replaced with Advisory Circular (AC) 91U-2(0). ICAO guidance material was originally published in ICAO Doc. 9613 Appendix E, and has been updated and included in this Manual.

1.3.2. Approval Process

The following steps must be completed before conducting RNP 10 operations:

a) Aircraft equipment eligibility must be determined and documented;

b) Operating procedures for the navigation systems to be used and the operator navigation database process must be documented;

c) Flight crew training based upon the operating procedures must be documented if necessary;

d) The above material must be accepted by the State regulatory authority; and

e) Operational approval must then be obtained in accordance with national operating rules.

1.3.2.1. Contents of an Application for an RNP 10 Operational Approval

Aircraft Eligibility

Many aircraft and navigation systems currently in use in oceanic or remote area operations will qualify for RNP 10 based on one or more provisions of the existing certification criteria. Thus, additional aircraft certification action may not be necessary for the majority of RNP 10 operational approvals. In these instances, additional aircraft certification will only be necessary if the operator chooses to claim additional performance beyond that originally certified or stated in the aircraft flight manual but cannot demonstrate the desired performance through data collection. Three methods of determining aircraft eligibility have been defined.

Method 1: RNP Certification

Method 1 can be used to approve aircraft that already have been formally certificated and approved for RNP operations. RNP compliance is documented in the flight manual and is typically not limited to RNP 10. The flight manual will address RNP levels that have been demonstrated and any related provisions applicable to their use (e.g. navaid sensor requirements). Operational approval will be based upon the performance stated in the flight manual.

An airworthiness approval specifically addressing RNP 10 performance may be obtained. Sample wording that could be used in the flight manual when an RNP 10 approval is granted for a change in the INS/IRU certified performance is as follows:

> "The XXX navigation system has been demonstrated to meet the criteria of [State's guidance material document] as a primary means of navigation for flights up to YYY hours' duration without updating. The determination of flight duration starts when the system is placed in navigation mode. For flights which include airborne updating of navigation position, the operator must address the effect that updating has on position accuracy and any associated time limits for RNP operations pertinent to the updating navaid facilities used and the area, routes or procedures to be flown. Demonstration of performance in accordance with the provisions of [State's guidance material document] does not constitute approval to conduct RNP operations."

Note: The above wording in a flight manual is based upon performance approval by the aviation authority and is only one element of the approval process. Aircraft that have had this wording entered into their flight manual will be eligible for approval through issuance of operations specifications or a letter of approval if all other criteria are met. The YYY hours specified in the flight manual do not include updating. When the operator proposes a credit for updating, the proposal must address the effect the updating has on position accuracy and any associated time limits for RNP operations pertinent to the updating navaid facilities used and the area, routes or procedures to be flown.

Method 2: Aircraft eligibility through prior navigation system certification

Method 2 can be used to approve aircraft whose level of performance, under other/previous standards, can be equated to the RNP 10 criteria. The standards listed in paragraph 1.3.3 can be used to qualify an aircraft. Other standards may also be used if they are sufficient to ensure that the RNP 10 requirements are met. If other standards are to be used, the applicant must propose an acceptable means of compliance.

Method 3: Aircraft eligibility through data collection

Method 3 requires that operators collect data to gain an RNP 10 approval for a specified period of time. The data collection programme must address the appropriate navigational accuracy requirements for RNP 10. The data collection must ensure that the applicant demonstrate to the aviation authority that the aircraft and the navigation system provide the flight crew with navigation situational awareness relative to the intended RNP 10 route. The data collection must also ensure that a clear understanding of the status of the navigation system is provided and that failure indications and procedures are consistent with maintaining the required navigation performance.

There are two data collection methods for Method 3:

a) The *sequential method* is a data collection programme meeting the provisions of FAA Order 8400.12A (as amended), Appendix 1. This method allows the operator to collect data and plot it against the “pass-fail” graphs to determine whether the operator’s aircraft system will meet the RNP 10 requirements for the length of time needed by the operator; and

b) The *periodic method* of data collection employs the use of a hand-held GNSS receiver as a baseline for collected INS data, which is described in FAA Order 8400.12A (as amended), Appendix 6 (Periodic Method). The data collected is then analysed as described in Appendix 6 to determine whether the system is capable of maintaining RNP 10 for the length of time needed by the operator.

Relevant documentation for the selected qualification method must be available to establish that the aircraft is equipped with long range navigation systems (LRNSs) which meet the requirements of RNP 10 (e.g. the flight manual). The applicant must provide a configuration list that details pertinent components and equipment to be used for long-range navigation and RNP 10 operations. The applicant’s proposed RNP 10 time limit for the specified INS or IRU must be provided. The applicant must consider the effect of headwinds in the area in which RNP 10 operations are intended to be carried out (see paragraph 1.3.4) to determine the feasibility of the proposed operation.

1.3.2.2 Operational Approval

The assessment of a particular operator is made by the State of Registry for that operator and in accordance with national operating rules (e.g., JAR-OPS 1, 14 CFR Part 121) supported through appropriate advisory and guidance material. The assessment should take into account:

a) Evidence of aircraft eligibility

b) Assessment of the operating procedures for the navigation systems to be used

c) Control of those procedures through acceptable entries in the Operations Manual

d) Identification of flight crew training requirements

e) Where required, control of navigation database process

The operational approval will likely be documented through the State endorsing the Air Operators Certificate (AOC) through issue of a letter of authorisation, appropriate operations specification (Ops Spec) or amendment to the operations manual.

1.3.2.2.1 Description of aircraft equipment

The operator must have a configuration list detailing pertinent components and equipment to be used for RNP 10 operation.

1.3.2.2.2 Training documentation

Commercial operators must have a training program addressing the operational practices, procedures and training items related to RNP 10 operations (e.g. initial, upgrade or recurrent training for flight crew, dispatchers or maintenance personnel).

NOTE: It is not required to establish a separate training program or regimen if RNAV training is already an integrated element of a training program. However, it should be possible to identify what aspects of RNAV are covered within a training program.

Private operators must be familiar with the practices and procedures identified in paragraph 1.3.5 "Pilot Knowledge/Training" of this chapter.

1.3.2.2.3 Operations manuals and checklists

Operations manuals and checklists for commercial operators must address information/guidance on the standard operating procedures detailed in the "Operating procedures" section of this chapter. The appropriate manuals should contain navigation operating instructions and contingency procedures where specified. Manuals and checklists must be submitted for review as part of the application process.

Non-commercial operators must create appropriate instructions containing navigation operating instructions and contingency procedures. This information must be available to crews in flight and should be entered into the Operations Manual or Pilot Operating Handbook, as appropriate. These manuals and manufacturer's instructions for operation of the aircraft navigation equipment, as appropriate, must be submitted for review as part of the application process.

Private operators must operate using the practices and procedures identified in paragraph 1.3.5 "Pilot Knowledge/Training" of this chapter.

1.3.2.2.4 Minimum Equipment List (MEL) considerations

Any minimum equipment list (MEL) revisions necessary to address RNP 10 provisions must be approved. Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions.

All operators should have an established maintenance program for the individual navigation systems. For others installing navigation systems, the operator will submit those changes appropriate to their existing maintenance manual for review and acceptability.

1.3.2.2.5 Past performance

An operating history of the operator must be included in the application. The applicant must address any events or incidents related to navigation errors for that operator (e.g. as reported on a State's navigation error investigation form) that have been covered by training, procedures, maintenance, or the aircraft/navigation system modifications which are to be used.

1.3.3. Aircraft Requirements

RNP 10 requires that aircraft operating in oceanic and remote areas be equipped with at least two independent and serviceable long-range navigation systems (LRNSs) comprising an inertial navigation system (INS), an inertial referencing system (IRS)/flight management system (FMS) or a global navigation satellite system (GNSS), with an integrity such that the navigation system does not provide an unacceptable probability of misleading information.

1.3.3.1. System Accuracy

All aircraft operating in RNP 10 airspace must have a cross-track navigation error no greater than ±18.5 km (±10 NM) for 95 per cent of the flight time. This includes positioning error, flight technical error (FTE), path definition error (PDE) and display error. The aircraft along-track positioning error must be no greater than ±18.5 km (±10 NM) for 95 per cent of the flight time.

Note: For RNP 10 operational approval of aircraft capable of coupling the area navigation (RNAV) system to the flight director or autopilot, navigational positioning error is considered to be the dominant contributor to cross-track and along-track error. Flight technical error, path definition error and display errors are considered to be insignificant for the purposes of RNP 10 approval.

It should be noted that when the data collection method described in Appendix 1 of FAA Order 8400.12A (as amended) is used as the basis for an RNP 10 operational approval, these error types are included in the analysis. However, when the data collection method described in Appendix 6 of that document is used, these errors are not included since that method is more conservative. The Appendix 6 method uses radial error instead of cross-track and along-track error.

1.3.3.2. Performance Monitoring and Alerting

On-board self-contained performance monitoring and alerting is not required for RNP 10 operations.

1.3.3.3. Criteria for Specific Navigation Services

1.3.3.3.1 Aircraft incorporating dual GNSS

Aircraft approved to use GNSS as a primary means of navigation for oceanic and remote operations, in accordance with the appropriate aviation authority's requirements, meet the RNP 10 requirements without time limitations.

Multi-sensor systems integrating GNSS with FDE that are approved using the guidance contained in United States FAA Advisory Circular AC 20-130A (*Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors*), or its equivalent, meet RNP 10 requirements without time limitations.

FAA Advisory Circular AC 20-138A provides an acceptable means of complying with installation requirements for aircraft that use GNSS but do not integrate it with other sensors. FAA AC 20-130A describes an acceptable means of compliance for multi-sensor navigation systems that incorporate GNSS. Aircraft that intend to use GNSS as the only navigation system (e.g. no INS or IRS) on RNP 10 routes or in RNP 10 airspace must also comply with the regulations and related advisory documentation of the relevant aviation authority, except for specific GNSS requirements described in this guidance material. This includes use of GNSS approved for primary oceanic/remote performance.

The flight manual must indicate that a particular GNSS installation meets the appropriate aviation authority's requirements. Dual TSO-authorized GNSS equipment must be fitted and an approved FDE availability prediction programme must be used. The maximum allowable time for which FDE capability is projected to be unavailable is 34 minutes for any one occasion. The maximum outage time must be included as a condition of the RNP 10 approval.

Note: If predictions indicate that the maximum FDE outage time for the intended RNP 10 operation will be exceeded, then the operation must be rescheduled when FDE is available, or RNP 10 must be predicated on an alternate means of navigation.

1.3.3.3.2 Aircraft incorporating dual inertial navigation systems (INS) or inertial reference units (IRU) – Standard time limit

Aircraft equipped with dual INS or IRU systems approved in accordance with any of the following standards have been determined to meet RNP 10 requirements for up to 6.2 hours of flight time:

a) 14 CFR, Part 121, Appendix G (or a State's equivalent)

b) Minimum Navigation Performance Specifications (MNPS)

c) Approved for RNAV operations in Australia

The timing starts from when the systems are placed in the navigation mode or at the last point at which the systems are updated.

Note: The 6.2 hours of flight time are based on an inertial system with a 95 per cent radial position error rate (circular error rate) of 3.7 km/h (2.0 NM/h), which is statistically equivalent to individual 95 per cent cross-track and 95 per cent along-track position error rates (orthogonal error rates) of 2.9678 km/h (1.6015 NM/h) each, and 95 per cent cross-track and 95 per cent along-track position error limits of 18.5 km (10 NM) each (e.g. 18.5 km (10 NM)/2.9678 km/h (1.6015 NM/h) = 6.2 hours)).

If the systems are updated en route, the operator must show the effect that the accuracy of the update has on the time limit (see paragraph1.4.4 for information on the adjustment factors for systems that are updated en route).

Note: Documents listed in paragraph 1.4 provide information on acceptable procedures for operators who wish to increase the 6.2 hour time limitation specified.

1.3.3.3.3 Aircraft incorporating dual inertial navigation systems (INS) or inertial reference units (IRU) – Extended time limit

For aircraft with INS certified under United States 14 CFR, Part 121, Appendix G, additional certification is only necessary for operators who choose to certify INS accuracy to better than 3.7 km (2 NM) per hour radial error (2.9678 km (1.6015 NM) per hour cross-track error). However, the following conditions apply:

a) The certification of INS performance must address all issues associated with maintaining the required accuracy, including accuracy and reliability, acceptance test procedures, maintenance procedures and training programmes; and

b) The operator must identify the standard against which INS performance is to be demonstrated. This standard may be a regulatory (i.e. Appendix G), an industry or an operator-unique specification. A statement must be added to the flight manual identifying the accuracy standard used for certification (see 1.4.1).

1.3.3.3.4 Aircraft equipped with a single INS/IRU and a single **GPS** *approved for primary means of navigation in oceanic and remote areas*

Aircraft equipped with a single INS or IRU and a single GNSS meet the RNP 10 requirements without time limitations. The INS or IRU must be approved to 14 CFR, Part 121, Appendix G. The GNSS must be TSO-C129( ) authorized and must have an approved fault detection and exclusion (FDE) availability prediction programme. The maximum allowable time for which the FDE capability is projected to be unavailable is 34 minutes on any one occasion. The maximum outage time must be included as a condition of the RNP 10 approval. The flight manual must indicate that the particular INS/GPS installation meets the appropriate aviation authority's requirements.

1.3.4. Operating Procedures

To satisfy the requirements for RNP 10 operations in oceanic and remote areas, an operator must also comply with the relevant requirements of ICAO *Annex 2 — Rules of the Air*.

1.3.4.1. Flight Planning

During flight planning, the flight crew should pay particular attention to conditions affecting operations in RNP 10 airspace (or on RNP 10 routes), including:

a) Verifying that the RNP 10 time limit has been accounted for;

b) Verifying the requirements for GNSS, such as FDE, if appropriate for the operation; and

c) Accounting for any operating restriction related to RNP 10 approval, if required for a specific navigation system.

1.3.4.2. Pre-Flight Procedures

The following actions should be completed during pre-flight:

a) Review maintenance logs and forms to ascertain the condition of the equipment required for flight in RNP 10 airspace or on an RNP 10 route. Ensure that maintenance action has been taken to correct defects in the required equipment;

b) During the external inspection of an aircraft, if possible check the condition of the navigation antennas and the condition of the fuselage skin in the vicinity of each of these antennas (this check may be accomplished by a qualified and authorized person other than the pilot, e.g. a flight engineer or maintenance person); and

c) Review the emergency procedures for operations in RNP 10 airspace or on RNP 10 routes. These are no different than normal oceanic emergency procedures with one exception — crews must be able to recognize and ATC must be advised when the aircraft is no longer able to navigate to its RNP 10 approval capability.

1.3.4.3. Navigation Equipment

All aircraft operating in RNP 10 oceanic and remote airspace must be fitted with two fully serviceable independent long-range navigation systems with integrity such that the navigation system does not provide misleading information.

A State authority may approve the use of a single long-range system in specific circumstances (e.g. North Atlantic MNPS and 14 CFR 121.351(c) refer). An RNP 10 approval is still required.

1.3.4.4. Flight Plan Designation

Operators should use the appropriate ICAO flight plan designation specified for the RNP route flown. The letter “R” should be placed in block 10 of the ICAO flight plan to indicate the pilot has reviewed the planned route of flight to determine RNP requirements and the aircraft and operator have been approved on routes where RNP is a requirement for operation. Additional information needs to be displayed in the remarks section that indicates the accuracy capability such as RNP-10 versus RNP 4.

1.3.4.5. Availability of Navaids

At dispatch or during flight planning, the operator must ensure that adequate navigation aids are available en route to enable the aircraft to navigate to RNP 10 for the duration of the planned RNP 10 operation.

For GNSS systems, the operator should ensure during dispatch or flight planning that adequate navigation capability is available en route for the aircraft to navigate to RNP 10, including the availability of FDE, if appropriate for the operation.

1.3.4.6. En Route

At least two long-range navigation systems capable of navigating to the RNP must be operational at the oceanic entry point. If this is not the case, then the pilot should consider an alternate routing which does not require that equipment or diverting for repairs.

Before entering oceanic airspace, the position of the aircraft must be checked as accurately as possible by using external navigation aids. This may require DME/DME and/or VOR checks to determine navigation system errors through displayed and actual positions. If the system must be updated, the proper procedures should be followed with the aid of a prepared checklist.

Operator in-flight operating drills must include mandatory cross-checking procedures to identify navigation errors in sufficient time to prevent aircraft from inadvertent deviation from ATC-cleared routes.

Crews must advise ATC of any deterioration or failure of the navigation equipment below the navigation performance requirements or of any deviations required for a contingency procedure.

Pilots are encouraged to use a lateral deviation indicator, flight director and/or autopilot in lateral navigation mode on RNP 10 operations. All pilots are expected to maintain route centrelines, as depicted by onboard lateral deviation indicators and/or flight guidance during all RNP operations described in this manual unless authorized to deviate by ATC or under emergency conditions. For normal operations, cross-track error/deviation (the difference between the RNAV system computed path and the aircraft position relative to the path) should be limited to +/- ½ the navigation accuracy associated with the route (i.e. 5 NM). Brief deviations from this standard (e.g., overshoots or undershoots) during and immediately after route turns, up to a maximum of 1 times the navigation accuracy (i.e. 10 NM), are allowable.

NOTE: Some aircraft do not display or compute a path during turns. As such, pilots of these aircraft may not be able to adhere to the ±½ accuracy standard during route turns but are still expected to satisfy the standard during intercepts following turns and on straight segments.

1.3.4.7. Route Evaluation for RNP 10 Time Limits for Aircraft Equipped Only With INSs or IRUs

An RNP 10 time limit must be established for aircraft equipped only with INSs or IRUs. When planning operations in areas where RNP 10 is applied, the operator must establish that the aircraft will comply with the time limitation on the routes that it intends to fly.

In making this evaluation, the operator must consider the effect of headwinds and, for aircraft not capable of coupling the navigation system or flight director to the autopilot, the operator may choose to make this evaluation on a one-time basis or on a per-flight basis. The operator should consider the points listed in the following subsections in making the evaluation.

Route evaluation

The operator must establish the capability of the aircraft to satisfy the RNP 10 time limit established for dispatch or departure into RNP 10 airspace.

Start point for calculation

The calculation must start at the point where the system is placed in the navigation mode or the last point at which the system is expected to be updated.

Stop point for calculation

The stop point may be one of the following:

a) The point at which the aircraft will begin to navigate by reference to ICAO standard navaids (VOR, DME, non-directional radio beacon (NDB)) and/or comes under ATC surveillance; or

b) The first point at which the navigation system is expected to be updated.

Sources of wind component data

The headwind component to be considered for the route may be obtained from any source found acceptable to the aviation authority. Acceptable sources for wind data include: the State's Bureau of Meteorology, National Weather Service, Bracknell, industry sources such as Boeing Winds on World Air Routes, and historical data supplied by the operator.

One-time calculation based on 75 per cent probability wind components

Certain sources of wind data establish the probability of experiencing a given wind component on routes between city pairs on an annual basis. If an operator chooses to make a one-time calculation of RNP 10 time limit compliance, the operator may use the annual 75 per cent probability level to calculate the effect of headwinds (this level has been found to be a reasonable estimation of wind components).

Calculation of time limit for each specific flight

The operator may choose to evaluate each individual flight using flight plan winds to determine if the aircraft will comply with the specified time limit. If it is determined that the time limit will be exceeded, then the aircraft must fly an alternate route or delay the flight until the time limit can be met. This evaluation is a flight planning or dispatch task.

1.3.4.8. Effect of En-route Updates

Operators may extend their RNP 10 navigation capability time by updating. Approvals for various updating procedures are based upon the baseline for which they have been approved minus the time factors shown below:

a) Automatic updating using distance measuring equipment (DME)/DME = baseline minus 0.3 hours (e.g. an aircraft that has been approved for 6.2 hours can gain 5.9 hours following an automatic DME/DME update);

b) Automatic updating using DME/DME/VHF omni-directional radio range (VOR) = baseline minus 0.5 hours; and

c) Manual updating using a method similar to that contained in FAA Order 8400 12A (as amended), Appendix 7 or approved by the aviation authority = baseline minus 1 hour.

1.3.4.9. Automatic Radio Position Updating

Automatic updating is any updating procedure that does not require the flight crew to manually insert coordinates. Automatic updating is acceptable provided that:

a) Procedures for automatic updating are included in an operator's training programme; and

b) Flight crews are knowledgeable of the updating procedures and of the effect of the update on the navigation solution.

An acceptable procedure for automatic updating may be used as the basis for an RNP 10 approval for an extended time as indicated by data presented to the aviation authority. This data must present a clear indication of the accuracy of the update and the effect of the update on the navigation capabilities for the remainder of the flight.

1.3.4.10. Manual Radio Position Updating

If manual updating is not specifically approved, manual position updates are not permitted in RNP 10 operations. Manual radio updating may be considered acceptable for operations in airspace where RNP 10 is applied provided that:

a) The procedures for manual updating are reviewed by the aviation authority on a case-by-case basis. An acceptable procedure for manual updating is described in FAA Order 8400.12A (as amended), Appendix 7 and may be used as the basis for an RNP 10 approval for an extended time when supported by acceptable data;

b) Operators show that their updating and training procedures include measures/cross-checking to prevent human factors errors and the flight crew qualification syllabus is found to provide effective pilot training; and

c) The operator provides data that establish the accuracy with which the aircraft navigation system can be updated using manual procedures and representative navigation aids.

Data should be provided that show the update accuracy achieved in in-service operations. This factor must be considered when establishing the RNP 10 time limit for INSs or IRUs.

1.3.5. Pilot Knowledge and Training

The following items should be standardized and incorporated into training programmes and operating practices and procedures. Certain items may already be adequately standardized in existing operator programmes and procedures. New technologies may also eliminate the need for certain crew actions. If this is found to be the case, then the intent of this attachment can be considered to have been met.

Note: This guidance material has been written for a wide variety of operator types and therefore certain items that have been included may not apply to all operators.

Commercial operators should ensure that flight crews have been trained so that they are knowledgeable of the topics contained in this guidance material, the limits of their RNP 10 navigation capabilities, the effects of updating, and RNP 10 contingency procedures.

Non-commercial operators should show the aviation authority that pilots are knowledgeable of RNP 10 operations. However, some States might not require non-commercial operators to have formal training programmes for some types of operations (e.g. FAA Order 8700.1, *General Aviation Operations Inspector's Handbook*). The aviation authority in determining whether a non-commercial operator's training is adequate might:

a) Accept a training centre certificate without further evaluation;

b) Evaluate a training course before accepting a training centre certificate from a specific centre;

c) Accept a statement in the operator's application for an RNP 10 approval that the operator has ensured and will continue to ensure that flight crews are knowledgeable of the RNP 10 operating practices and procedures; and

d) Accept an operator's in-house training programme.

1.3.6. Navigation Database

If a navigation database is carried, it must be current and appropriate for the operations and must include the navigation aids and waypoints required for the route.

1.3.7. Oversight of Operators

An aviation authority may consider any navigation error reports in determining remedial action. Repeated navigation error occurrences attributed to a specific piece of navigation equipment or operational procedure may result in cancellation of the operational approval pending replacement or modifications on the navigation equipment or changes in the operator's operational procedures.

Information that indicates the potential for repeated errors may require modification of an operator's training programme, maintenance programme or specific equipment certification. Information that attributes multiple errors to a particular pilot crew may necessitate remedial training or crew licence review.

1.4. REFERENCES

Websites

- Federal Aviation Administration (FAA), United States

  http://www.faa.gov/ats/ato/rnp.htm

  http://www.faa.gov (See Regulations and Policies)

- Civil Aviation Safety Authority (CASA), Australia.

  http://www.casa.gov.au/rules/1998casr/index.htm

Related Publications

- Federal Aviation Administration (FAA), United States

  FAA Order 8400.12A (as amended). *Required Navigation Performance 10 (RNP 10) Operational Approval*

  FAA Order 8700.1. *General Aviation Operations Inspector's Handbook*

  Code of Federal Regulations (CFR), Part 121, Appendix G

  Advisory Circular (AC) 20-130A. *Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors*

  AC 20-138A. *Airworthiness Approval of Global Navigation Satellite System (GNSS) Equipment*

- Joint Aviation Authorities

  AMJ 20X9 Temporary Guidance Material for Recognition of FAA Order 8400.12A for RNP-10 Operations

- Civil Aviation Safety Authority (CASA), Australia

  Advisory Circular (AC) 91U-2(0): Required Navigation Performance 10 (RNP 10) Operational Authorisation

- International Civil Aviation Organization (ICAO)

  Annex 6 – Operation of Aircraft

  Annex 11 – Air Traffic Services

  Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM) (Doc 4444)

  (Copies may be obtained from the Document Sales Unit, ICAO, 999 University Street, Montreal, Quebec, Canada H3C 5H7

  RTCA. Minimum Aviation System Performance Standards (MASPS): Required Navigation Performance for Area Navigation, RTCA SC-236B

  (Copies may be obtained from RTCA, Inc., 1828 L Street NW, Suite 805, Washington, DC 20036, United States)

CHAPTER 2

IMPLEMENTING RNAV 5

2.1. INTRODUCTION

2.1.1. Background

JAA Temporary Guidance Leaflet No. 2 was first published in July 1996, containing Advisory Material for the Airworthiness Approval of Navigation Systems for use in European Airspace designated for Basic RNAV operations. Following the adoption of AMC material by JAA and subsequently responsibility being assigned to EASA, this document has been re-issued as AMC 20-4.

The FAA published comparable material under AC 90-96 on 20 March 1998. The two documents seek to provide identical functional and operational requirements.

In the context of the terminology adopted by this manual on Performance Based Navigation, B-RNAV requirements are termed RNAV 5.

2.1.2. Purpose

This chapter provides guidance to States implementing RNAV 5 in the en route phase of flight.

For the Air Navigation Service Provider, it provides an ICAO recommendation on the implementation requirements, avoiding the proliferation of standards and the need for multiple regional approvals. For the operator, it provides criteria to enable operation in airspace where the carriage of RNAV meeting 5 NM lateral accuracy is already required (e.g. ECAC B-RNAV). It avoids the need for further approvals in other Regions or areas needing to implement RNAV with the same lateral accuracy and functional requirements.

While primarily addressing requirements of RNAV operation in an ATS Surveillance environment, RNAV 5 implementation has occurred in areas where there is no Surveillance. This has required an increase in route spacing commensurate with the assurance of meeting the Target Level of Safety.

The RNAV 5 specification does not require an alert to the pilot in the event of excessive navigation errors. As the specification does not require the carriage of dual RNAV systems, the potential for loss of RNAV capability requires an alternative navigation source.

This chapter does not address all requirements that may be specified for operation on a particular RNAV 5 route or in a particular RNAV 5 area. These requirements are specified in other documents such as operating rules, aeronautical information publications (AIPs) and, where appropriate, the ICAO Regional Supplementary Procedures (Doc 7030). While operational approval primarily relates to the navigation requirements of the airspace, operators and flight crew are still required to take account of all operational documents relating to the airspace that are required by the appropriate State authority before conducting flights into that airspace.

2.1.3. Terminology

RNAV 5 Routes. RNAV routes requiring a total system error of not more than ±5 NM for 95% of the total flight time. No integrity/continuity requirement is defined as part of the specification.

2.2. ANSP CONSIDERATIONS

States may prescribe the carriage of RNAV 5 on specific routes or for specific areas/flight levels of their airspace.

2.2.1. Navaid Infrastructure

RNAV 5 systems permit aircraft navigation along any desired flight path within the coverage of either station referenced navigation aids (space or terrestrial) or within the limits of the capability of self-contained aids, or a combination of both methods.

RNAV 5 operations are based upon the use of RNAV equipment that automatically determines aircraft position in the horizontal plane using inputs from one or a combination of the following types of position sensors, together with the means to establish and follow a desired path:

a) VOR/DME

b) DME/DME

c) INS or IRS

d) GNSS

The ANSP must undertake an assessment of the NAVAID infrastructure. It should be shown to be sufficient for the proposed operations, including reversionary modes. It is acceptable for gaps in navigation aid coverage to be present. Where this occurs, route spacing and obstacle clearance surfaces need to take due account for the expected increase in lateral track keeping errors during the “dead reckoning” phase of flight.

2.2.2. Communication & ATS Surveillance

Direct pilot to ATC (voice) communication is required.

Where reliance is placed on the use of ATS Surveillance to assist contingency procedures, its performance should be adequate for that purpose.

Radar monitoring by the Air Traffic Service may be used to mitigate the risk of gross navigation errors, provided the route lies within the ATS Surveillance and communications service volumes and the ATS resources are sufficient for the task.

2.2.3. Obstacle Clearance and Route Spacing

Detailed guidance on obstacle clearance is provided in PANS-OPS (Doc 8168, Volume II). The general criteria in Part 1 and Part 3 apply, together with the en-route criteria from Doc 8168, Volume II, Part III, Section 1, Chapter 7 (5NM) and Section 3, Chapter 8.

The State is responsible for route spacing and should account for the availability of ATS surveillance and monitoring tools to support detection and correction of navigation errors. Route spacing between RNAV 5 routes or between RNAV 5 routes and conventional routes should refer to applicable ICAO material. One State demonstrated a route spacing of 30 NM to meet the safety targets of $5 * 10^{-9}$ fatal accidents per flight hour in the absence of ATS surveillance and in a high traffic density.

Where traffic density is lower, route spacing may be reduced. In an ATC surveillance environment, the route spacing will depend upon acceptable ATC workload and availability of controller tools. One regional RNAV 5 implementation adopted standard route spacing of 16.5 NM for same direction and 18 NM for opposite direction traffic. Moreover, route spacing as low as 10 NM has been used where ATC intervention capability permits.

The route design should account for the navigation performance achievable with the available NAVAID infrastructure, and the functional capabilities required by this document. Two aspects are of particular importance:

Spacing between routes in turns

Automatic leg sequencing and associated turn anticipation is only a recommended function for RNAV 5. The track followed in executing turns depends upon the true airspeed, applied bank angle limits and wind. These factors, together with the different turn initiation criteria used by manufacturers, result in a large spread of turn performance. Studies have shown that for a track change of as little as 20 degrees, the actual path flown can vary by as much as 2 NM. This variability of turn performance needs to be taken into account in the design of the route structure where closely spaced routes are proposed.

Along track distance between leg changes

The turn can start as early as 20 NM before the waypoint in the case of a large track angle change with a "fly by" turn. Manually initiated turns may overshoot the following track.

The track structure design needs to ensure leg changes do not occur too closely together. The required track length between turns depends upon the required turn angle.

2.2.4. Additional Considerations

Many aircraft have the capability to fly a path parallel to, but offset left or right from, the original active route. The purpose of this function is to enable offsets for tactical operations authorized by ATC.

Many aircraft have the capability to execute a holding pattern manoeuvre using their RNAV system. The purpose of this function is to provide flexibility to ATC in designing RNAV operations.

Guidance in this chapter does not supersede appropriate State operating requirements for equipage.

2.2.5. Publication

The AIP should clearly indicate the navigation application is RNAV 5.

The requirement for the carriage of RNAV 5 equipment in specific airspace or on identified routes should be published in the AIP.

The route should rely on normal descent profiles and identify minimum segment altitude requirements.

The navigation data published in the State AIP for the routes and supporting navigation aids must meet the requirements of ICAO Annex 15.

All routes must be based upon WGS 84 coordinates.

The available NAVAID infrastructure should be clearly designated on all appropriate charts (for example, GNSS, DME/DME, VOR/DME). Any navigation facilities that are critical to RNAV 5 operations should be identified in the relevant publications.

A navigation database does not form part of the required functionality of RNAV 5. The absence of such a data base necessitates manual waypoint entry, increasing significantly the potential for waypoint errors. En-route charts should support gross error checking by the flight crew by publishing fix data for selected waypoints on RNAV 5 routes.

2.2.6. Controller Training

Air traffic controllers providing area control services in airspace where RNAV 5 is implemented should have completed training in the following:

a) RNAV 5 functional capabilities and limitations This is to specifically consider the variation of capabilities across the fleet and to demonstrate the limited capability of the older systems such as "VOR movers" which meet the RNAV 5 requirements but can present high pilot workload where waypoints and navigation system tuning is undertaken manually

b) RNAV- systems accuracy, integrity, availability and continuity;

c) RNAV operational and contingency procedures and RNAV related phraseology;

d) The operational limitations of positioning systems that can be used by RNAV 5 and the impact of outage on the ability of aircraft to meet RNAV 5 accuracy requirements. This specifically needs to address the fact that outage of specific navigation aids may not prevent aircraft from meeting RNAV 5 accuracy requirements.

2.2.7. Status monitoring

The NAVAID infrastructure should be monitored and maintained and timely warnings of outages (NOTAM) should be issued.

2.2.8. ATS System Monitoring

Monitoring of navigation performance is required for two reasons

a) Demonstrated "typical" navigation accuracy provides a basis for determining whether the performance of the ensemble of aircraft operating on the RNAV routes meets the required performance

b) The lateral route spacing and separation minima necessary for traffic operating on a given route are determined both by the core performance and upon normally rare system failures.

Both lateral performance and failures need to be monitored in order to establish the overall system safety and to confirm it meets the required Target level of safety.

When available, radar observations of each aircraft's proximity to track and altitude are typically noted by Air Traffic Service (ATS) facilities and aircraft track-keeping capabilities are analyzed.

A process should be established to allow pilots and controllers to report incidents where navigation errors are observed. If an observation/analysis indicates that a loss of separation or obstacle clearance has occurred, the reason for the apparent deviation from track or altitude should be determined and steps taken to prevent a recurrence.

2.3. NAVIGATION SPECIFICATION

2.3.1. Background

This section identifies the operational requirements for RNAV 5 operations. Operational compliance with these requirements should be addressed through national operational regulations, and may require a specific operational approval in some cases. Operators will be approved against their National Operating Rules. For example, in ECAC, JAR OPS 1 requires operators to apply to their national authority for operational approval.

RNAV 5 does not require the carriage of a navigation database. Because of the specific limitations (e.g. workload and potential for data insertion errors) associated with manual insertion of waypoint coordinate data, RNAV 5 operations should be restricted to the en route phase of flight.

2.3.2. Approval Process

The following steps must be completed before conducting RNAV 5 operations:

a) Aircraft equipment eligibility must be determined and documented, which may be accomplished taking credit for prior approval to AMC 20-4 or AC 90-96.

b) Operating procedures for the navigation systems to be used must be documented;

c) Flight crew training based upon the operating procedures must be documented;

d) The above material must be accepted by the State regulatory authority; and

e) Operational approval should then be obtained in accordance with national operating rules.

Following the successful completion of the above steps, an RNAV 5 operational approval, letter of authorization or appropriate operations specification (Ops Spec), if required, should then be issued by the State.

2.3.2.1 Aircraft Eligibility

The aircraft eligibility has to be determined through demonstration of compliance against the relevant airworthiness criteria e.g., AMC 20-4 or AC 90-96. The OEM or the holder of installation approval for the aircraft e.g., STC holder, will demonstrate the compliance to their National Airworthiness Authority (NAA) (e.g., EASA, FAA) and the approval can be documented in manufacturer documentation (e.g., Service Letters, etc.). Aircraft Flight Manual (AFM) entries are not required provided the State accepts manufacturer documentation.

2.3.2.2 Operational Approval

The assessment of a particular operator is made by the State of Registry for that operator and in accordance with national operating rules (e.g., JAR-OPS 1, 14 CFR Part 121) supported through the advisory and guidance material found in documents such as AMC 20-4 or AC 90-96. The assessment should take into account:

a) Evidence of aircraft eligibility

b) Assessment of the operating procedures for the navigation systems to be used

c) Control of those procedures through acceptable entries in the Operations Manual

d) Identification of flight crew training requirements

e) Where required, control of navigation database process

NOTE: It is envisaged that an operational approval against either AMC 20-4 or AC 90-96 can lead to compliance with requirements in any RNAV 5 designated route, subject to the approval process mentioned below. The assessment, including the flight crew operating procedures and training, are linked to the aircraft operation and should take into account specific local requirements.

The operational approval will likely be documented through the State endorsing the Air Operators Certificate (AOC) through issue of a letter of authorisation, appropriate operations specification (Ops Spec) or amendment to the operations manual.

2.3.2.2.1 Description of aircraft equipment

The operator must have a configuration list detailing pertinent components and equipment to be used for RNAV 5.

2.3.2.2.2 Training documentation

Commercial operators should have a training program addressing the operational practices, procedures and training items related to RNAV 5 operations (e.g. initial, upgrade or recurrent training for flight crew, dispatchers or maintenance personnel).

NOTE: It is not required to establish a separate training program or regimen if RNAV training is already an integrated element of a training program. However, it should be possible to identify what aspects of RNAV are covered within a training program.

Private operators should be familiar with the practices and procedures identified in section 2.3.5, Pilot Knowledge/Training.

2.3.2.2.3 Operations Manuals and Checklists

Operations manuals and checklists for commercial operators must address information/guidance on the standard operating procedures detailed in section 2.3.4 of this chapter. The appropriate manuals should contain navigation operating instructions and contingency procedures where specified. Manuals and checklists must be submitted for review as part of the application process.

Private operators should operate using the practices and procedures identified in section 2.3.5, Pilot Knowledge/Training.

2.3.2.2.4 Minimum Equipment List (MEL) Considerations

Any minimum equipment list (MEL) revisions necessary to address RNAV 5 provisions must be approved. Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions.

2.3.3. Aircraft Requirements

RNAV 5 operations are based upon the use of RNAV equipment automatically determining aircraft position using inputs from one or a combination of the following types of position sensors, together with the means to establish and follow a desired path:

a) VOR/DME

b) DME/DME

c) INS or IRS

d) GNSS

2.3.3.1. System Accuracy

During operations in airspace or on routes designated as RNAV 5, the lateral track keeping accuracy of the on-board RNAV 5 system must be equal to or better than ±5 NM for 95% of the total flight time. This value includes signal source error, airborne receiver error, display system error and flight technical error.

Integrity and Contintuity

Acceptable means of compliance for assessment of the effects associated with the loss of navigation function or erroneous display of related information is given in EASA/AMC 25-11 paragraph 4 a (3)(viii).

The minimum level of availability and integrity required for RNAV 5 systems for use in airspace designated for RNAV 5 would normally be met by a single installed system comprising one or more sensors, RNAV computer, control display unit and navigation display(s) (e.g. ND, HSI or CDI) provided that the system is monitored by the flight crew and that in the event of a system failure the aircraft retains the capability to navigate relative to ground based navigation aids (e.g. VOR, DME and NDB).

2.3.3.2. Performance Monitoring and Alerting

N/A

2.3.3.3. Criteria for Specific Navigation Services

INS/IRS

Inertial systems may be used either as a stand alone inertial navigation system (INS) or an Inertial Reference system (IRS) acting as part of a multi-sensor RNAV system where inertial sensors provides augmentation to the basic position sensors as well as a reversionary position data source when out of cover of radio navigation sources.

INS without a function for automatic radio updating of aircraft position and approved in accordance with AC 25-4, when complying with the functional criteria of this chapter, may be used only for a maximum of 2 hours from the last alignment/position update performed on the ground. Consideration may be given to specific INS configurations (e.g. triple mix) where either equipment or aircraft manufacturer's data, justifies extended use from the last position update.

INS with automatic radio updating of aircraft position, including those systems where manual selection of radio channels is performed in accordance with flight crew procedures, should be approved in accordance with AC 90-45A, AC 20-130A or equivalent material.

VOR

VOR accuracy can typically meet the accuracy requirements for RNAV 5 up to 60NM from the navigation aid and DVOR up to 75 NM. Specific regions within the VOR coverage may experience larger errors due to propagation effects (e.g. multipath). Where such errors exist this can be accommodated by prescribing areas where the affected VOR may not be used. Alternative actions could be to take account of lower VOR performance in the setting up of the proposed RNAV routes by, for example, increasing by additional route spacing. Due account has to be taken of the availability of other navigation aids to provide coverage in the affected area and that not all aircraft may be using the VOR concerned and may therefore not exhibit the same track keeping performance.

DME

DME signals are considered sufficient to meet requirements of RNAV 5 wherever the signals are received and there is no closer DME on the same channel, regardless of the published coverage volume. Where the RNAV 5 system does not take account of published “Designated Operational Coverage” of the DME, the RNAV system must execute data integrity checks to confirm that the correct DME signal is being received.

The individual components of the NAVAID infrastructure must meet the performance requirements detailed in ICAO Annex 10. Navigation aids that are not compliant with Annex 10 should not be published in the State AIP.

GNSS

The use of GNSS to perform RNAV 5 operations is limited to equipment approved to ETSO-C129(), ETSO-C145, ETSO-C146, FAA TSO-C145a, TSO-C146a, and TSO-C129() or equivalent, and include the minimum system functions specified in section 7.

Integrity should be provided by SBAS GNSS or Receiver Autonomous Integrity Monitoring (RAIM) or an equivalent means within a multi-sensor navigation system. In addition, GPS stand-alone equipment should include the following functions:

(i) Pseudorange step detection

(ii) Health word checking.

Note: These two additional functions are required to be implemented in accordance with ETSO-C129( ) or equivalent criteria.

Where approval for RNAV 5 operations requires the use of traditional navigation equipment as a back up in the event of loss of GNSS, the required navigation aids as defined in the approval (i.e. VOR, DME and/or ADF) will need to be installed and be serviceable.

Positioning data from other types of navigation sensors may be integrated with the GNSS data provided it does not cause position errors exceeding the track keeping accuracy requirements.

2.3.3.4. Functional Requirements

The following system functions are the minimum required to conduct RNAV 5 operations.

a) Continuous indication of aircraft position relative to track to be displayed to the pilot flying on a navigation display situated in his primary field of view

b) Where the minimum flight crew is two pilots, indication of aircraft position relative to track to be displayed to the pilot not flying on a navigation display situated in his primary field of view.

c) Display of distance and bearing to the active (To) waypoint

d) Display of ground speed or time to the active (To) waypoint

e) Storage of waypoints; minimum of 4

f) Appropriate failure indication of the RNAV system, including the sensors.

RNAV 5 Navigation Displays

Navigation data must be available for display either on a display forming part of the RNAV equipment or on a lateral deviation display (CDI, (E)HSI) and/or a navigation map display.

These must be used as primary flight instruments for the navigation of the aircraft, for manoeuvre anticipation and for failure/status/integrity indication. They should meet the following requirements:

a) The displays must be visible to the pilot when looking forward along the flight path.

b) The lateral deviation display scaling should be compatible with any alerting and annunciation limits, where implemented.

c) The lateral deviation display must have a scaling and full-scale deflection suitable for the RNAV 5 Operation.

2.3.4. Operating Procedures

General

Airworthiness certification alone does not authorise flight in airspace or along routes for which RNAV 5 approval is required. Operational approval is also required to confirm the adequacy of the operator's normal and contingency procedures for the particular equipment installation.

Pre-flight Planning

Operators and pilots intending to conduct operations on RNAV 5 routes should file the appropriate flight plan suffixes indicating their approval for operation on the routes.

During the pre-flight planning phase, the availability of the NAVAID infrastructure, required for the intended routes, including any non-RNAV contingencies, must be confirmed for the period of intended operations. The pilot must also confirm availability of the onboard navigation equipment necessary for the operation.

Where a navigation data base is used, it must be current and appropriate for the region of intended operation and must include the navigation aids, waypoints required for the route.

ABAS Availability

When using GNSS for navigation, SBAS or ABAS fault detection (e.g., RAIM) functionality is required to meet Annex 10 navigation performance. Therefore, the availability of the NAVAID infrastructure, required for the intended routes, including any non-RNAV contingencies, must be confirmed for the period of intended operations using all available information. The pilot must also confirm availability of the onboard navigation equipment necessary for the route to be flown.

The availability of SBAS or ABAS fault detection can be determined through NOTAMs (if available) or through prediction for the intended RNAV 5 operation. Operators using TSO-C145/C146 receivers should check GPS RAIM availability in areas where SBAS is not usable or available. RAIM availability prediction services may be provided by the ANSP, avionics manufacturer or other entities. Operators should be familiar with the prediction information provided by any State within which they operate. Receiver RAIM prediction capability can also be used. Any prediction should take into account the latest GPS constellation NOTAMs.

In the event of a predicted, continuous loss of fault detection of more than five (5) minutes for any part of the RNAV 5 operation, the flight planning should be revised (e.g., delaying the departure or planning a different departure procedure). If the prediction service is temporarily unavailable, ANSPs may still allow RNAV 5 operations to be conducted.

RAIM availability prediction software does not guarantee the service, they are rather tools to asses the expected capability to meet the required navigation performances. Because of unplanned failure of some GNSS elements, pilots/ANSP must realize that RAIM (or GPS navigation) altogether may be lost while airborne which may require to revert to an alternative means of navigation. Therefore, pilots should assess their capability to navigate (potentially to an alternate destination) in case of failure of GPS navigation.

General Operating Procedures

Operators and pilots should not request or file RNAV 5 routes unless they satisfy all the criteria in the relevant documents. If an aircraft not meeting these criteria receives a clearance from ATC to conduct an RNAV procedure, the pilot must advise ATC that he/she is unable to accept the clearance and must request alternate instructions.

The pilot should comply with any instructions or procedures identified by the manufacturer as necessary to comply with the performance requirements in this appendix.

Pilots of RNAV 5 aircraft must adhere to any AFM limitations or operating procedures required to maintain the navigation accuracy specified for the procedure.

Where a navigation database is installed, pilots must confirm its currency.

Flight crews should crosscheck the cleared flight plan by comparing charts or other applicable resources with the navigation system textual display and the aircraft map display, if applicable. If required, the exclusion of specific navigation aids should be confirmed.

During the flight, where feasible, the flight progress should be monitored for navigational reasonableness, by cross-checks with conventional navigation aids using the primary displays in conjunction with the RNAV Control and Display Unit.

Pilots are encouraged to use a lateral deviation indicator, flight director and/or autopilot in lateral navigation mode on RNAV 5 routes. All pilots are expected to maintain route centrelines, as depicted by onboard lateral deviation indicators and/or flight guidance during all RNAV operations described in this manual unless authorized to deviate by ATC or under emergency conditions. For normal operations, cross-track error/deviation (the difference between the RNAV system computed path and the aircraft position relative to the path) should be limited to +/- ½ the navigation accuracy associated with the route (i.e., 2.5 NM). Brief deviations from this standard (e.g., overshoots or undershoots) during and immediately after route turns, up to a maximum of 1 times the navigation accuracy (i.e., 5 NM), are allowable.

NOTE 1: Some aircraft do not display or compute a path during turns. As such, pilots of these aircraft may not be able to adhere to the ±½ accuracy standard during route turns but are still expected to satisfy the standard during intercepts of the final track following the turn and on straight segments.

NOTE 2: Pilots and operators should be aware of possible lateral deviations when using raw data or navigation map displays for lateral guidance in lieu of flight director.

If ATS issues a heading assignment taking the aircraft off a route, the pilot should not modify the flight plan in the RNAV system until a clearance is received to rejoin the route or the controller confirms a new clearance. When the aircraft is not on the published route, the specified accuracy requirement does not apply.

Contingency Procedures

The pilot must notify ATC where the RNAV performance ceases to meet the requirements for RNAV 5. The communication to ATC must be in accordance with the authorised procedures (Doc 4444 or Doc 7030 as appropriate).

In the event of communications failure, the flight crew should continue with the flight plan in accordance with the published lost communication procedure.

Where stand-alone GNSS equipment is used:

a) In the event of loss of the RAIM detection function, the GNSS position may continue to be used for navigation. The flight crew should attempt to cross-check the aircraft position, with other sources of position information, (e.g. VOR, DME and/or NDB information) to confirm an acceptable level of navigation performance. Otherwise, the flight crew should revert to an alternative means of navigation.

b) In the event of a RAIM alert, the flight crew should revert to an alternative means of navigation.

2.3.5. Pilot Knowledge and Training

The following items should be addressed in the pilot training program (for example, simulator, training device, or aircraft) for the aircraft's RNAV system:

a) The capabilities and limitations of the RNAV system installed

b) The operations and airspace for which the RNAV system is approved to operate

c) The navaid limitations in respect of the operation of the RNAV system to be used for the RNAV 5 operation

d) Contingency procedures for RNAV failures

e) The R/T Phraseology for the airspace in accordance to Doc 4444 and Doc 7030 as appropriate

f) The flight planning requirements for the RNAV operation

g) RNAV requirements as determined from chart depiction and textual description.

h) RNAV system-specific information, including:

   i) Levels of automation, mode annunciations, changes, alerts, interactions, reversions, and degradation.

   ii) Functional integration with other aircraft systems.

   iii) Monitoring procedures for each phase of flight (for example, monitor PROG or LEGS page).

   iv) Types of navigation sensors (for example, DME, IRU, GNSS) utilized by the RNAV system and associated system prioritization/weighting/logic.

   v) Turn anticipation with consideration to speed and altitude effects.

   vi) Interpretation of electronic displays and symbols.

i) RNAV equipment operating procedures, as applicable, including how to perform the following actions:

   i) Verify currency of aircraft navigation data.

   ii) Verify successful completion of RNAV system self-tests.

   iii) Initialize RNAV system position.

iv) Fly direct to a waypoint

v) Intercept a course/track.

vi) Be vectored off and rejoin a procedure.

vii) Determine cross-track error/deviation.

viii) Remove and reselect navigation sensor input.

ix) When required, confirm exclusion of a specific navigation aid or navigation aid type.

x) Perform gross navigation error check using conventional navigation aids.

2.3.6. Navigation Database

Where a navigation data base is carried and used, it must be current and appropriate for the region of intended operation and must include the navigation aids, waypoints required for the route.

NOTE: Navigation databases are expected to be current for the duration of the flight. If the AIRAC cycle is due to change during flight, operators and pilots should establish procedures to ensure the accuracy of navigation data, including suitability of navigation facilities used to define the routes for flight. Traditionally, this has been accomplished by verifying electronic data against paper products.

2.3.7. Oversight of Operators

A process needs to be established whereby navigation error reports can be submitted and analysed to establish the need for remedial action. Repeated navigation error occurrences attributed to a specific piece of navigation equipment need to be followed up and action taken to remove the causal factor(s).

The nature of the error cause will determine the remedial action which could include the need for remedial training, restrictions in the application of the system or requirements for software changes in the Navigation system.

The nature and severity of the error may result in temporary cancellation of the approval for use of that equipment until the cause of the problem has been identified and rectified.

2.4. REFERENCES

EASA Acceptable means of Compliance

a) AMC 25-11 Electronic Display Systems

b) AMC 20-5 Acceptable Means of Compliance for Airworthiness Approval and Operational Criteria for the use of the NAVSTAR Global Positioning System (GPS)

FAA Advisory Circulars

a) AC 25-4 Inertial Navigation Systems (INS)

b) AC 25-15 Approval of FMS in Transport Category Airplanes

c) AC 90-45 A Approval of Area Navigation Systems for use in the U S. National Airspace System

ETSOs

a) ETSO-C115b Airborne Area Navigation Equipment Using Multi Sensor Inputs

b) ETSO-C129a Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)

c) ETSO-C145 Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS).

d) ETSO-C146 Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS)

EUROCAE/RTCA documents

a) ED-27 Minimum Operational Performance Requirements (MOPR) for Airborne Area Navigation Systems, based on VOR and DME as sensors

b) ED-28 Minimum Performance Specification (MPS) for Airborne Area Navigation Computing Equipment based on VOR and DME as sensors

c) ED-39 MOPR for Airborne Area Navigation Systems, based on two DME as sensors

d) ED-40 MPS for Airborne Computing Equipment for Area Navigation System using two DME as sensors.

e) ED-58 Minimum Operational Performance Specification (MOPS) for Area Navigation Equipment using Multi-Sensor Inputs

f) ED-72() MOPS for Airborne GPS Receiving Equipment

g) DO-180() Minimum Operational Performance Standards (MOPS) for Airborne Area Navigation Equipment Using a Single Collocated VOR/DME Sensor Input

h) DO-187 MOPS for Airborne Area Navigation Equipment Using Multi Sensor Inputs

i) DO-200 Preparation, Verification and Distribution of User-Selectable Navigation Data Bases

j) DO-201 User Recommendations for Aeronautical Information Services

k) DO-208 MOPS for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)

DOCUMENT AVAILABILITY

Copies of ICAO documents may be purchased from Document Sales Unit, International Civil Aviation Organization, 999 University Street, Montreal, Quebec, Canada H3C 5H7, (Fax: 1 514 954 6769, or e-mail: sales_unit@icao.org) or through national agencies.

Copies of ARINC documents may be obtained from Aeronautical Radio Inc., 2551 Riva Road, Annapolis, Maryland 24101-7465, USA. Web site: http://www.arinc.com

Copies of EASA documents may be obtained from EASA (European Aviation Safety Agency),101253, D-50452 Koln, Germany.

Copies of EUROCAE documents may be purchased from EUROCAE, 17 rue Hamelin, 75783 PARIS Cedex 16, France, (Fax : 33 1 45 05 72 30). Web site: http://www.eurocae.org

Copies of EUROCONTROL documents may be requested from EUROCONTROL, Documentation Centre, GS4, Rue de la Fusée, 96, B-1130 Brussels, Belgium; (Fax: 32 2 729 9109). Web site: http://www.ecacnav.com

Copies of FAA documents may be obtained from Superintendent of Documents, Government Printing Office, Washington, DC 20402-9325, USA. Web site: http://www.faa.gov/certification/aircraft/ (Regulation and Guidance Library)

Copies of JAA documents are available from JAA's publisher Information Handling Services (IHS). Information on prices, where and how to order, is available on the JAA web site, http://www.jaa.nl, and on the IHS web sites http://www.global.his.com, and http://www.avdataworks.com .

Copies of RTCA documents may be obtained from RTCA Inc., 1140 Connecticut Avenue, N.W., Suite 1020, Washington, DC 20036-4001, USA, (Tel: 1 202 833 9339). Web site www.rtca.org.

CHAPTER 3

IMPLEMENTING RNAV 1 AND RNAV 2

3.1. INTRODUCTION

3.1.1. Background

The Joint Aviation Authorities (JAA) published airworthiness and operational approval for Precision Area Navigation (P-RNAV) on 1 November 2000 through TGL-10. The Federal Aviation Administration (FAA) published guidance on U.S. Terminal and En Route Area Navigation (RNAV) Operations on 7 January 2005 through AC 90-100. While similar in functional requirements, differences exist between these two documents. ICAO sought harmonization between European and U.S. RNAV criteria with this single ICAO RNAV specification.

3.1.2. Purpose

This chapter avoids the proliferation of standards and the need for multiple regional approvals. It provides guidance to States and Air Navigation Service Providers implementing en route and terminal area navigation (RNAV) applications. For the operator, it provides a combination of European P-RNAV and U.S. RNAV criteria. For existing systems, compliance with <u>both</u> P-RNAV (TGL-10) and U.S. RNAV (FAA AC 90-100) assures automatic compliance with this ICAO specification. Operators with compliance to only TGL-10 or AC 90-100 should refer to paragraph 3.4.2 to see whether their system also gives automatic compliance to this specification. Compliance to ICAO RNAV through either of the above obviates the need for further assessment or AFM documentation. In addition, an operational approval to this specification allows an operator to conduct RNAV operations globally. The aircraft requirements for RNAV 1 and RNAV 2 are identical, while some operating procedures are different.

RNAV 1 and RNAV 2 navigation specifications were primarily developed for RNAV operations in a radar environment (for SIDs, radar coverage is expected prior to the first RNAV course change). The navigation specification is applicable to all ATS routes, including routes in the en route domain, Standard Instrument Departures (SIDs) and Standard Arrival Routes (STARS). The Basic-RNP 1 navigation specification is intended for similar operations outside radar coverage on SIDs and STARs. However, RNAV 1 and RNAV 2 may be used in a non radar environment or below MRA if the implementing State ensures appropriate system safety, accounting for lack of performance monitoring and alerting.

RNAV 1 and RNAV 2 routes are envisioned to be conducted in direct controller pilot communication environments.

This chapter does *not* address all requirements that may be specified for operation on a particular route or in a particular area. These requirements are specified in other documents such as operating rules, aeronautical information publications (AIPs) and the ICAO *Regional Supplementary Procedures* (Doc 7030). While operational approval primarily relates to the navigation requirements of the airspace, operators and flight crew are still required to take account of all operational documents relating to the airspace required by the appropriate State authority before conducting flights into that airspace.

3.1.3. Terminology

An explanation of the following terms is provided:

RNAV 2 Routes/SIDs/STARs. RNAV 2 requires a total system error of not more than 2 NM for 95% of the total flight time.

RNAV 1 Routes/SIDs/STARs. RNAV 1 requires a total system error of not more than 1 NM for 95% of the total flight time.

3.2. ANSP CONSIDERATIONS

The ANSP is responsible for the development of the route as described in Volume 1, part B, chapter 2. Changes in the route or available NAVAID infrastructure should be accomplished in accordance with the guidance in that chapter.

3.2.1. Navaid Infrastructure

The route design should take account of the navigation performance, achievable with the available NAVAID infrastructure, and the functional capabilities required by this document. While the aircraft's navigation equipment requirements for RNAV 1 and RNAV 2 are identical, NAVAID infrastructure impacts the achievable performance. Accommodation of existing user equipment should be considered a primary goal. The following navigation criteria are defined: GNSS, DME/DME, and DME/DME/IRU. Where DME is the only navigation service used for position updates, gaps in DME coverage can prevent position update. The size of the gap that can be accepted while meeting the accuracy requirement will depend upon the on-board equipment. For example, integration of Inertial Reference Units can permit extended gaps in coverage. If an IRU is not carried then only air data (airspeed and heading) together with the learned wind data, are available to support position updating during the gaps. In such cases additional protection, in accordance with ICAO 8168 PANS-OPS, will be needed to cater for the increased error. In light of the *Global Air Navigation Plan for CNS/ATM Systems* (Doc 9750), GNSS should be authorized whenever possible and limitations on the use of specific system elements should be avoided.

NOTE: Most modern RNAV systems will prioritize inputs from GNSS and then DME/DME positioning. Although VOR/DME positioning is usually performed within a flight management computer when DME/DME positioning criteria does not exist, avionics and infrastructure variability pose serious challenges to standardization. Therefore, the criteria in this document only discusses GNSS, DME/DME and DME/DME/IRU. This does not preclude the conduct of operations by systems that also use VOR provided they satisfy the criteria in paragraph 3.3.

The NAVAID infrastructure should be validated by modelling, and the anticipated performance should be adequately assessed and, where necessary, flight checked. The assessment should consider the aircraft capability described in this Chapter. For example, a DME signal can only be assured for use if the aircraft is between 3 NM and 160 NM from the facility, below 40 degrees above the horizon (as viewed from the facility) and if the DME/DME include angle is between 30^o and 150^o. DME infrastructure assessment is significantly simplified when using a suitable screening tool which accurately matches ground infrastructure and aircraft performance and uses an accurate representation of the terrain. Guidance material concerning this assessment can be found in PANS-OPS and ICAO Doc 8071.

DME signals are considered to meet signal-in-space accuracy tolerances everywhere the signals are received, regardless of the published coverage volume. Errors resulting from field strength below the minimum requirement or where co-channel or adjacent-channel interference may exist are considered receiver errors and are addressed in paragraph 3.3.3. Errors resulting from multipath of the DME signal should be identified by the ANSP. Where such errors exist and are not acceptable to the operation, the ANSP may identify such aids as not appropriate for RNAV 1 and RNAV 2 applications (to be inhibited by the flight crew) or may not authorize the use of DME/DME or DME/DME/IRU. The individual components of the NAVAID infrastructure must meet the performance requirements detailed in ICAO Annex 10. Navigation aids that are not compliant with Annex 10 should not be published in the State AIP. If significant performance differences are measured for a published DME facility, RNAV 1 and RNAV 2 operations in airspace affected by that facility may need to be limited to GNSS.

For RNAV operations where reliance is placed upon IRS, some aircraft systems revert to VOR/DME-based navigation before reverting to inertial coasting. The impact of VOR radial accuracy, when the VOR is within 40 NM from the route and there is insufficient DME/DME NAVAID infrastructure, must be evaluated by the ANSP to ensure that it does not affect aircraft position accuracy.

The available NAVAID infrastructure should be clearly designated on all appropriate charts (for example, GNSS, DME/DME or DME/DME/IRU).

Any DME facilities that are critical to RNAV 1 or RNAV 2 operations should be identified in the relevant publications.

ANSPs should ensure operators of GNSS-equipped aircraft have access to a means of predicting the availability of fault detection using ABAS (e.g., RAIM). Where applicable, ANSPs should also ensure operators of SBAS-equipped aircraft have access to a means of predicting the availability of fault detection. This prediction service may be provided by the ANSP, airborne equipment manufacturers or other entities. Prediction services can be for receivers meeting only the minimum TSO performance or be specific to the receiver design. The prediction service should use status information on GNSS satellites, and should use a horizontal alert limit appropriate to the operation (1 NM for RNAV 1 and 2 NM for RNAV 2). Outages should be identified in the event of a predicted, continuous loss of ABAS fault detection of more than five (5) minutes for any part of the RNAV 1 and RNAV 2 operation. If the prediction service is temporarily unavailable, ANSPs may still allow RNAV 1 and RNAV 2 operations to be conducted, considering the operational impact of aircraft reporting outages or the potential risk associated with an undetected satellite failure when fault detection is not available.

Since DME/DME RNAV systems must only use DME facilities identified in State AIPs, the State must indicate facilities inappropriate for RNAV 1 and RNAV 2 operation in the AIP or facilities associated with an ILS or MLS using a range offset.

NOTE 1: Database suppliers may exclude specific DME facilities, which have a deleterious effect on the navigation solution from the aircraft's navigation database when the RNAV routes are within reception range of these DME facilities.

NOTE 2: Where temporary restrictions occur, the publication of restrictions on the use of DME should be accomplished by use of NOTAM to identify the need to exclude the DME.

3.2.2. Communication & ATS Surveillance

Where reliance is placed on the use of radar to assist contingency procedures, its performance should be adequate for that purpose. This means that the Radar coverage, its accuracy, continuity and availability should be adequate to ensure separation on the RNAV 1 and RNAV 2 ATS Route structure and provide contingency in cases where several aircraft are unable to achieve the navigation performance prescribed in this navigation specification.

3.2.3. Obstacle Clearance and Route Spacing

Obstacle clearance guidance is provided in PANS-OPS (Doc 8168, Volume II). The general criteria in Part 1 and Part 3 apply; together with the following additional specific criteria:

a) RNAV-1

i) Where a GNSS infrastructure is provided, apply the criteria from Doc 8168, Volume II, Part III, Section 1, Chapter 2 and the chapter in Section 3 for the appropriate phase of flight.

ii) Where a DME/DME NAVAID infrastructure is provided apply the criteria for three-DME cover from Doc 8168, Volume II, Part III, Section 1, Chapter 3 and the chapter in Section 3 for the appropriate phase of flight. If the infrastructure does not support continuous DME/DME updating, consider basing the route on DME/DME/IRU or expanding the route width to accommodate a gap in coverage.

iii) Where both a GNSS and a DME/DME NAVAID infrastructure are provided, apply the greater semi-area width from the two sets of criteria.

b) RNAV 2

i) Where a GNSS infrastructure is provided, apply the en-route criteria from Doc 8168, Volume II, Part III, Section 1, Chapter 2 and Section 3, Chapter 8.

ii) Where a DME/DME NAVAID infrastructure is provided, apply the criteria for pre-1989 two-DME cover from Doc 8168, Volume II, Part III, Section 1, Chapter 3 and Section 3, Chapter 8. If the infrastructure does not support continuous DME/DME updating, consider basing the route on DME/DME/IRU or expanding the route width to accommodate a gap in coverage.

iii) Where both a GNSS and a DME/DME NAVAID infrastructure are provided, apply the greater semi-area width from the two sets of criteria.

States may prescribe RNAV 1 or RNAV 2 ATS routes. Route spacing for RNAV 1 and RNAV 2 depends on the route configuration, air traffic density and intervention capability. Until specific standards and ATM procedures are developed, RNAV 1 and RNAV 2 applications can be implemented based on radar ATS Surveillance.

3.2.4. Additional Considerations

Many aircraft have the capability to fly a path parallel to, but offset left or right from, the original active route. The purpose of this function is to enable offsets for tactical operations authorized by ATC.

Many aircraft have the capability to execute a holding pattern manoeuvre using their RNAV system. The purpose of this function is to provide flexibility to ATC in designing RNAV operations.

Guidance in this chapter does not supersede appropriate State operating requirements for equipage.

3.2.5. Publication

The AIP should clearly indicate whether the navigation application is RNAV 1 or RNAV 2.

The route should rely on normal descent profiles and identify minimum segment altitude requirements.

The navigation data published in the State AIP for the routes and supporting navigation aids must meet the requirements of ICAO Annex 15.

All routes must be based upon WGS 84 coordinates

3.2.6. Controller Training

Air traffic controllers providing area and/or approach control services in an ATC unit where RNAV is implemented, should have completed training in the following:

a) RNAV capable systems e.g. DME/DME, DME/DME/IRU and GNSS

b) RNAV systems accuracy, integrity, availability and continuity;

c) RNAV equipment airworthiness requirements and operational approvals;

d) RNAV approach and related procedures;

e) Waypoint fly-by vs. fly-over concept;

f) RNAV overlay procedures;

g) Effect of signal coverage, distance from NAVAIDs and altitude on RNAV accuracy;

h) RNAV longitudinal separation;

i) RNAV lateral separation;

j) Effect of on-board performance monitoring and alerting on route spacing and lateral separation;

k) RNAV STAR and SID routes;

l) GNSS receiver, RAIM integrity concept, integrity alerts, and Fault Detection and Exclusion (FDE); and

m) RNAV related phraseology.

3.2.7. Status monitoring

The status of critical NAVAID infrastructure should be monitored and, where appropriate, maintained by the service provider and timely warnings of outages (NOTAM) should be issued.

3.2.8. ATS System Monitoring

Demonstrated navigation accuracy provides a basis for determining the lateral route spacing and separation minima necessary for traffic operating on a given route. When available, radar observations of each aircraft's proximity to track and altitude are typically noted by Air Traffic Service (ATS) facilities and aircraft track-keeping capabilities are analyzed.

If an observation/analysis indicates that a loss of separation or obstacle clearance has occurred, the reason for the apparent deviation from track or altitude should be determined and steps taken to prevent a recurrence.

3.3. NAVIGATION SPECIFICATION

3.3.1. Background

This chapter identifies the operational requirements for RNAV 1 and RNAV 2 operations. Operational compliance with these requirements should be addressed through national operational regulations, and may require a specific operational approval in some cases. For example, JAR OPS 1 requires operators to apply to the State of the Operator/Registry, as appropriate, for operational approval.

This RNAV 1 and RNAV 2 specification constitutes harmonization between European Precision RNAV (P-RNAV) and U.S. RNAV criteria. Aircraft approved to RNAV 1 and RNAV 2 are automatically approved to operate within the United States or airspace of the member states of the European Civil Aviation Conference (ECAC).

3.3.2. Approval Process

The following steps must be completed before conducting RNAV 1 and RNAV 2 operations:

a) Aircraft equipment eligibility must be determined and documented, which may be accomplished taking credit for prior approval to P-RNAV or US-RNAV. A comparison of TGL-10 and AC 90-100 is provided in this section;

b) Operating procedures for the navigation systems to be used and the operator navigation database process must be documented;

c) Flight crew training based upon the operating procedures must be documented;

d) The above material must be accepted by the State regulatory authority; and

e) Operational approval should then be obtained in accordance with national operating rules.

Following the successful completion of the above steps, an RNAV 1 and/or RNAV 2 operational approval, letter of authorization or appropriate operations specification (Ops Spec), if required, should then be issued by the State.

3.3.2.1. Aircraft Eligibility

The aircraft eligibility has to be determined through demonstration of compliance against the relevant airworthiness criteria e.g., TGL No. 10 or AC 90-100. The OEM or the holder of installation approval for the aircraft e.g., STC holder, will demonstrate the compliance to their National Airworthiness Authority (NAA) (e.g., EASA, FAA) and the approval can be documented in manufacturer documentation (e.g., Service Letters, etc.). Aircraft Flight Manual (AFM) entries are not required provided the State accepts manufacturer documentation.

3.3.2.2. Operational Approval

The assessment of a particular operator is made by the State of Registry for that operator and in accordance with national operating rules (e.g., JAR-OPS 1, 14 CFR Part 121) supported through the advisory and guidance material found in documents such as TGL No. 10 and AC 90-100. The assessment should take into account:

a) Evidence of aircraft eligibility

b) Assessment of the operating procedures for the navigation systems to be used

c) Control of those procedures through acceptable entries in the Operations Manual

d) Identification of flight crew training requirements

e) Where required, control of navigation database process

NOTE: It is envisaged that an operational approval against either TGL No. 10 or AC 90-100 can lead to compliance with requirements in any RNAV 1 or RNAV 2 designated route, subject to the approval process mentioned below. The assessment, including the flight crew operating procedures and training, are linked to the aircraft operation and should take into account specific local requirements.

The operational approval will likely be documented through the State endorsing the Air Operators Certificate (AOC) through issue of a letter of authorisation, appropriate operations specification (Ops Spec) or amendment to the operations manual.

3.3.2.2.1 Description of aircraft equipment

The operator must have a configuration list detailing pertinent components and equipment to be used for RNAV 1 or RNAV 2.

3.3.2.2.2 Training documentation

Commercial operators should have a training program addressing the operational practices, procedures and training items related to RNAV 1 and RNAV 2 operations (e.g. initial, upgrade or recurrent training for flight crew, dispatchers or maintenance personnel).

NOTE: It is not required to establish a separate training program or regimen if RNAV training is already an integrated element of a training program. However, it should be possible to identify what aspects of RNAV are covered within a training program.

Private operators should be familiar with the practices and procedures identified in section 3.3.5, Pilot Knowledge/Training.

3.3.2.2.3 Operations manuals and checklists

Operations manuals and checklists for commercial operators must address information/guidance on the standard operating procedures detailed in section 3.3.4 of this chapter. The appropriate manuals should contain navigation operating instructions and contingency procedures where specified. Manuals and checklists must be submitted for review as part of the application process.

Private operators should operate using the practices and procedures identified in section 3.3.5, Pilot Knowledge/Training.

3.3.2.2.4 Minimum Equipment List (MEL) Considerations

Any minimum equipment list (MEL) revisions necessary to address RNAV 1 and RNAV 2 provisions must be approved. Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions.

3.3.2.3. PBN Navigation Specification and the Approval Process

The Navigation Specification found in the Performance Based Navigation Manual does not in itself constitute regulatory guidance material against which either the aircraft or the operator will be assessed and approved. OEMs manufacture their products against an airworthiness basis containing the basic code for the aircraft type and the relevant guidance material held in Advisory Material. Operators will be approved against their National Operating Rules. The Navigation Specification provides the technical and operational criteria. Therefore, with RNAV 1 and RNAV 2 there is still a need to have the instruments for approval, either through a dedicated approval document or through recognition that existing regional RNAV implementation certification documents (TGL No. 10 and AC 90-100) can be applied with the necessary differences, to satisfy the objectives set out in the PBN Navigation Specification.

3.3.2.4. Migration Path to RNAV 1 and RNAV 2

The following steps identify the transition path to RNAV 1 and RNAV 2.

Operator Holding No Approval

An operator wishing to fly into RNAV 1 or RNAV 2 designated airspace:

a) First establish the aircraft eligibility. This may be accomplished through prior documentation of compliance to the requirements of this navigation specification (e.g., compliance with AC 90-100A), or to TGL No. 10 or AC 90-100 and then the differences to achieve an acceptable means of compliance to RNAV 1 and RNAV 2. Armed with evidence of aircraft eligibility, the operator will then be required to obtain the necessary operational approval from their State Authority who should again refer to the existing material and the deltas that satisfy the RNAV 1 or RNAV 2 standard.

b) An operator approved against the criteria for RNAV 1 and RNAV 2 is eligible to operate on US RNAV Type A and Type B and European P-RNAV routes and no further approval is required.

c) An operator wishing to fly in just airspace designated for P-RNAV; should obtain a P-RNAV approval against TGL No. 10.

d) An operator wishing to fly on just US RNAV Type A and Type B routes; should obtain an approval against AC 90-100.

Operator Already Holding P-RNAV Approval

An operator already holding a P-RNAV approval in accordance with TGL No. 10:

a) Is eligible to operate in any State where routes are predicated on TGL-10,

b) Must obtain an operational approval, with evidence provided of compliance against the deltas from TGL No. 10 to the criteria of the RNAV 1 and/or RNAV 2 Navigation Specification in order to fly into airspace designated as RNAV 1 or RNAV 2. This must be accomplished through RNAV 1 and/or RNAV 2 approval following Table 3-1.

Table 3-1: Additional Requirements for obtaining an RNAV 1 and RNAV 2 approval from a TGL-10 approval

Operator has TGL-10	**Needs to confirm these performance capabilities to ICAO RNAV 1 and RNAV 2**	**Note**
If approval includes use of DME/VOR. (DME/VOR may only be used as the only positioning input where this is explicitly allowed.)	RNAV 1 does not accommodate any routes based on DME/VOR RNAV.	RNAV system performance must be based on GNSS, DME/DME, or DME/DME/IRU. However, DME/VOR inputs do not have to be inhibited or deselected.
If approval includes use of DME/DME	No action required if RNAV system performance meets specific navigation service criteria in this Chapter, 3.3.3.3.2 (DME/DME only) or 3.3.3.3.3 (DME/DME/IRU)	Operator can ask manufacturer or check FAA website for list of compliant systems - see Note below this table.
RNAV SID Specific Requirement with DME/DME Aircraft	RNAV guidance available no later than 500ft AFE on AC 90-100 Type B routes	Operator should add these operational procedures.
If approval includes use of GNSS	No action required	

Note. –
http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/afs400/afs410/policy_guidance/

Operator Already Holding US RNAV AC 90-100 Approval

An operator already holding an approval in accordance with FAA AC 90-100:

a) Is eligible to operate in any State where routes are predicated on AC 90-100,

b) Must obtain an operational approval, with evidence provided of compliance against the deltas from AC 90-100 to the criteria of the RNAV 1 and RNAV 2 Navigation in order to fly into airspace designated as RNAV 1 or RNAV 2. This must be accomplished through the RNAV 1 and RNAV 2 approval following Table 3-2.

Note: In many cases, the OEMs have already made an airworthiness assessment of their systems against both the TGL No. 10 and AC 90-100 standards and can provide supporting *evidence through Service Letters or AFM statements that compliance has been shown. The operational differences are limited to the navigation database being obtained from an accredited source. In this way, the regulatory effort from migrating from one approval to another should be minimised, avoiding the need for time consuming re-investigation and costly assessment.*

Table 3-2: Additional Requirements for obtaining RNAV 1 and RNAV 2 approval from an AC 90-100 approval

Operator has AC 90-100	***Needs to confirm these performance capabilities to ICAO RNAV 1/RNAV 2***	***Note***
If approval based on GNSS	GPS pseudorange step detector and GPS health word checking is required in accordance with TSO C129a/ETSO C129a.	Operator should check if pseudorange step detector and health word checking is supported by the installed GPS receiver or check if GPS receiver is approved in accordance with TSO C129a/ETSO C129a.
No navigation database updating process required under AC 90-100.	Data supplier and avionics data supplier must have letter of acceptance (LOA) in accordance with this chapter, paragraph 3.3.3.4.m.	Operator should ask data supplier for status

3.3.2.5. Summary of RNAV 1 / TGL-10 / AC 90-100 Insignificant Differences

Appendix 1 contains a list of insignificant differences between TGL-10 and AC 90-100.

3.3.3. Aircraft Requirements

Navigation systems. RNAV 1 and RNAV 2 operations are based upon the use of RNAV equipment that automatically determines aircraft position in the horizontal plane using inputs from the following types of position sensors (no specific priority).

a) Global Navigation Satellite System (GNSS) in accordance with FAA TSO-C145A, TSO-C146A, or TSO-C129/C129a. Positioning data from other types of navigation sensors may be integrated with the GNSS data provided it does not cause position errors exceeding the total system accuracy requirements. The use of GNSS equipment approved to TSO-C129 () is limited to those which include the minimum system functions specified in section 3.3.3.4. As a minimum, integrity should be provided by an aircraft-based augmentation system. In addition, GNSS stand-alone equipment should include the following additional functions:

   (i) Pseudorange step detection

   (ii) Health word checking.

b) DME/DME RNAV equipment complying with the criteria listed in section 3.3.3.3.2.

c) DME/DME/IRU RNAV equipment complying with the criteria listed in section 3.3.3.3.3.

3.3.3.1. System accuracy

During operations on routes designated as RNAV 2, the lateral total system error of the on-board RNAV 2 system must be equal to or better than 2 NM for 95% of the total flight time. During operations on routes designated as RNAV 1, the lateral total system error of the on-board RNAV

1 system must be equal to or better than 1 NM for 95% of the total flight time. Also, the aircraft along-track positioning error must be no greater than ±2 NM for 95 per cent of the flight time for RNAV 2, and no greater than ±1 NM for 95 per cent of the flight time for RNAV 1. The total system error is dependent on the signal-in-space error, airborne receiver error, path definition error, display error and Flight Technical Error (FTE).

Flight technical error: An FTE of 0.5 NM (95%) is acceptable for RNAV 1 operations. An FTE of 1.0 NM (95%) is acceptable for RNAV 2 operations. An acceptable means of complying with these accuracy requirements is to have a Basic GNSS system in accordance with section 3.3.3.3.1, a DME/DME RNAV system in accordance with section 3.3.3.3.2, or a DME/DME/IRU system in accordance with section 3.3.3.3.3.

3.3.3.2. Performance Monitoring and Alerting

If not equipped with GNSS, aircraft must be capable of navigation system updating using DME/DME or DME/DME/IRU. For routes and/or aircraft approvals requiring GNSS, if the navigation system does not automatically alert the flight crew of a loss of GNSS, the operator must develop procedures to verify correct GNSS operation.

3.3.3.3. Criteria For Specific Navigation Services

3.3.3.3.1 Criteria for GNSS

The following systems meet the accuracy requirements of these criteria.

a) Aircraft with TSO-C129/C129a sensor (Class B or C) and the requirements in a TSO-C115B FMS, installed for IFR use in accordance with FAA AC 20-130A.

b) Aircraft with TSO-C145a sensor, and the requirements in a TSO-C115B FMS, installed for IFR use IAW FAA AC 20-130A or AC 20-138A.

c) Aircraft with TSO-C129/C129a Class A1 (without deviating from the functionality described in 3.3.3.4) installed for IFR use IAW FAA AC 20-138 or AC 20-138A.

d) Aircraft with TSO-C146a (without deviating from the functionality described in section 3.3.3.4 of this document) installed for IFR use IAW AC 20-138A.

3.3.3.3.2 Criteria for Distance Measuring Equipment (DME/DME RNAV System)

Paragraph	Criteria	Explanation
a)	Accuracy is based on the performance standards of TSO-C66c.	
b)	Tuning and Updating Position of DME Facilities	The DME/DME RNAV system must: (i) Position update within 30 seconds of tuning DME navigation facilities. (ii) Auto-tune multiple DME facilities. (iii) Provide continuous DME/DME position updating. (Given a third DME facility or a second pair has been available for at least the previous 30 seconds, there must be no interruption in DME/DME positioning when the RNAV system switches between DME stations/pairs.)
c)	Using Facilities in the State AIPs	DME/DME RNAV systems must only use DME facilities identified in State AIPs. Systems must not use facilities indicated by the State

		as inappropriate for RNAV 1 and/or RNAV 2 operation in the AIP or facilities associated with an ILS or MLS that uses a range offset. This may be accomplished by: i) Excluding specific DME facilities, which are known to have a deleterious effect on the navigation solution, from the aircraft's navigation database when the RNAV routes are within reception range of known these DME facilities. ii) Using an RNAV system which performs reasonableness checks to detect errors from all received DME facilities and excludes these facilities from the navigation position solution when appropriate (e.g., preclude tuning co-channel DME facilities when the DME facilities signals-in-space overlap). See the guidance on testing of reasonableness checks beginning in section 3.3.3.3.2.l.
d)	DME Facility Relative Angles	When needed to generate a DME/DME position, the RNAV system must use, as a minimum, DMEs with a relative include angle between 30° and 150°.
e)	RNAV System Use of DMEs	The RNAV system may use any valid receivable DME facility (listed in the AIP) regardless of its location. A valid DME facility: i) Broadcasts an accurate facility identifier signal, ii) Satisfies the minimum field strength requirements, and iii) Is protected from other interfering DME signals according to the co-channel and adjacent channel requirements. When needed to generate a DME/DME position, as a minimum, the RNAV system must use an available and valid terminal (low altitude) and/or en route (high altitude) DME anywhere within the following region around the DME facility: i) Greater than or equal to 3 NM from the facility; and ii) Less than 40 degrees above the horizon when viewed from the DME facility and out to 160 NM. *Note: The use of a figure-of-merit in approximating the domain of coverage of a particular facility is accepted, provided precautions are taken to ensure that the figure-of-merit is coded so that the aircraft will use the facility everywhere within the DOC. The use of DMEs associated with ILS or MLS is not required.*
f)	No Requirement to Use VOR, NDB, LOC, IRU or AHRS	There is no requirement to use VOR (VHF omni-range), LOC (localizer), NDB (non-directional beacon), IRU (inertial reference unit) or AHRS (attitude heading reference system) during normal operation of the DME/DME RNAV system.
g)	Position Estimation Error	When using a minimum of two DME facilities satisfying the criteria in paragraph 3.3.3.3.2.e, and any other DME facilities not meeting that criteria, the 95% position estimation error must be better than or equal to the following equation: $$2\sigma_{DME/DME} \le 2\frac{\sqrt{(\sigma^2_{1,air}+\sigma^2_{1,sis})+(\sigma^2_{2,air}+\sigma^2_{2,sis})}}{\sin(\alpha)}$$ Where: σ_{sis} = 0.05 NM

		σ_{air} is MAX {(0.085 NM, (0.125% of distance)} α = inclusion angle (30^o to 150^o) *NOTE: This performance requirement is met for any navigation system that uses two DME stations simultaneously, limits the DME inclusion angle to between 30° and 150° and uses DME sensors that meet the accuracy requirements of TSO-C66c. If the RNAV system uses DME facilities outside of their published designated operational coverage, the DME signal-in-space error of valid facilities can still be assumed to be σ_{ground}=0.05 NM.*
h)	Preventing Erroneous Guidance from Other Facilities	The RNAV system must ensure the use of facilities outside their service volume (where the minimum field strength, co-channel and adjacent-channel interference requirements may not be satisfied) do not cause erroneous guidance. This could be accomplished by including reasonableness checking when initially tuning a DME facility or excluding a DME facility when there is a co-channel DME within line-of-sight.
i)	Preventing Erroneous VOR Signals-in-Space	VOR may be used by the RNAV system. However, the RNAV system must ensure an erroneous VOR signal-in-space does not affect the position error when in DME/DME coverage. For example, this may be accomplished by weighting and/or monitoring the VOR signal with DME/DME to ensure it does not mislead position results (for example, through reasonableness checks (see section 3.3.3.3.2.l)).
j)	Ensuring RNAV Systems Use Operational Facilities	The RNAV system must use operational DME facilities. DME facilities listed by NOTAM as unavailable (for example, under test or other maintenance) could still reply to an airborne interrogation. (Therefore, non-operational facilities must not be used.) An RNAV system may exclude non-operational facilities by checking the identification or inhibiting the use of facilities identified as not operational.
k)	Operational Mitigations	Operational mitigations such as pilot monitoring of the RNAV system's navigation updating source(s), or time intensive programming/ blackballing of multiple DME stations, should be performed before any workload intensive or critical phase of flight. *NOTE: Blackballing single facilities listed by NOTAM as out-of-service and/or programming route-defined "critical" DME is acceptable when this mitigation requires no pilot action during a critical phase of flight. A programming requirement also does not imply the pilot should complete manual entry of DME facilities which are not in the navigation database.*
l)	Reasonableness Checks	Many RNAV systems perform a reasonableness check to verify valid DME measurements. Reasonableness checks are very effective against database errors or erroneous system acquisition (such as co-channel facilities), and typically fall into two classes: (i) Those the RNAV system uses after it acquires a new DME, where it compares the aircraft's position before using the DME to the aircraft's range to the DME, and (ii) Those the RNAV system continuously uses, based on redundant information (for example, extra DME signals or IRU data). **General Requirements.** The reasonableness checks are intended

		to prevent navigation aids from being used for navigation update in areas where the data can lead to radio position fixing errors due to co-channel interference, multipath, and direct signal screening. In lieu of using radio navigation aid published service volume, the navigation system should provide checks, which preclude use of duplicate frequency NAVAIDs within range, over-the-horizon NAVAIDs, and use of NAVAIDs with poor geometry. **Assumptions.** Under certain conditions, reasonableness checks can be invalid: (i) A DME signal does not remain valid just because it was valid when acquired. (ii) Extra DME signals may not be available. The intent of this specification is to support operations where the infrastructure is minimal (for example, when only two DMEs are available for parts of the route). **Use of Stressing Conditions to Test Effectiveness.** When a reasonableness check is used to satisfy any requirement in these criteria, the effectiveness of the check must be tested under stressing conditions. An example of this condition is a DME signal that is valid at acquisition and ramps off during the test (similar to what a facility under test might do), when there is only one other supporting DME or two signals of equal strength.

3.3.3.3.3 Criteria For Distance Measuring Equipment and Inertial Reference Unit (IRU) (DME/DME/IRU RNAV System)

This section defines the minimum DME/DME/IRU (or abbreviated D/D/I) RNAV system baseline performance. The performance standards for the DME/DME positioning are as detailed in section 3.3.3.3.2.

Paragraph	Criteria	Explanation
a)	Inertial system performance must satisfy the criteria of US 14 CFR Part 121, Appendix G.	
b)	Automatic position updating capability from the DME/DME solution is required.	*NOTE: Operators/pilots should contact manufacturers to discern if any annunciation of inertial coasting is suppressed following loss of radio updating.*
c)	Since some aircraft systems revert to VOR/DME-based navigation before reverting to inertial coasting, the impact of VOR radial accuracy, when the VOR is greater than 40 NM from the aircraft, must not affect aircraft position accuracy.	One means of accomplishing this objective is for RNAV systems to exclude VORs greater than 40 NM from the aircraft.

3.3.3.4. Functional Requirements – Navigation Displays and Functions

Paragraph	Functional Requirement	Explanation
a)	Navigation data, including a	**Non-numeric lateral deviation display (for example,**

	to/from indication and a failure indicator, must be displayed on a lateral deviation display (CDI, (E)HSI) and/or a navigation map display. These must be used as primary flight instruments for the navigation of the aircraft, for manoeuvre anticipation and for failure/status/integrity indication. They must meet the following requirements:	**CDI, (E)HSI), with a To/From indication and a failure annunciation, for use as primary flight instruments for navigation of the aircraft, for manoeuvre anticipation, and for failure/status/integrity indication, with the following five attributes:** 1) The displays must be visible to the pilot and located in the primary field of view (± 15 degrees from pilot's normal line of sight) when looking forward along the flight path. 2) The lateral deviation display scaling should agree with any alerting and annunciation limits, if implemented. 3) The lateral deviation display must also have a full-scale deflection suitable for the current phase of flight and must be based on the required total system accuracy. 4) The display scaling may be set automatically by default logic or set to a value obtained from a navigation database. The full-scale deflection value must be known or must be available for display to the pilot commensurate with en route, terminal, or approach values. 5) The lateral deviation display must be automatically slaved to the RNAV computed path. The course selector of the deviation display should be automatically slewed to the RNAV computed path. As an alternate means, a navigation map display should give equivalent functionality to a lateral deviation display as described in section 3.3.3.4.a (1-5), with appropriate map scales (scaling may be set manually by the pilot), and giving equivalent functionality to a lateral deviation display.
b)	The following system functions are required as a minimum within any RNAV 2 or RNAV 1 equipment:	1) The capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft (primary navigation display), the RNAV computed desired path and aircraft position relative to the path. For operations where the required minimum flight crew is two pilots, the means for the pilot not flying to verify the desired path and the aircraft position relative to the path must also be provided. 2) A navigation database, containing current navigation data officially promulgated for civil aviation, which can be updated in accordance with the Aeronautical Information Regulation and Control (AIRAC) cycle and from which ATS routes be retrieved and loaded into the RNAV system. The stored resolution of the data must be sufficient to achieve negligible path definition error. The database must be protected against pilot modification of the stored data. 3) The means to display the validity period of the navigation data to the pilot. 4) The means to retrieve and display data stored in

		the navigation database relating to individual waypoints and navigation aids, to enable the pilot to verify the route to be flown. 5) Capacity to load from the database into the RNAV system the entire RNAV segment of the SID or STAR to be flown. *NOTE: Due to variability in RNAV systems, this document defines the RNAV segment from the first occurrence of a named waypoint, track, or course to the last occurrence of a named waypoint, track, or course. Heading legs prior to the first named waypoint or after the last named waypoint do not have to be loaded from the database.*
c)	The means to display the following items, either in the pilot's primary field of view, or on a readily accessible display page:	1) The active navigation sensor type 2) The identification of the active (To) waypoint 3) The ground speed or time to the active (To) waypoint 4) The distance and bearing to the active (To) waypoint
d)	The capability to execute a "Direct to" function	
e)	The capability for automatic leg sequencing with the display of sequencing to the pilot.	
f)	The capability to execute ATS routes extracted from the onboard database including the capability to execute fly-over and fly-by turns.	
g)	The aircraft must have the capability to automatically execute leg transitions and maintain tracks consistent with the following ARINC 424 path terminators, or their equivalent. • Initial Fix (IF) • Course to Fix (CF) • Direct to Fix (DF) • Track to Fix (TF)	*NOTE 1: Path terminators are defined in ARINC Specification 424, and their application is described in more detail in RTCA documents DO-236B and DO-201A.* *NOTE 2: Numeric values for courses and tracks must be automatically loaded from the RNAV system database.*
h)	The aircraft must have the capability to automatically execute leg transitions consistent with VA, VM and VI ARINC 424 path terminators, or must be able to be manually flown on a heading to intercept a course or to go direct to another fix after reaching a procedure-specified altitude.	

i)	The aircraft must have the capability to automatically execute leg transitions consistent with CA and FM ARINC 424 path terminators, or the RNAV system must permit the pilot to readily designate a waypoint and select a desired course to or from a designated waypoint.	
j)	The capability to load an RNAV ATS route from the database, by route name, into the RNAV system is a recommended function. However, if all or part of the RNAV route (not SID or STAR) is entered through the manual entry of waypoints from the navigation database, the paths between a manually entered waypoint and the preceding and following waypoint must be flown in the same manner as a TF leg in terminal airspace.	
k)	The capability to display an indication of the RNAV system failure, including the associated sensors, in the pilot's primary field of view.	
l)	For multi-sensor systems, the capability for automatic reversion to an alternate RNAV sensor if the primary RNAV sensor fails. This does not preclude providing a means for manual navigation source selection.	
m)	Database Integrity	The navigation database suppliers should comply with RTCA DO-200A/EUROCAE document ED 76, Standards for Processing Aeronautical Data (see paragraph 3.3.6). A Letter of Acceptance (LOA) issued by the appropriate regulatory authority demonstrates compliance with this requirement. Discrepancies that invalidate a route must be reported to the navigation database supplier and affected routes must be prohibited by an operator's notice to its flight crew. Aircraft operators should consider the need to conduct periodic checks of the operational navigation databases in order to meet existing quality system requirements.

3.3.4. Operating Procedures

Airworthiness certification alone does not authorise flight in airspace or along routes for which RNAV 2 or RNAV 1 approval is required. Operational approval is also required to confirm the adequacy of the operator's normal and contingency procedures for the particular equipment installation.

3.3.4.1. Pre-flight Planning

Operators and pilots intending to conduct operations on RNAV and RNAV 2 routes should file the appropriate flight plan suffixes.

The onboard navigation data must be current and appropriate for the region of intended operation and must include the navigation aids, waypoints, and relevant coded ATS routes for the departure, arrival, and alternate airfields.

NOTE: Navigation databases are expected to be current for the duration of the flight. If the AIRAC cycle is due to change during flight, operators and pilots should establish procedures to ensure the accuracy of navigation data, including suitability of navigation facilities used to define the routes and procedures for flight.

ABAS Availability

When using GNSS for navigation, SBAS or ABAS fault detection (e.g.,, RAIM) functionality is required to meet Annex 10 navigation performance. Therefore, the availability of the NAVAID infrastructure, required for the intended routes, SIDs, and STARs, including any non-RNAV contingencies, must be confirmed for the period of intended operations using all available information. The pilot must also confirm availability of the onboard navigation equipment necessary for the route, SID, or STAR to be flown.

The availability of SBAS or ABAS fault detection can be determined through NOTAMs (if available) or through prediction for the intended RNAV 1 or RNAV 2 operation. Operators using TSO-C145/C146 receivers should check GPS RAIM availability in areas where SBAS is not usable or available. RAIM availability prediction services may be provided by the ANSP, avionics manufacturer or other entities. Operators should be familiar with the prediction information provided by any State within which they operate. Receiver RAIM prediction capability can also be used. Any prediction should take into account the latest GPS constellation NOTAMs.

In the event of a predicted, continuous loss of fault detection of more than five (5) minutes for any part of the RNAV 1 and RNAV 2 operation, the flight planning should be revised (e.g., delaying the departure or planning a different departure procedure). If the prediction service is temporarily unavailable, ANSPs may still allow RNAV 1 and RNAV 2 operations to be conducted.

RAIM availability prediction software does not guarantee the service, they are rather tools to asses the expected capability to meet the required navigation performances. Because of unplanned failure of some GNSS elements, pilots/ANSP must realize that RAIM (or GPS navigation) altogether may be lost while airborne which may require to revert to an alternative means of navigation. Therefore, pilots should assess their capability to navigate (potentially to an alternate destination) in case of failure of GPS navigation.

DME Availability

For navigation relying on DME, NOTAMs should be checked to verify the health of critical DMEs. Pilots should assess their capability to navigate (potentially to an alternate destination) in case of failure of critical DME while airborne.

3.3.4.2. General Operating Procedures

The pilot should comply with any instructions or procedures identified by the manufacturer as necessary to comply with the performance requirements in this chapter.

NOTE: Pilots of RNP aircraft must adhere to any AFM limitations or operating procedures required to maintain the navigation accuracy specified for the route.

Operators and pilots should not request or file RNAV 1 and RNAV 2 routes unless they satisfy all the criteria in the relevant State documents. If an aircraft not meeting these criteria receives a clearance from ATC to conduct an RNAV route, the pilot must advise ATC that he/she is unable to accept the clearance and must request alternate instructions.

At system initialization, pilots must confirm the navigation database is current and verify that the aircraft position has been entered correctly. Pilots must verify proper entry of their ATC assigned route upon initial clearance and any subsequent change of route. Pilots must ensure the waypoints sequence depicted by their navigation system matches the route depicted on the appropriate chart(s) and their assigned route.

Pilots must not fly an RNAV 1 or RNAV 2 SID or STAR unless it is retrievable by route name from the onboard navigation database and conforms to the charted route. However, the route may subsequently be modified through the insertion or deletion of specific waypoints in response to ATC clearances. The manual entry, or creation of new waypoints, by manual entry of latitude and longitude or rho/theta values is not permitted. Additionally, pilots must not change any RNAV SID or STAR database waypoint type from a fly-by to a fly-over or vice versa.

Whenever possible, RNAV 1 and RNAV 2 routes in the en route domain should be extracted from the database in their entirety, rather than loading RNAV 1 and RNAV 2 individual waypoints from the database into the flight plan. However, it is permitted to select and insert individual, named fixes waypoints from the navigation database, provided all fixes along the published route to be flown are inserted. Moreover, the route may subsequently be modified through the insertion or deletion of specific waypoints in response to ATC clearances. The creation of new waypoints by manual entry of latitude and longitude or rho/theta values is not permitted.

Flight crews should crosscheck the cleared flight plan by comparing charts or other applicable resources with the navigation system textual display and the aircraft map display, if applicable. If required, the exclusion of specific navigation aids should be confirmed.

NOTE: Pilots may notice a slight difference between the navigation information portrayed on the chart and their primary navigation display. Differences of 3° or less may result from equipment manufacturer's application of magnetic variation and are operationally acceptable.

During the flight, where feasible, the flight crew should use available data from ground-based navigation aids to confirm navigational reasonableness.

Pilots must use a lateral deviation indicator (or equivalent navigation map display), flight director and/or autopilot in lateral navigation mode on RNAV 1 routes. Pilots are encouraged to use a lateral deviation indicator (or equivalent navigation map display), flight director and/or autopilot in lateral navigation mode on RNAV 2 routes. Pilots of aircraft with a lateral deviation indicator (e.g., a standalone GNSS receiver) must ensure that lateral deviation indicator scaling (full-scale deflection) is suitable for the navigation accuracy associated with the route/procedure (i.e.,+-1 nm for RNAV 1, +- 2.0 nm for RNAV 2). All pilots are expected to maintain route centerlines, as depicted by onboard lateral deviation indicators and/or flight guidance during all RNAV operations described in this manual unless authorized to deviate by ATC or under emergency conditions. For normal operations, cross-track error/deviation (the difference between the RNAV system computed path and the aircraft position relative to the path) should be limited to +/- ½ the navigation accuracy associated with the procedure or route (i.e., 0.5 nm for RNAV 1, 1.0 nm for RNAV 2). Brief deviations from this standard (e.g., overshoots or undershoots) during and immediately after procedure/route turns, up to a maximum of 1 times the navigation accuracy (i.e., 1.0 nm for RNAV 1, 2.0 nm for RNAV 2), are allowable.

NOTE: Some aircraft do not display or compute a path during turns. As such, pilots of these aircraft may not be able to adhere to the ±½ Lateral navigation accuracy during procedural/route turns but are still expected to satisfy the standard during intercepts following turns and on straight segments.

If ATC issues a heading assignment taking the aircraft off a route, the pilot should not modify the flight plan in the RNAV system until a clearance is received to rejoin the route or the controller confirms a new route clearance. When the aircraft is not on the published route, the specified accuracy requirement does not apply.

Manually selecting aircraft bank limiting functions may reduce the aircraft's ability to maintain its desired track and are not recommended. Pilots should recognize manually selectable aircraft bank-limiting functions might reduce their ability to satisfy ATC path expectations, especially when executing large angle turns. This should not be construed as a requirement to deviate from Airplane Flight Manual procedures; rather, pilots should be encouraged to limit the selection of such functions within accepted procedures.

3.3.4.3. RNAV SID Specific Requirements

Prior to commencing takeoff, the pilot must verify the aircraft's RNAV system is available, operating correctly, and the correct airport and runway data are loaded. Prior to flight, pilots must verify their aircraft navigation system is operating correctly and the correct runway and departure procedure (including any applicable en route transition) are entered and properly depicted. Pilots who are assigned an RNAV departure procedure and subsequently receive a change of runway, procedure or transition must verify the appropriate changes are entered and available for navigation prior to takeoff. A final check of proper runway entry and correct route depiction, shortly before takeoff, is recommended.

RNAV Engagement Altitude. The pilot must be able to use RNAV equipment to follow flight guidance for lateral RNAV no later than 500 feet above airport elevation. The altitude at which RNAV guidance begins on a given route may be higher (e.g., climb to 1000 ft then direct to…).

Pilots must use an authorized method (lateral deviation indicator/navigation map display/flight director/autopilot) to achieve an appropriate level of performance for RNAV 1.

DME/DME Aircraft. Pilots of aircraft without GPS, using DME/DME sensors without inertial input, cannot use their RNAV system until the aircraft has entered adequate DME coverage. The Air Navigation Service Provider (ANSP) will ensure adequate DME coverage is available on each $RNAV_{(DME/DME)}$ SID at an acceptable altitude. The initial legs of the SID may be defined based on heading.

DME/DME/IRU (D/D/I) Aircraft. Pilots of aircraft without GPS, using DME/DME RNAV systems with an IRU (DME/DME/IRU), should ensure the aircraft navigation (inertial) system position is confirmed, within 1,000 feet (0.17 NM) of a known position, at the start point of take-off roll. This is usually achieved by the use of an automatic or manual runway update function. A navigation map may also be used to confirm aircraft position, if pilot procedures and display resolution allow for compliance with the 1,000-foot tolerance requirement.

NOTE: Based on evaluated IRU performance, the growth in position error after reverting to IRU can be expected to be less than 2 NM per 15 minutes.

GNSS Aircraft. When using GNSS, the signal must be acquired before the take-off roll commences. For aircraft using TSO-C129/C129A equipment, the departure airport must be loaded into the flight plan in order to achieve the appropriate navigation system monitoring and sensitivity. For aircraft using TSO-C145a/C146a avionics, if the departure begins at a runway waypoint, then the departure airport does not need to be in the flight plan to obtain appropriate monitoring and sensitivity.

3.3.4.4. RNAV STAR Specific Requirements

Prior to the arrival phase, the flight crew should verify that the correct terminal route has been loaded. The active flight plan should be checked by comparing the charts with the map display (if applicable) and the MCDU. This includes confirmation of the waypoint sequence, reasonableness of track angles and distances, any altitude or speed constraints, and, where possible, which waypoints are fly-by and which are fly-over. If required by a route, a check will need to be made to confirm that updating will exclude a particular navigation aid. A route must not be used if doubt exists as to the validity of the route in the navigation database.

Note: As a minimum, the arrival checks could be a simple inspection of a suitable map display that achieves the objectives of this paragraph.

The creation of new waypoints by manual entry into the RNAV system by the flight crew would invalidate the route and is not permitted.

Where the contingency procedure requires reversion to a conventional arrival route, necessary preparation must be completed before commencing the RNAV route.

Route modifications in the terminal area may take the form of radar headings or “direct to” clearances and the flight crew must be capable of reacting in a timely fashion. This may include the insertion of tactical waypoints loaded from the database. Manual entry or modification by the flight crew of the loaded route, using temporary waypoints or fixes not provided in the database, is not permitted.

Pilots must verify their aircraft navigation system is operating correctly and the correct arrival procedure and runway (including any applicable transition) are entered and properly depicted.

Although a particular method is not mandated, any published altitude and speed constraints must be observed.

3.3.4.5. Contingency Procedures

The pilot must notify ATC of any loss of the RNAV capability, together with the proposed course of action. If unable to comply with the requirements of an RNAV route, pilots must advise Air Traffic Service as soon as possible. For example, "....[Aircraft call sign], failure of GNSS system, unable RNAV, request amended clearance." The loss of RNAV capability includes any failure or event causing the aircraft to no longer satisfy the RNAV requirements of the route.

In the event of communications failure, the flight crew should continue with the RNAV route in accordance with established lost communication procedures.

3.3.5. Pilot Knowledge and Training

The following items should be addressed in the pilot training program (for example, simulator, training device, or aircraft) for the aircraft’s RNAV system.

a) The information in this chapter.

b) The meaning and proper use of Aircraft Equipment/Navigation Suffixes.

c) Procedure characteristics as determined from chart depiction and textual description.

d) Depiction of waypoint types (fly-over and fly-by) and path terminators (provided in section 3.3.3.4 AIRINC 424 path terminators) and any other types used by the operator) as well as associated aircraft flight paths.

e) Required navigation equipment for operation on RNAV routes/SIDs/STARs, e.g., DME/DME. DME/DME/IRU, and GNSS.

f) RNAV system-specific information:

   i) Levels of automation, mode annunciations, changes, alerts, interactions, reversions, and degradation.

   ii) Functional integration with other aircraft systems.

   iii) The meaning and appropriateness of route discontinuities as well as related flight crew procedures.

iv) Pilot procedures consistent with the operation (for example, monitor PROG or LEGS page).

v) Types of navigation sensors (e.g. DME, IRU, GNSS) utilized by the RNAV system and associated system prioritization/weighting/logic.

vi) Turn anticipation with consideration to speed and altitude effects.

vii) Interpretation of electronic displays and symbols

viii) Understanding of the aircraft configuration and operational conditions required to support RNAV operations, i.e. appropriate selection of CDI scaling (lateral deviation display scaling)

g) RNAV equipment operating procedures, as applicable, including how to perform the following actions:

i) Verify currency and integrity of aircraft navigation data.

ii) Verify successful completion of RNAV system self-tests.

iii) Initialize navigation system position.

iv) Retrieve and fly a SID or a STAR with appropriate transition.

v) Adhere to speed and/or altitude constraints associated with a SID or STAR.

vi) Select the appropriate STAR or SID for the active runway in use and be familiar with procedures to deal with a runway change.

vii) Perform a manual or automatic update (with takeoff point shift, if applicable)

viii) Verify waypoints and flight plan programming.

ix) Fly direct to a waypoint.

x) Fly a course/track to a waypoint.

xi) Intercept a course/track.

xii) Flying radar vectors and rejoining an RNAV route from ‘heading’ mode.

xiii) Determine cross-track error/deviation. More specifically, the maximum deviations allowed to support RNAV must be understood and respected.

xiv) Insert and delete route discontinuity.

xv) Remove and reselect navigation sensor input.

xvi) When required, confirm exclusion of a specific navigation aid or navigation aid type.

xvii) When required by the State aviation authority, perform gross navigation error check using conventional navigation aids.

xviii) Change arrival airport and alternate airport.

xix) Perform parallel offset function if capability exists. Pilots should know how offsets are applied, the functionality of their particular RNAV system and the need to advise ATC if this functionality is not available.

xx) Perform RNAV holding function.

h) Operator-recommended levels of automation for phase of flight and workload, including methods to minimize cross-track error to maintain route centerline.

i) R/T phraseology for RNAV/RNP applications

j) Contingency procedures for RNAV/RNP failures.

3.3.6. Navigation Database

The navigation database should be obtained from a supplier that complies with RTCA DO-200A/EUROCAE document ED 76, Standards for Processing Aeronautical Data. A Letter of Acceptance (LOA) issued by the appropriate regulatory authority demonstrates compliance with this requirement (e.g., FAA LOA issued in accordance with FAA AC 20-153 or EASA LOA issued in accordance with EASA IR 21 subpart G.

Discrepancies that invalidate a route must be reported to the navigation database supplier and affected routes must be prohibited by an operator's notice to its flight crew.

Aircraft operators should consider the need to conduct periodic checks of the operational navigation databases in order to meet existing quality system requirements.DME/DME RNAV systems must only use DME facilities identified in State AIPs. Systems must not use facilities indicated by the State as inappropriate for RNAV 1 and RNAV 2 operation in the AIP or facilities associated with an ILS or MLS that uses a range offset. This may be accomplished by excluding specific DME facilities, which are known to have a deleterious effect on the navigation solution, from the aircraft's navigation database when the RNAV routes are within reception range of these DME facilities.

3.3.7. Oversight of Operators

A regulatory authority may consider any navigation error reports in determining remedial action. Repeated navigation error occurrences attributed to a specific piece of navigation equipment may result in cancellation of the approval for use of that equipment.

Information that indicates the potential for repeated errors may require modification of an operator's training program. Information that attributes multiple errors to a particular pilot crew may necessitate remedial training or license review.

3.4. REFERENCES

Copies of EUROCONTROL documents may be requested from EUROCONTROL, Documentation Centre, GS4, Rue de la Fusée, 96, B-1130 Brussels, Belgium; (Fax: 32 2 729 9109). Web site: http://www.ecacnav.com

Copies of EUROCAE documents may be purchased from EUROCAE, 17 rue Hamelin, 75783 PARIS Cedex 16, France, (Fax : 33 1 45 05 72 30). Web site: http://www.eurocae.org

Copies of FAA documents may be obtained from Superintendent of Documents,

Government Printing Office, Washington, DC 20402-9325, USA. Web site: http://www.faa.gov/certification/aircraft/ (Regulation and Guidance Library)

Copies of RTCA documents may be obtained from RTCA Inc., 1140 Connecticut Avenue, N.W., Suite 1020, Washington, DC 20036-4001, USA, (Tel: 1 202 833 9339). Web site www.rtca.org.

Copies of ARINC documents may be obtained from Aeronautical Radio Inc., 2551 Riva Road, Annapolis, Maryland 24101-7465, USA. Web site: http://www.arinc.com

Copies of JAA documents are available from JAA's publisher Information Handling Services (IHS). Information on prices, where and how to order, is available on the JAA web site, http://www.jaa.nl , and on the IHS web sites http://www.global.his.com , and http://www.avdataworks.com .

Copies of EASA documents may be obtained from EASA (European Aviation Safety Agency), 101253, D-50452 Koln, Germany.

Copies of ICAO documents may be purchased from Document Sales Unit, International Civil Aviation Organization, 999 University Street, Montreal, Quebec, Canada H3C 5H7, (Fax: 1 514 954 6769, or e-mail: sales_unit@icao.org) or through national agencies.

Appendix 1: Summary of RNAV 1/TGL 10/ AC 90-100 non significant difference

	Difference of RNAV 1/AC 90-100/TGL-10	NAV-1	FAA AC90-100	JAA TGL-10 Rev.1	Conclusion
Aircraft Equipment	ARINC424 Path Terminator	IF,CF,DF,TF 3.4.3.7	IF,CF,DF,TF, 6.c	IF,TF,CF,DF,FA	TGL 10 doesn't specify automatic versus manual leg management. F.A. path terminator required in TGL 10 could be manually conducted by pilot. There is no difference between TGL 10 and AC 90-100/RNAV 1.
	MCDU	No requirement	The system must be capable of displaying lateral deviation with a resolution of at least 0.1 NM, 6.c.12	Where the MCDU is to be used to support the accuracy checks of Section 10, display of lateral deviation with a resolution of 0.1NM, 7.1.12	It WAS agreed: 1) in PRNAV its really good practice and not universal requirement; 2) RNAV 1&2 would be tailored for radar environments where such checks are not required.
	Support Gross error check	No requirement	No requirement	Alternative means of displaying navigation information, sufficient to perform the checking procedures of Section 10. 7.1.21	It WAS agreed: 1) in PRNAV its really good practice and not universal requirement; 2) RNAV 1&2 would be tailored for radar environments where such checks are not required.

	General Operating Procedure 3.4.4.2	During the flight, where feasible, the flight crew should use available data from ground-based navigation aids to confirm navigational reasonableness.	No requirement	During the procedure and where feasible, flight progress should be monitored for navigational reasonableness by cross-checks with conventional navigation aids using the primary displays in conjunction with the MCDU. 10.2.2.5, 10.2.3.4	Navigation cross check is only recommended in RNAV 1 and in TGL. It was agreed: 1) in PRNAV its really good practice and not universal requirement; 2) RNAV 1&2 would be tailored for radar environments where such checks are not required.
	RNAV STAR Specific Requirement (3.4.4.4)	Prior to the arrival phase, the flight crew should verify that the correct terminal route has been loaded. (3.4.4.4.1 Block)	No requirement	Prior to the arrival phase, the flight crew should verify that the correct terminal procedure has been loaded.10.2.3.1	Covered in AC 90-100 as a general issue rather than specific to arrivals: *“Flight crews should crosscheck the cleared flight plan against charts or other applicable resources, as well as the navigation system textual display and the aircraft map display, if applicable”* No discrepancy.

Operational Requirement	RNAV STAR Specific Requirement (3.4.4.4)	The creation of new waypoints by manual entry into the RNAV system by the flight crew would invalidate the route and is not permitted (3.4.4.4.1 Block2)	No Requirement	The creation of new waypoints by manual entry into the RNAV system by the flight crew would invalidate the P-RNAV procedure and is not permitted. (10.2.3.2)	AC 90-100 specifies that: “Capacity to load from the database into the RNAV system the entire RNAV segment of the SID or STAR procedure(s) to be flown.” and **“P**ilots must not fly an RNAV SID or STAR unless it is retrievable by procedure name from the onboard navigation database and conforms to the charted procedure.” FAA did not include prohibition against altering flight plan in equipment as ATC clearance can amend procedure in some circumstances. No discrepancy.

		Where the contingency procedure requires reversion to a conventional arrival route, necessary preparation must be completed before commencing the RNAV route. (3.4.4.4.1 Block3)	No requirement	Where the contingency to revert to a conventional arrival procedure is required, the flight crew must make the necessary preparation.(10.2.3.3)	Under TGL-10, such contingency is required for below MOCA or outside radar coverage. RNAV 1 is intended for application within radar coverage (MOCA not significant constraint if radar service is available and aircraft above MSA). Discrepancy resolved through decision to base ICAO implementation on radar.
		Route modifications in the terminal area may take the form of radar headings or 'direct to' clearances and the flight crew must be capable of reacting in a timely fashion. (3.4.4.4.1 Block4)	No requirement	Route modifications in the terminal area may take the form of radar headings or 'direct to' clearances and the flight crew must be capable of reacting in a timely fashion.(10.2.3.5)	In US, crew training includes knowledge of how to go direct, rest is basic airmanship. No discrepancy.

	Contingency Procedure (3.4.4.5)	Although a particular method is not mandated, any published altitude and speed constraints must be observed.(3.4.4.4 . Block5)	No requirement	Although a particular method is not mandated, any published altitude and speed constraints must be observed.(10.2.3.6)	USRNAV does not define any new requirements for altitude or airspeed (nor does TGL-10), so this statement is not included. No discrepancy.
		The pilot must notify ATC of any loss of the RNAV capability, together with the proposed course of action. (3.4.4.5. Block1)	No requirement	The flight crew must notify ATC of any problem with the RNAV system that results in the loss of the required navigation capability, together with the proposed course of action.10.3.2	It is specified in AC 90-100, 8d: "The pilot must notify ATC of any loss of the RNAV capability, together with the proposed course of action. " No discrepancy.
Database Requirement	Database Integrity	Aircraft operators should consider the need to conduct periodic checks of the operational navigation databases in order to meet existing quality system requirements. (3.4.4 Database Block3)	No requirement	No requirement	No specific requirement in TGL 10 and in AC 90-100. This requirement is recognized as a good practice. No discrepancy.

	Invalidated report	Discrepancies that invalidate a route must be reported to the navigation database supplier and affected routes must be prohibited by an operator's notice to its flight crew. (3.4.4 Database Block2)	No requirement	Discrepancies that invalidate a procedure must be reported to the navigation database supplier and affected procedures must be prohibited by a operator's notice to its flight crew.(8.2, 10.6.3)	No specific requirement for nav data base integrity in AC 90-100. Will not be the case in AC 90-100A.
	Periodical checks	Aircraft operators should consider the need to conduct periodic checks of the operational navigation databases in order to meet existing quality system requirements. (3.4.4 Database Block3)	No requirement	No requirement	No specific requirement in TGL 10 and in AC 90-100. This requirement is recognized as a good practice. No discrepancy

Maintenance Requirement	MEL Revision	Any minimum equipment list (MEL) revisions necessary to address RNAV 2/RNAV 1 provisions must be approved. Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions. (3.4.2.4)	No specific requirement	No specific requirement	Covered in TGL-10 (10.7.2.) and in AC 90-100 as general guidance (not specific to MEL as means to regulate it): “The pilot must also confirm availability of the onboard navigation equipment necessary for the route, SID, or STAR to be flown”. No discrepancy.

PART C

– IMPLEMENTING RNP –

CHAPTER 1

IMPLEMENTING RNP 4

1.1. INTRODUCTION

1.1.1. Background

This chapter addresses the implementation of RNP 4 to support 30 NM lateral and the 30 NM longitudinal distance-based separation minima in oceanic or remote area airspace.

1.1.2. Purpose

This chapter provides guidance to States implementing RNP 4 to assist in developing operational approval or authorization processes. The operational approval process described herein is limited to aircraft which have received airworthiness certification indicating the installed navigation systems meet the performance requirements for RNP 4. This certification may have been issued at the time of manufacture, or where aircraft have been retrofitted in order to meet the requirements for RNP 4, by the granting of an appropriate supplemental type certificate (STC).

This chapter does *not* address all requirements that may be specified for particular operations. These requirements are specified in other documents such as operating rules, aeronautical information publications (AIPs) and the ICAO *Regional Supplementary Procedures* (Doc 7030). While operational approval primarily relates to the navigation requirements of the airspace, operators and flight crew are still required to take account of all operational documents relating to the airspace that are required by the appropriate State authority before conducting flights into that airspace.

1.1.3. Terminology

RNP 4 requires a total system error of not more than ±4 NM for 95% of the total flight time, and on-board performance monitoring and alerting.

1.2. ANSP CONSIDERATIONS

1.2.1. Navaid Infrastructure Considerations

RNP 4 was developed for operations in oceanic and remote airspace and, as such, does not require any ground-based NAVAID infrastructure. GNSS is the primary navigation sensor to support RNP 4, either as a stand-alone navigation system or as part of a multi-sensor system.

1.2.2. Communication and Surveillance Considerations

While this guidance material was developed to support the 30 NM lateral and longitudinal separation minima based on RNP 4, it should be noted that it addresses only the navigation requirements associated with these standards. It does not specifically address the communications or ATS surveillance requirements.

NOTE: The provisions relating to these separation minima, including the communications and ATS surveillance requirements, can be found in paragraph 3.4.1 e) of Attachment B to Annex 11 and Section 5.4 of the PANS-ATM (Doc 4444). Provided that they can support the increased reporting rate required, controller-pilot data link communications (CPDLC) and automatic dependent surveillance - contract (ADS-C) systems which meet the requirements for application of the 50 NM lateral and longitudinal minima based on RNP 10 will also meet the requirements for the application of the 30 NM lateral and longitudinal minima.

1.2.3. Obstacle Clearance and Route Spacing

Detailed guidance on obstacle clearance is provided in PANS-OPS (Doc 8168, Volume II). The general criteria in Part 1 and Part 3 apply, together with the en-route criteria from Doc 8168, Volume II, Part III, Section 1, Chapter 7 (4 NM) and Section 3, Chapter 8.

The separation minima are described in Section 5.4 of the Procedures for Air Navigation Services — Air Traffic Management (PANS-ATM, Doc 4444).

RNP 4 may be used to support the application of separation standards/route spacing less than 30 NM in continental airspace provided a State has undertaken the necessary safety assessments outlined in PANS-ATM (Doc 4444). However, the communications and ATS Surveillance parameters that support the application of the new separation standards will be different to those for a 30 NM standard.

1.2.4. Additional Considerations

Many aircraft have the capability to fly a path parallel to, but offset left or right from, the original active route. The purpose of this function is to enable offsets for tactical operations authorized by ATC.

Many aircraft have the capability to execute a holding pattern manoeuvre using their RNAV system. The purpose of this function is to provide flexibility to ATC in designing RNAV operations.

Guidance in this chapter does not supersede appropriate State operating requirements for equipage.

1.2.5. Publication

The AIP should clearly indicate the navigation application is RNP 4.

The route should identify minimum segment altitude requirements.

The navigation data published in the State AIP for the routes and supporting navigation aids must meet the requirements of ICAO Annex 15.

All routes must be based upon WGS 84 coordinates.

1.2.6. Controller Training

Air traffic controllers who will provide separation services that are based on RNP 4 must have completed training in the following areas:

(a) lateral and longitudinal separation based on RNP 4;

(b) GNSS systems and other RNP capable systems

(c) GNSS system accuracy, integrity and alerting (e.g., RAIM), availability and continuity;

(d) RNP 4 operational approvals processes; and

(e) RNP 4 related phraseology.

1.2.7. Status Monitoring

The air traffic service provider must monitor the status of GNSS and issue timely warnings of outages (NOTAMS).

1.2.8. ATS System Monitoring

Demonstrated navigation accuracy provides the basis for determining the lateral route spacing and separation minima necessary for traffic operating on a given route. Accordingly, lateral and longitudinal navigation errors are monitored through monitoring programmes. Radar observations of each aircraft's proximity to track and altitude, before coming into coverage of short-range navaids at the end of the oceanic route segment, are noted by ATS facilities. If an observation indicates that an aircraft is not within the established limit, a navigation error report is submitted, and an investigation undertaken to determine the reason for the apparent deviation from track or altitude, in order that steps may be taken to prevent a recurrence.

1.3. NAVIGATION SPECIFICATION

1.3.1. Background

This section identifies the airworthiness and operational requirements for RNP 4 operations. Operational compliance with these requirements must be addressed through national operational regulations, and may require a specific operational approval in some cases. For example, certain operational regulation requires operators to apply to their national authority (State of registry) for operational approval.

This chapter addresses only the lateral part of the navigation system.

1.3.2. Approval Process

The following steps must be completed before conducting RNP 4 operations:

a) Aircraft equipment eligibility must be determined and documented;

b) Operating procedures for the navigation systems to be used and the operator navigation database process must be documented;

c) Flight crew training based upon the operating procedures must be documented if necessary;

d) The above material must be accepted by the State regulatory authority; and

e) Operational approval must then be obtained in accordance with national operating rules.

1.3.2.1 Aircraft Eligibility

Eligibility airworthiness documents. Relevant documentation acceptable to the State of operation must be available to establish that the aircraft is equipped with an RNAV systems meeting RNP 4 requirements. To avoid unnecessary regulatory activity, the determination of eligibility for existing systems should consider acceptance of manufacturer documentation of compliance e.g. as with EASA AMC 20 series document.

Aircraft Eligibility Groups

a) Group 1: RNP certification

Group 1 aircraft are those with formal certification and approval of RNP integration in the aircraft. RNP compliance is documented in the aircraft's flight manual.

The certification will not necessarily be limited to a specific RNP specification. The flight manual must address the RNP levels that have been demonstrated and any related provisions applicable to their use (e.g. navaid sensor requirements). Operational approval is based upon the performance stated in the flight manual.

This method also applies in the case where certification is received through a STC issued to cover retrofitting of equipment, such as GNSS receivers, to enable the aircraft to meet RNP 4 requirements in oceanic and remote area airspace.

b) Group 2: Prior navigation system certification

Group 2 aircraft are those that can equate their certified level of performance, given under previous standards, to RNP 4 criteria. Those standards listed below in subparagraphs i) to iii) can be used to qualify aircraft under Group 2.

i) *Global navigation satellite systems (GNSS).* Aircraft fitted with GNSS only as an approved long-range navigation system for oceanic and remote airspace operations must meet the technical requirements specified in paragraph 1.4.4. The flight manual must indicate that dual GNSS equipment approved under an appropriate standard is required. Appropriate standards are FAA Technical Standard Orders (TSO) C129a or C146, and JAA Joint Technical Standard Orders (JTSO) C129a or C146. In addition, an approved dispatch fault detection and exclusion (FDE) availability prediction program must be used. The maximum allowable time for which FDE capability is projected to be unavailable on any one event is 25 minutes. This maximum outage time must be included as a condition of the RNP 4 operational approval. If predictions indicate that the maximum allowable FDE outage will be exceeded the operation must be rescheduled to a time when FDE is available.

ii) *Multi-Sensor Systems Integrating GNSS with integrity provided by Receiver Autonomous Integrity Monitoring (RAIM).* Multi-sensor systems incorporating Global Positioning System (GPS) with RAIM and FDE that are approved under FAA AC20-130A, or other equivalent documents, meet the technical requirements specified in paragraph 1.4.4. Note that there is no requirement to use dispatch FDE availability prediction programmes when multi-sensor systems are fitted and used.

iii) *Aircraft Autonomous Integrity Monitoring (AAIM).* AAIM uses the redundancy of position estimates from multiple sensors, including GNSS, to provide integrity performance that is at least equivalent to RAIM. These airborne augmentations must be certified in accordance with TSO C-115b, JTSO C-115b or other equivalent documents. An example is the use of an inertial navigation system or other navigation sensors as an integrity check on GNSS data when RAIM is unavailable but GNSS positioning information continues to be valid.

c) Group 3: New technology

This group has been provided to cover new navigation systems that meet the technical requirements for operations in airspace where RNP 4 is specified.

1.3.2.2 Operational Approval

The assessment of a particular operator is made by the State of Registry for that operator and in accordance with national operating rules (e.g., JAR-OPS 1, 14 CFR Part 121) supported through appropriate advisory and guidance material. The assessment should take into account:

a) Evidence of aircraft eligibility

b) Assessment of the operating procedures for the navigation systems to be used

c) Control of those procedures through acceptable entries in the Operations Manual

d) Identification of flight crew training requirements

e) Where required, control of navigation database process

The operational approval will likely be documented through the State endorsing the Air Operators Certificate (AOC) through issue of a letter of authorisation, appropriate operations specification (Ops Spec) or amendment to the operations manual.

1.3.2.2.1 Description of aircraft equipment

The operator must have a configuration list detailing pertinent components and equipment to be used for RNP 4 operation.

1.3.2.2.2 Training documentation

Commercial operators must have a training program addressing the operational practices, procedures and training items related to RNP 4 operations (e.g. initial, upgrade or recurrent training for flight crew, dispatchers or maintenance personnel).

NOTE: It is not required to establish a separate training program or regimen if RNAV training is already an integrated element of a training program. However, it should be possible to identify what aspects of RNAV are covered within a training program.

Private operators must be familiar with the practices and procedures identified in paragraph 1.3.5 “Pilot Knowledge/Training” of this chapter.

1.3.2.2.3 Operations manuals and checklists

Operations manuals and checklists for commercial operators must address information/guidance on the standard operating procedures detailed in the “Operating procedures” section of this chapter. The appropriate manuals should contain navigation operating instructions and contingency procedures where specified. Manuals and checklists must be submitted for review as part of the application process.

Non-commercial operators must create appropriate instructions containing navigation operating instructions and contingency procedures. This information must be available to crews in flight and should be entered into the Operations Manual or Pilot Operating Handbook, as appropriate. These manuals and manufacturer’s instructions for operation of the aircraft navigation equipment, as appropriate, must be submitted for review as part of the application process.

Private operators must operate using the practices and procedures identified in paragraph 1.3.5 “Pilot Knowledge/Training” of this chapter.

1.3.2.2.4 Minimum Equipment List (MEL) considerations

Any minimum equipment list (MEL) revisions necessary to address RNP 4 provisions must be approved.

Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions.

All operators/owners must submit their maintenance programme, including a reliability programme for monitoring the equipment, for approval at the time of application. The holder of the design approval, including either the type certificate (TC) or supplemental type certificate (STC) for each individual navigation system installation must furnish at least one set of complete instructions for continuing airworthiness.

1.3.3. Aircraft Requirements

For RNP 4 operations in oceanic or remote airspace, at least two fully serviceable independent long-range navigation systems (LRNSs), with integrity such that the navigation system does not provide misleading information, must be fitted to the aircraft and form part of the basis upon which RNP 4 operational approval is granted. GNSS must be used. It can be used as either a stand-alone navigation system or as one of the sensors to a multi-sensor system.

United States FAA Advisory Circular AC 20-138A, or equivalent documents, provides an acceptable means of complying with installation requirements for aircraft that use but do not integrate the GNSS output with that of other sensors. FAA AC 20-130A describes an acceptable means of compliance for multi-sensor navigation systems that incorporate GNSS.

The equipment configuration used to demonstrate the required accuracy must be identical to the configuration specified in the MEL or flight manual.

The design of the installation must comply with the design standards that are applicable to the aircraft being modified and changes must be reflected in the flight manual prior to commencing operations requiring an RNP 4 navigation approval.

1.3.3.1. System Accuracy

Navigation accuracy is defined relative to a geodesic path along a route or defined procedure. The navigation accuracy requirement for issuance of an RNP 4 approval requires that the aircraft navigate with a cross-track total system error (TSE) no greater than ±7.4 km (±4 NM) for 95 per cent of the total flight time. The aircraft along-track positioning error must also be no greater than ±7.4 km (±4 NM) for 95 per cent of the flight time.

1.3.3.2. Performance Monitoring and Alerting

The installation must also meet the following on-board performance monitoring and alerting requirements.

Integrity

The probability that the total system error of each aircraft operation on RNP 4 exceeds two times navigation accuracy without alerting shall be less than 10-5 per flight hour.

NOTE: If using GNSS, the probability of signal-in-space errors causing a lateral position error of greater than 2 NM is 10-7 per hour.

Continuity

The continuity requirement is satisfied by the carriage of dual independent long range navigation systems (excluding signal in space).

1.3.3.3. Functional Requirements

The on-board navigation system must have the following required functionalities:

a) display of navigation data;

b) track to fix (TF);

c) direct to fix (DF);

d) direct—to function;

e) course to fix (CF);

f) parallel offset;

g) fly-by transition criteria;

h) user interface displays;

i) flight planning path selection;

j) flight planning fix sequencing;

k) user defined course to fix;

l) path steering;

m) alerting requirements;

n) navigation data base access;

o) WGS 84 geodetic reference system, and

p) automatic radio position updating.

1.3.3.4. Explanation of Required Functionalities

Display of navigation data

The display of navigation data must use either a lateral deviation display (see (a) below) **<u>or</u>** a navigation map display (see (b) below) that meets the following requirements:

a) A non-numeric lateral deviation display (e.g. CDI, electronic horizontal situation indicator ((E)HSI), with a To/From indication and failure annunciation, for use as a primary flight instruments for navigation of the aircraft, for manoeuvre anticipation, and for failure/status/integrity indication, with the following attributes:

1. Must be visible to the pilot and located in the primary view (+/-15 degrees from the pilot's normal line of sight) when looking forward along the flight path;

2. Lateral deviation scaling must agree with any alerting and annunciation limits, if implemented;

3. Lateral deviation display must be automatically slaved to the RNAV computed path. The lateral deviation display also must have full-scale deflection suitable for the current phase of flight and must be based on the required track-keeping accuracy. The course selector of the lateral deviation display should be automatically slewed to the RNAV computed path, or the pilot must adjust the CDI or HSI selected course to the computed desired track.

Note: The normal function of stand-alone GNSS equipment meets this requirement.

4. Display scaling may be set automatically by default logic or set to a value obtained from the navigation database. The full-scale deflection value must be known or must be available to the pilot commensurate with en-route, terminal or approach phase values.

b) A navigation map display, readily visible to the pilot, with appropriate map scales (scaling may be set manually by the pilot), and giving equivalent functionality to a lateral deviation display.

Track to fix (TF)

The TF leg is a geodesic path between two fixes. The first fix is either the previous leg termination or an IF leg. The termination fix is normally provided by the navigation database, but may also be a user-defined fix.

Direct to fix (DF)

The DF leg is a geodesic path starting near the area of initiation and terminating at a fix.

Direct-to function

The direct-to function must be able to be activated at any time by the flight crew, when required. The direct-to function must be available to any fix. The system must be capable of generating a geodesic path to the designated "To" fix. The aircraft must capture this path without "S-turning" and without undue delay.

Course to fix (CF)

The CF leg is a geodesic path terminating at a fix with a specified course at that fix. The inbound course at the termination fix and the fix are provided by the navigation database. If the inbound course is defined as a magnetic course, the source of the magnetic variation needed to convert magnetic courses to true courses is required.

Parallel offset

The system must have the capability to fly parallel tracks at a selected offset distance. When executing a parallel offset, the navigation accuracy and all performance requirements of the original route in the active flight plan must be applicable to the offset route. The system must provide for entry of offset distances in increments of 1 NM, left or right of course. The system must be capable of offsets of at least 20 NM. When in use, system offset mode operation must be clearly indicated to the flight crew. When in offset mode, the system must provide reference parameters (for example, cross-track deviation, distance-to-go, time-to-go) relative to the offset path and offset reference points. An offset must not be propagated through route discontinuities, unreasonable path geometries, or beyond the initial approach fix. Annunciation must be given to the flight crew prior to the end of the offset path, with sufficient time to return to the original path. Once a parallel offset is activated, the offset must remain active for all flight plan route segments until removed automatically, until the flight crew enters a Direct-To routing, or until flight crew (manual) cancellation. The parallel offset function must be available for en route TF and geodesic portion of DF leg types.

Fly-by transition criteria

The navigation system must be capable of accomplishing fly-by transitions. No predictable and repeatable path is specified, because the optimum path varies with airspeed and bank angle. However, predictable and repeatable boundaries of the transition area are defined. Path definition error is defined as the difference between the defined path and the theoretical transition area. If the path lies within the transition area, there is no path definition error. Fly-by transitions must be the default transition when the transition type is not specified. The theoretical transition area requirements are applicable for the following assumptions:

a) Course changes do not exceed 120 degrees for low altitude transitions (referred as when the aircraft barometric altitude is less than FL 195); and

b) Course changes do not exceed 70 degrees for high altitude transitions (referred as when the aircraft barometric altitude is equal to or greater than FL 195).

User interface displays

General user interface display features must provide for presentation of information, provide situational awareness and be designed and implemented to accommodate human factors considerations. Essential design considerations include:

a) Minimizing reliance on flight crew memory for any system operating procedure or task;

b) Developing a clear and unambiguous display of system modes/sub modes and navigational data with emphasis on enhanced situational awareness requirements for any automatic mode changes if provided;

c) Use of context sensitive help capability and error messages (for example, invalid inputs or invalid data entry messages should provide a simple means to determine how to enter “valid” data);

d) Fault tolerant data entry methods rather than rigid rule based concepts;

e) Placing particular emphasis on the number of steps and minimizing the time required to accomplish flight plan modifications to accommodate ATS clearances, holding procedures, runway and instrument approach changes, missed approaches and diversions to alternate destinations; and

f) Minimizing the number of nuisance alerts so the flight crew will recognize and react appropriately when required.

Displays and controls

Each display element used as a primary flight instrument in the guidance and control of the aircraft, for manoeuvre anticipation, or for failure/status/integrity annunciation, must be located where it is clearly visible to the pilot (in the pilot’s primary field of view) with the least practicable deviation from the pilot’s normal position and line of vision when looking forward along the flight path. For those aircraft meeting the requirements of FAR/JAR 25, it is intended that provisions of certification documents such as AC 25-11, AMJ 25-11 and other applicable documents should be satisfied.

All system displays, controls and annunciations must be readable under normal cockpit conditions and expected ambient light conditions. Night lighting provisions must be compatible with other cockpit lighting.

All displays and controls must be arranged to facilitate flight crew accessibility and usage. Controls that are normally adjusted in flight must be readily accessible with standardized labelling as to their function. System controls and displays must be designed to maximize operational suitability and minimize pilot workload. Controls intended for use during flight must be designed to minimize errors, and when operated in all possible combinations and sequences, must not result in a condition whose presence or continuation would be detrimental to the continued performance of the system. System controls must be arranged to provide adequate protection against inadvertent system shutdown.

Flight planning path selection

The navigation system must provide the capability for the crew to create, review and activate a flight plan. The system must provide the capability for modification (for example, deletion and addition of fixes and creation of along-track fixes), review and user acceptance of changes to the flight plans. When this capability is exercised, guidance outputs must not be affected until modification(s) is/are activated.

Activation of any flight plan modification must require positive action by the flight crew after input and verification by the flight crew.

Flight planning fix sequencing

The navigation system must provide the capability for automatic sequencing of fixes.

User-defined course to fix

The navigation system must provide the capability to define a user-defined course to a fix. The pilot must be able to intercept the user-defined course.

Path steering

The system must provide data to enable the generation of command signals for autopilot/flight director/CDI, as applicable. In all cases a path steering error (PSE) must be defined at the time of certification, which will meet the requirements of the desired RNP operation in combination with the other system errors. During the certification process, the ability of the crew to operate the aircraft within the specified PSE must be demonstrated. Aircraft type, operating envelope, displays, autopilot performance, and leg transitioning guidance (specifically between arc legs) should be accounted for in the demonstration of PSE compliance. A measured value of PSE may be used to monitor system compliance to RNP requirements. For operation on all leg types, this value must be the distance to the defined path. For cross-track containment compliance, any inaccuracies in the cross-track error computation (for example, resolution) must be accounted for in the total system error.

Alerting requirements

The system must also provide an annunciation when the manually entered navigation accuracy is larger than the navigation accuracy associated with the current airspace as defined in the navigation database. Any subsequent reduction of the navigation accuracy must reinstate this annunciation. When approaching RNP airspace from non-RNP airspace, alerting must be enabled when the cross-track to the desired path is equal to or less than one-half the navigation accuracy and the aircraft has passed the first fix in the RNP airspace.

Navigation database access

The navigation database must provide access to navigation information in support of the navigation systems reference and flight planning features. Manual modification of the navigation database data must not be possible. This requirement does not preclude the storage of “user defined data” within the equipment (e.g., for flex track routes). When data are recalled from storage they must also be retained in storage. The system must provide a means to identify the navigation database version and valid operating period.

Geodetic reference system

WGS-84 or an equivalent earth reference model must be the reference earth model for error determination. If WGS-84 is not employed, any differences between the selected earth model and the WGS-84 earth model must be included as part of the path definition error. Errors induced by data resolution must also be considered.

1.3.4. Operating Procedures

Airworthiness certification alone does not authorize RNP 4 operations. Operational approval is also required to confirm the adequacy of the operator’s normal and contingency procedures for the particular equipment installation.

Pre-flight Planning

Operators should use the appropriate ICAO flight plan designation specified for the RNP route flown. The letter “R” should be placed in block 10 of the ICAO flight plan to indicate the pilot has reviewed the planned route of flight to determine RNP requirements and the aircraft and operator have been approved on routes where RNP is a requirement for operation. Additional information needs to be displayed in the remarks section that indicates the accuracy capability such as RNP-4 versus RNP-10. It is important to understand that additional requirements will have to be met for operational authorization in RNP-4 airspace or routes.

Controller-Pilot Data Link Communication (CPDLC) and Air Data System (ADS) will also be required when the separation standard is 30 nm lateral and/or longitudinal.

The onboard navigation data must be current and include appropriate procedures.

NOTE: Navigation databases are expected to be current for the duration of the flight. If the AIRAC cycle is due to change during flight, operators and pilots should establish procedures to ensure the accuracy of navigation data, including suitability of navigation facilities used to define the routes and procedures for flight.

The flight crew must:

a) Review maintenance logs and forms to ascertain the condition of the equipment required for flight in RNP 4 airspace or on routes requiring RNP 4 navigation capability;

b) Ensure that maintenance action has been taken to correct defects in the required equipment; and

c) Review the contingency procedures for operations in RNP 4 airspace or on routes requiring an RNP 4 navigation capability. These are no different than normal oceanic contingency procedures with one exception; crews must be able to recognize and ATC must be advised when the aircraft is no longer able to navigate to its RNP 4 navigational capability.

Availability of GNSS

At dispatch or during flight planning, the operator should ensure that adequate navigation capability is available en route to enable the aircraft to navigate to RNP-4, to include the availability of FDE, if appropriate for the operation.

En-route

At least two LRNSs, capable of navigating to RNP 4, and listed in the flight manual, must be operational at the entry point of the RNP airspace. If an item of equipment required for RNP 4 operations is unserviceable, then the pilot should consider an alternate routing, or diversion for repairs.

In-flight operating procedures must include mandatory cross-checking procedures to identify navigation errors in sufficient time to prevent inadvertent deviation from ATC-cleared routes.

Crews must advise ATC of any deterioration or failure of the navigation equipment that causes navigation performance to fall below the required level, and/or any deviations required for a contingency procedure.

Pilots are encouraged to use a lateral deviation indicator, Flight Director and/or Autopilot in lateral navigation mode on RNP 4 routes. Pilots of aircraft with a lateral deviation indicator (e.g. a standalone GNSS receiver) must ensure that lateral deviation indicator scaling (full-scale deflection) is suitable for the navigation accuracy associated with the route (i.e. +/-4 NM). All pilots are expected to maintain route centrelines, as depicted by onboard lateral deviation indicators and/or flight guidance during all RNP operations described in this manual unless authorized to deviate by ATC or under emergency conditions. For normal operations, cross-track error/deviation (the difference between the RNAV system computed path and the aircraft position relative to the path) should be limited to +/- ½ the navigation accuracy associated with the route (i.e. 2 NM). Brief deviations from this standard (e.g. overshoots or undershoots) during and immediately after route turns, up to a maximum of 1 times the navigation accuracy (i.e. 4 NM), are allowable.

1.3.5. Pilot Knowledge and Training

Operators/owners must ensure that flight crews are trained and have appropriate knowledge of the topics contained in this guidance material, the limits of their RNP 4 navigation capabilities, the effects of updating, and RNP 4 contingency procedures.

In determining whether training is adequate, an approving authority might:

a) Evaluate a training course before accepting a training centre certificate from a specific centre;

b) Accept a statement in the operator's/owner's application for an RNP 4 approval that the operator has ensured and will continue to ensure that flight crews are familiar with the RNP 4 operating practices and procedures contained in this chapter; or

c) Accept a statement by the operator that it has conducted or will conduct an RNP 4 training programme utilizing the guidance contained in this chapter.

1.3.6. Navigation Database

The navigation database should be obtained from a supplier that complies with RTCA DO-200A/EUROCAE document ED 76, Standards for Processing Aeronautical Data. A Letter of Acceptance (LOA) issued by the appropriate regulatory authority demonstrates compliance with this requirement (e.g., FAA LOA issued in accordance with FAA AC 20-153 or EASA LOA issued in accordance with EASA IR 21 subpart G.

Discrepancies that invalidate the route must be reported to the navigation database supplier and the affected route must be prohibited by an operator's notice to its flight crew.

Aircraft operators should consider the need to conduct ongoing checks of the operational navigation databases in order to meet existing quality system requirements.

Note: To minimize path definition error, the database should comply with DO-200A/ED-76, or an equivalent operational means must be in place to ensure database integrity for the RNP 4.

1.3.7. Oversight of Operators

An aviation authority may consider any navigation error reports in determining remedial action. Repeated navigation error occurrences attributed to a specific piece of navigation equipment or operational procedure may result in cancellation of the operational approval pending replacement or modifications on the navigation equipment or changes in the operator's operational procedures.

Information that indicates the potential for repeated errors may require modification of an operator's training programme, maintenance programme or specific equipment certification. Information that attributes multiple errors to a particular pilot crew may necessitate remedial training or crew licence review.

1.4. REFERENCES

1.4.1. Websites

- Federal Aviation Administration (FAA), United States

  http://www.faa.gov/ats/ato/rnp.htm

  http://www.faa.gov/ats/ato/ispacg.htm (see FANS Operations Manual)

- Civil Aviation Safety Authority (CASA), Australia

  http://www.casa.gov.au/avreg/rules/1998casr/index.htm

1.4.2. Related Publications

- Federal Aviation Administration (FAA), United States

  Code of Federal Regulations (CFR), Part 121, Appendix G

  Advisory Circular (AC) 20-130A. Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors

  AC 20-138A. Airworthiness Approval of Global Navigation Satellite System (GNSS) Equipment

  FAA Order 7110.82. Monitoring of Navigation/Altitude Performance in Oceanic Airspace

  FAA Order 8400.33. Procedures for Obtaining Authorization for Required Navigation Performance 4 (RNP 4) Oceanic and Remote Area Operations

- Civil Aviation Safety Authority (CASA), Australia

  Advisory Circular (AC) 91U-3(1): Required Navigation Performance 4 (RNP 4) Operational Authorisation

- International Civil Aviation Organization (ICAO)

  Annex 6 – Operation of Aircraft

  Annex 11 – Air Traffic Services

  Procedures for Air Navigation Services – Air Traffic Management (PANS-ATM) (Doc 4444)

  Air Navigation Plan for CNS/ATM Systems (Doc 9750)

  (Copies may be obtained from the Document Sales Unit, ICAO, 999 University Street, Montreal, Quebec, Canada H3C 5H7)

- RTCA

  Minimum Aviation System Performance Standards (MASPS): Required Navigation Performance for Area Navigation (DO 236B), RTCA

  Minimum Operational Performance Standards (MOPS) for Required Navigation Performance for Area Navigation (DO 283), RTCA

  Standards for Processing Aeronautical Data (DO 200A), RTCA

  (Copies may be obtained from RTCA, Inc., 1828 L Street NW, Suite 805, Washington, DC 20036, United States)

CHAPTER 2

IMPLEMENTING RNP 2

To Be Developed

CHAPTER 3

IMPLEMENTING BASIC-RNP 1

3.1. INTRODUCTION

3.1.1. Background

This specification was developed to take advantage of the 'on-board performance monitoring and alerting' capability of the TSO-C129a GPS receiver.

3.1.2. Purpose

This navigation specification provides guidance to States implementing Basic-RNP 1 for arrival and departure procedures. Basic-RNP 1 is intended for TMAs with no or limited ATS Surveillance, for low to medium density traffic.

The Basic-RNP 1 navigation specification was primarily developed for RNAV operations in a non-radar environment. Basic-RNP 1 aircraft may not qualify for RNAV 1 without a full assessment against the RNAV 1 and RNAV 2 Navigation Specification.

This chapter does *not* address all requirements that may be specified for particular operations. These requirements are specified in other documents such as operating rules, aeronautical information publications (AIPs) and the ICAO *Regional Supplementary Procedures* (Doc 7030). While operational approval primarily relates to the navigation requirements of the airspace, operators and flight crew are still required to take account of all operational documents relating to the airspace that are required by the appropriate State authority before conducting flights into that airspace.

3.1.3. Terminology

Basic-RNP 1 SIDs/STARs.

Basic-RNP 1 arrival and departure procedures require a total system error of not more than ±1 NM for 95% of the total flight time, and on-board performance monitoring and alerting, within 30 NM of the ARP. Outside of 30 NM, a total system error of not more than ±2 NM for 95% of the total flight time is accommodated through procedure design criteria (based on existing TSO-C129a equipment performance).

3.2. ANSP CONSIDERATIONS

3.2.1. Navaid Infrastructure Considerations

GNSS will be the primary navigation system to support the Basic-RNP 1 in the vast majority of environments. While some DME/DME based RNAV systems are capable of Basic-RNP 1 performance, this navigation specification is primarily intended for environments where the DME infrastructure cannot support DME/DME area navigation to the required performance.

Basic-RNP 1 shall not be used in areas of known navigation signal (GNSS) interference.

3.2.2. Communication & ATS Surveillance Considerations

This navigation specification is intended for environments where ATS Surveillance is either not available or limited. It is equally recommended for TMAs served by only single-source radar where outages are common. Basic-RNP 1 SIDs/STARs are envisioned to be conducted in direct controller pilot communication environments.

3.2.3. Obstacle Clearance and Horizontal Separation

Detailed guidance on obstacle clearance is provided in PANS-OPS (Doc 8168, Volume II). The general criteria in Part 1 and Part 3 apply, together with the criteria from Doc 8168, Volume II, Part III, Section 1, Chapter 2 and the chapter in Section 3 for the appropriate phase of flight regarding Basic GNSS.

Route spacing for Basic-RNP 1 depends on the route configuration, air traffic density and intervention capability. Horizontal separation standards are published in Doc 4444 PANS-ATM.

3.2.4. Additional Considerations

The default alerting functionality of a TSO C129a sensor (stand-alone or integrated), switches between terminal alerting (±1 NM) and en route alerting (±2 NM) at 30 miles from the Airport Reference Point (ARP). (See paragraph 3.1.3)

3.2.5. Publication

The procedure should rely on normal descent profiles and identify minimum segment altitude requirements.

The navigation data published in the State AIP for the procedures and supporting navigation aids must meet the requirements of ICAO Annex 15.

All procedures must be based upon WGS 84 coordinates

3.2.6. Controller Training

Air traffic controllers providing approach control services in an ATS unit where RNP is implemented, should have completed training in the following:

a) RNP capable systems e.g. DME/DME, DME/DME/IRU and GNSS

b) RNAV systems accuracy, integrity, availability and continuity;

c) RNAV and RNP equipment airworthiness requirements and operational approvals;

d) RNAV procedures vs RNAV overlay procedures;

e) Waypoint fly-by vs. fly-over concept;

f) RNP procedures;

g) Effect of interference on signal coverage,

h) RNAV longitudinal separation;

i) RNAV lateral separation;

j) GNSS receiver, RAIM integrity concept, integrity alerts, and Fault Detection and Exclusion (FDE).

3.2.7. Status monitoring

The NAVAID infrastructure should be monitored and, where appropriate, maintained by the service provider. Timely warnings of outages (NOTAM) should be issued.

Status information should be provided in accordance with ICAO Annex 11 for navigation facilities or services that may be used to support the operation.

3.2.8. ATS System Monitoring

Demonstrated navigation accuracy provides a basis for determining the lateral route spacing and horizontal separation minima necessary for traffic operating on a given procedure. When available, radar observations of each aircraft's proximity to track and altitude are typically noted by Air Traffic Service (ATS) facilities and aircraft track-keeping capabilities are analyzed.

If an observation/analysis indicates that a loss of separation or obstacle clearance has occurred, the reason for the apparent deviation from track or altitude should be determined and steps taken to prevent a recurrence.

3.3. NAVIGATION SPECIFICATION

3.3.1. Background

This chapter identifies the operational requirements for Basic-RNP 1 operations. Operational compliance with these requirements should be addressed through national operational regulations, and may require a specific operational approval in some cases. For example, JAR-OPS 1 requires operators to apply to the State of the Operator/Registry, as appropriate, for operational approval.

3.3.2. Approval Process

The following steps must be completed before conducting Basic-RNP 1 operations:

a) Aircraft equipment eligibility must be determined and documented;

b) Operating procedures for the navigation systems to be used and the operator navigation database process must be documented;

c) Flight crew training based upon the operating procedures must be documented;

d) The above material must be accepted by the State regulatory authority; and

e) Operational approval should then be obtained in accordance with national operating rules.

Following the successful completion of the above steps, a Basic-RNP 1 operational approval, letter of authorization or appropriate operations specification (Ops Spec), if required, should then be issued by the State.

3.3.2.1. Aircraft Eligibility

The aircraft eligibility has to be determined through demonstration of compliance against the relevant airworthiness criteria. The OEM or the holder of installation approval for the aircraft e.g., STC holder, will demonstrate the compliance to their National Airworthiness Authority (NAA) (e.g., EASA, FAA) and the approval can be documented in manufacturer documentation (e.g., Service Letters, etc.). Aircraft Flight Manual (AFM) entries are not required provided the State accepts manufacturer documentation.

3.3.2.2. Operational Approval

The assessment of a particular operator is made by the State of Registry for that operator and in accordance with national operating rules (e.g., JAR-OPS 1, 14 CFR Part 121) supported through appropriate advisory and guidance material. The assessment should take into account:

a) Evidence of aircraft eligibility

b) Assessment of the operating procedures for the navigation systems to be used

c) Control of those procedures through acceptable entries in the Operations Manual

d) Identification of flight crew training requirements

e) Where required, control of navigation database process

The operational approval will likely be documented through the State endorsing the Air Operators Certificate (AOC) through issue of a letter of authorisation, appropriate operations specification (Ops Spec) or amendment to the operations manual.

3.3.2.2.1 Description of aircraft equipment

The operator must have a configuration list detailing pertinent components and equipment to be used for Basic-RNP 1.

3.3.2.2.2 Training documentation

Commercial operators should have a training program addressing the operational practices, procedures and training items related to Basic-RNP 1 operations (e.g. initial, upgrade or recurrent training for flight crew, dispatchers or maintenance personnel).

NOTE: It is not required to establish a separate training program or regimen if RNAV training is already an integrated element of a training program. However, it should be possible to identify what aspects of RNP are covered within a training program.

Private operators should be familiar with the practices and procedures identified in section 3.3.5, Pilot Knowledge/Training.

3.3.2.2.3 Operations manuals and checklists

Operations manuals and checklists for commercial operators must address information/guidance on the standard operating procedures detailed in section 3.3.4 of this chapter. The appropriate manuals should contain navigation operating instructions and contingency procedures where specified. Manuals and checklists must be submitted for review as part of the application process.

Private operators should operate using the practices and procedures identified in section 3.3.5, Pilot Knowledge/Training.

3.3.2.2.4 Minimum Equipment List (MEL) considerations

Any minimum equipment list (MEL) revisions necessary to address Basic-RNP 1 provisions must be approved. Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions.

3.3.3. Aircraft Requirements

The following systems meet the accuracy, integrity and continuity requirements of these criteria.

a) Aircraft with E/TSO-C129a sensor (Class B or C), E/TSO-C145a and the requirements of E/TSO-C115B FMS, installed for IFR use in accordance with FAA AC 20-130A.

b) Aircraft with E/TSO-C129a Class A1 or E/TSO-C146a equipment installed for IFR use in accordance with FAA AC 20-138 or AC 20-138A.

c) Aircraft with RNP capability certified or approved to equivalent standards

3.3.3.1. System Accuracy

During Basic-RNP 1 operations the lateral TSE should not exceed ±1NM 95% of the total flight time. Along track position error should not exceed ±1NM 95% of the total flight time. The total system error is dependent on the signal-in-space error, airborne receiver error, path definition error, display error and Flight Technical Error (FTE).

Flight technical error: An FTE of 0.5 NM (95%) is acceptable for Basic-RNP 1 operations. An acceptable means of complying with these accuracy requirements is to have a Basic GNSS system in accordance with section 3.3.3.3.1.

3.3.3.2. Performance Monitoring and Alerting

The installation must meet the following on-board performance monitoring and alerting requirements.

Integrity

The system shall provide integrity performance as specified in Table 2-1 of RTCA/DO-208, dependent on distance from the departure and destination points.

The system must provide an alert if the accuracy requirement is not met, or if the probability that the total system error exceeds 2.0 NM (terminal) or 4NM (en route) is greater than 10-5.

Continuity

The probability of loss navigation shall be no worse than 10-5 per flight hour.

Bounding FTE for equipment not monitoring TSE performance:

For operational consistency, it is desirable to use the same flight crew procedures on all Basic RNP-1 arrival and departure routes. While 2 NM full-scale deflection applies outside 30 NM from the ARP, the total system performance should still meet Basic-RNP 1 requirements. The following mitigations may be considered as operational means to limit FTE.

a) Systems with automatic 1-NM CDI scaling for the arrival or departure route: The performance requirements shall be satisfied by means of one or more of the following:
   i) Crew procedure: requires remaining within <u>half scale</u> deflection (unless there is other substantiated FTE data)
   ii) Flight director: must be tied to cross track deviation (Roll stabilization systems do not qualify)
   iii) Auto-pilot: must be tied to cross track deviation (Roll stabilization systems do not qualify)

b) The preceding guidance also applies to systems without automatic scalable CDIs, which must be manually selected to not greater than 1 NM full scale prior to commencing Basic-RNP 1 SID or STAR.

c) Aircraft with Electronic map display or other means of flight path deviation display must select appropriate map scaling for manual flight, or otherwise have the flight director or autopilot tied to cross track deviation.

An automatic monitoring of the flight technical error is not required. The on board monitoring and alerting function should consist at least of a Navigation System Error (NSE) monitoring and alerting algorithm and a lateral navigation display indicator enabling the crew to monitor the Flight Technical Error (FTE). Path Definition Error (PDE) is considered negligible if quality assurance process is applied at the navigation data base level (paragraph 3.3.6) and if crew procedures (paragraph 3.3.4) are applied.

3.3.3.3. Functional Requirements

The following Navigation Displays and Functions installed per AC 20-130A and AC 20-138A or equivalent airworthiness installation advisory material are required.

Paragraph	Functional Requirement	Explanation
a)	Navigation data, including a to/from indication and a failure indicator, must be displayed on a lateral deviation display (CDI, (E)HSI) and/or a navigation map display. These must be used as primary flight instruments for the navigation of the aircraft, for manoeuvre anticipation and for failure/status/integrity indication. They must meet the following requirements:	1) The displays must be visible to the pilot and located in the primary field of view (± 15 degrees from pilot's normal line of sight) when looking forward along the flight path. 2) The lateral deviation display scaling should agree with any alerting and annunciation limits, if implemented. 3) The lateral deviation display must also have a full-scale deflection suitable for the current phase of flight and must be based on the required total system accuracy. 4) The display scaling may be set automatically by default logic or set to a value obtained from a navigation database. The full-scale deflection value must be known or must be available for display to the pilot commensurate with en route, terminal, or approach values. 5) The lateral deviation display must be automatically slaved to the RNAV computed path. The course selector of the deviation display should be automatically slewed to the RNAV computed path. As an alternate means, a navigation map display should give equivalent functionality to a lateral deviation display as described in section 3.3.3.3.a (i-v), with appropriate map scales (scaling may be set manually by the pilot), and giving equivalent functionality to a lateral deviation display.

b)	The following system functions are required as a minimum within any Basic-RNP 1 equipment:	1) The capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft (primary navigation display), the RNAV computed desired path and aircraft position relative to the path. For operations where the required minimum flight crew is two pilots, the means for the pilot not flying to verify the desired path and the aircraft position relative to the path must also be provided. 2) A navigation database, containing current navigation data officially promulgated for civil aviation, which can be updated in accordance with the Aeronautical Information Regulation and Control (AIRAC) cycle and from which ATS routes be retrieved and loaded into the RNAV system. The stored resolution of the data must be sufficient to achieve negligible path definition error. The database must be protected against pilot modification of the stored data. 3) The means to display the validity period of the navigation data to the pilot. 4) The means to retrieve and display data stored in the navigation database relating to individual waypoints and navigation aids, to enable the pilot to verify the route to be flown. 5) Capacity to load from the database into the Basic-RNP 1 system the entire segment of the SID or STAR to be flown. *NOTE: Due to variability in systems, this document defines the RNAV segment from the first occurrence of a named waypoint, track, or course to the last occurrence of a named waypoint, track, or course. Heading legs prior to the first named waypoint or after the last named waypoint do not have to be loaded from the database. The entire SID will be still be considered an RNP 1 procedure.*
c)	The means to display the following items, either in the pilot's primary field of view, or on a readily accessible display page:	1) The active navigation sensor type 2) The identification of the active (To) waypoint 3) The ground speed or time to the active (To) waypoint 4) The distance and bearing to the active (To) waypoint
d)	The capability to execute a "Direct to" function	
e)	The capability for automatic leg sequencing with the display of sequencing to the pilot.	
f)	The capability to execute Basic-RNP 1 terminal procedures extracted from the onboard database including the capability to execute fly-over and fly-by turns.	

g)	The aircraft must have the capability to automatically execute leg transitions and maintain tracks consistent with the following ARINC 424 path terminators, or their equivalent. • Initial Fix (IF) • Course to Fix (CF) • Direct to Fix (DF) • Track to Fix (TF)	*NOTE 1: Path terminators are defined in ARINC Specification 424, and their application is described in more detail in RTCA documents DO-236B and DO-201A.* *NOTE 2: Numeric values for courses and tracks must be automatically loaded from the RNAV system database.*
h)	The aircraft must have the capability to automatically execute leg transitions consistent with VA, VM and VI ARINC 424 path terminators, or must be able to be manually flown on a heading to intercept a course or to go direct to another fix after reaching a procedure-specified altitude.	
i)	The aircraft must have the capability to automatically execute leg transitions consistent with CA and FM ARINC 424 path terminators, or the RNAV system must permit the pilot to readily designate a waypoint and select a desired course to or from a designated waypoint.	
j)	The capability to load a Basic RNP-1 procedure from the database, by procedure name, into the RNAV system.	
k)	The capability to display an indication of the Basic RNP-1 system failure, in the pilot's primary field of view.	
l)	Database Integrity	The navigation database suppliers should comply with RTCA DO-200A/EUROCAE document ED 76, Standards for Processing Aeronautical Data (see paragraph 6.1). A Letter of Acceptance (LOA) issued by the appropriate regulatory authority demonstrates compliance with this requirement. Discrepancies that invalidate a route must be reported to the navigation database supplier and affected routes must be prohibited by an operator's notice to its flight crew. Aircraft operators should consider the need to conduct periodic checks of the operational navigation databases in order to meet existing quality system requirements.

3.3.4. Operating Procedures

Airworthiness certification alone does not authorize Basic-RNP 1 operations. Operational approval is also required to confirm the adequacy of the operator's normal and contingency procedures for the particular equipment installation.

Pre-flight Planning

Operators and pilots intending to conduct operations on Basic-RNP 1 SIDs and STARs should file the appropriate flight plan suffixes.

The onboard navigation data must be current and include appropriate procedures.

NOTE: Navigation databases are expected to be current for the duration of the flight. If the AIRAC cycle is due to change during flight, operators and pilots should establish procedures to ensure the accuracy of navigation data, including suitability of navigation facilities used to define the routes and procedures for flight.

ABAS Availability

When using GNSS for navigation, SBAS or ABAS fault detection (e.g., RAIM) functionality is required to meet Annex 10 navigation performance. Therefore, the availability of the NAVAID infrastructure, required for the Basic-RNP 1 SIDs, and STARs, including any non-RNAV contingencies, must be confirmed for the period of intended operations using all available information. The pilot must also confirm availability of the onboard navigation equipment necessary for the SID or STAR to be flown.

The availability of SBAS or ABAS fault detection can be determined through NOTAMs (if available) or through prediction for the intended Basic-RNP 1 operation. Operators using TSO-C145/C146 receivers should check GPS RAIM availability in areas where SBAS is not usable or available. RAIM availability prediction services may be provided by the ANSP, avionics manufacturer or other entities. Operators should be familiar with the prediction information provided by any State within which they operate. Receiver RAIM prediction capability can also be used. Any prediction should take into account the latest GPS constellation NOTAMs.

In the event of a predicted, continuous loss of fault detection of more than five (5) minutes for any part of the Basic-RNP 1 operation, the flight planning should be revised (e.g., delaying the departure or planning a different departure procedure). If the prediction service is temporarily unavailable, ANSPs may still allow Basic-RNP 1 operations to be conducted.

RAIM availability prediction software does not guarantee the service, they are rather tools to asses the expected capability to meet the required navigation performances. Because of unplanned failure of some GNSS elements, pilots/ANSP must realize that RAIM (or GNSS navigation) altogether may be lost while airborne which may require to revert to an alternative means of navigation. Therefore, pilots should assess their capability to navigate (potentially to an alternate destination) in case of failure of GNSS navigation.

General Operating Procedures

The pilot should comply with any instructions or procedures identified by the manufacturer as necessary to comply with the performance requirements in this chapter.

NOTE: Pilots must adhere to any AFM limitations or operating procedures required to maintain Basic-RNP 1 performance for the SID or STAR.

Operators and pilots should not request or file Basic-RNP 1 procedures unless they satisfy all the criteria in the relevant State documents. If an aircraft not meeting these criteria receives a clearance from ATC to conduct a Basic-RNP 1 procedure, the pilot must advise ATC that he/she is unable to accept the clearance and must request alternate instructions.

At system initialization, pilots must confirm the navigation database is current and verify that the aircraft position has been entered correctly. Pilots must verify proper entry of their ATC assigned route upon initial clearance and any subsequent change of route. Pilots must ensure the waypoints sequence depicted by their navigation system matches the route depicted on the appropriate chart(s) and their assigned route.

Pilots must not fly a Basic-RNP 1 SID or STAR unless it is retrievable by procedure name from the onboard navigation database and conforms to the charted procedure. However, the procedure may subsequently be modified through the insertion or deletion of specific waypoints in response to ATC clearances. The manual entry, or creation of new waypoints, by manual entry of latitude and longitude or rho/theta values is not permitted. Additionally, pilots must not change any SID or STAR database waypoint type from a fly-by to a fly-over or vice versa.

Flight crews should crosscheck the cleared flight plan by comparing charts or other applicable resources with the navigation system textual display and the aircraft map display, if applicable. If required, the exclusion of specific navigation aids should be confirmed.

NOTE: Pilots may notice a slight difference between the navigation information portrayed on the chart and their primary navigation display. Differences of 3° or less may result from equipment manufacturer's application of magnetic variation and are operationally acceptable.

Cross-checking with conventional NAVAIDs is not required as the absence of integrity alert is considered sufficient to meet the integrity requirements. However, monitoring of navigation reasonableness is suggested, and any loss of RNP capability shall be reported to ATC.

Unless already required by the State Authority, when operating on RNP SIDs or STARs, pilots are encouraged to use flight director and/or autopilot in lateral navigation mode, if available.

Pilots must use a lateral deviation indicator (or equivalent navigation map display), flight director and/or autopilot in lateral navigation mode on Basic-RNP 1procedures. Pilots of aircraft with a lateral deviation indicator (e.g., a standalone GNSS receiver) must ensure that lateral deviation indicator scaling (full-scale deflection) is suitable for the navigation accuracy associated with the procedure (i.e.,+-1 nm for Basic-RNP 1). All pilots are expected to maintain centrelines, as depicted by onboard lateral deviation indicators and/or flight guidance during all Basic-RNP 1 operations described in this manual unless authorized to deviate by ATC or under emergency conditions. For normal operations, cross-track error/deviation (the difference between the system computed path and the aircraft position relative to the path) should be limited to +/- ½ the navigation accuracy associated with the procedure (i.e., 0.5 nm for Basic-RNP 1). Brief deviations from this standard (e.g., overshoots or undershoots) during and immediately after turns, up to a maximum of 1 times the navigation accuracy (i.e., 1.0 nm for Basic-RNP 1), are allowable.

NOTE: Some aircraft do not display or compute a path during turns. As such, pilots of these aircraft may not be able to adhere to the ±½ lateral navigation accuracy during turns but are still expected to satisfy the standard during intercepts following turns and on straight segments.

If ATC issues a heading assignment taking the aircraft off a route, the pilot should not modify the flight plan in the RNAV system until a clearance is received to rejoin the route or the controller confirms a new route clearance. When the aircraft is not on the published route, the specified accuracy requirement does not apply.

Manually selecting aircraft bank limiting functions may reduce the aircraft's ability to maintain its desired track and are not recommended. Pilots should recognize manually selectable aircraft bank-limiting functions might reduce their ability to satisfy ATC path expectations, especially when executing large angle turns. This should not be construed as a requirement to deviate from Airplane Flight Manual procedures; rather, pilots should be encouraged to limit the selection of such functions within accepted procedures.

Aircraft with RNP selection capability

Pilots of aircraft with RNP input selection capability should select RNP 1 or lower, for Basic-RNP 1 SIDs and STARs.

Basic-RNP 1 SID Specific Requirements

Prior to commencing takeoff, the pilot must verify the aircraft's Basic-RNP 1 system is available, operating correctly, and the correct airport and runway data are loaded. Prior to flight, pilots must verify their aircraft navigation system is operating correctly and the correct runway and departure procedure (including any applicable en route transition) are entered and properly depicted. Pilots who are assigned a Basic-RNP 1 departure procedure and subsequently receive a change of runway, procedure or transition must verify the appropriate changes are entered and available for navigation prior to takeoff. A final check of proper runway entry and correct route depiction, shortly before takeoff, is recommended.

Engagement Altitude. The pilot must be able to use Basic-RNP 1 equipment to follow flight guidance for lateral RNAV no later than 500 feet above airport elevation. The altitude at which RNAV guidance begins on a given route may be higher (e.g., climb to 1000 ft then direct to…).

Pilots must use an authorized method (lateral deviation indicator/navigation map display/flight director/autopilot) to achieve an appropriate level of performance for Basic-RNP 1.

GNSS Aircraft. When using GNSS, the signal must be acquired before the take-off roll commences. For aircraft using TSO-C129/C129A equipment, the departure airport must be loaded into the flight plan in order to achieve the appropriate navigation system monitoring and sensitivity. For aircraft using TSO-C145a/C146a avionics, if the departure begins at a runway waypoint, then the departure airport does not need to be in the flight plan to obtain appropriate monitoring and sensitivity.

Basic-RNP 1 STAR Specific Requirements

Prior to the arrival phase, the flight crew should verify that the correct terminal route has been loaded. The active flight plan should be checked by comparing the charts with the map display (if applicable) and the MCDU. This includes confirmation of the waypoint sequence, reasonableness of track angles and distances, any altitude or speed constraints, and, where possible, which waypoints are fly-by and which are fly-over. If required by a route, a check will need to be made to confirm that updating will exclude a particular navigation aid. A route must not be used if doubt exists as to the validity of the route in the navigation database.

Note: As a minimum, the arrival checks could be a simple inspection of a suitable map display that achieves the objectives of this paragraph.

The creation of new waypoints by manual entry into the Basic-RNP 1 system by the flight crew would invalidate the route and is not permitted.

Where the contingency procedure requires reversion to a conventional arrival route, necessary preparation must be completed before commencing the Basic-RNP 1 procedure.

Procedure modifications in the terminal area may take the form of radar headings or “direct to” clearances and the flight crew must be capable of reacting in a timely fashion. This may include the insertion of tactical waypoints loaded from the database. Manual entry or modification by the flight crew of the loaded route, using temporary waypoints or fixes not provided in the database, is not permitted.

Pilots must verify their aircraft navigation system is operating correctly and the correct arrival procedure and runway (including any applicable transition) are entered and properly depicted.

Although a particular method is not mandated, any published altitude and speed constraints must be observed.

Contingency Procedures

The pilot must notify ATC of any loss of the RNP capability (integrity alerts or loss of navigation), together with the proposed course of action. If unable to comply with the requirements of a Basic-RNP 1 SID or STAR for any reason, pilots must advise ATS as soon as possible. The loss of RNP capability includes any failure or event causing the aircraft to no longer satisfy the Basic-RNP 1 requirements of the route.

In the event of communications failure, the flight crew should continue with the published lost communication procedure.

3.3.5. Pilot Knowledge and Training

The training program should provide sufficient training (for example, simulator, training device, or aircraft) on the aircraft’s RNP system to the extent that the pilots are familiar with the following:

a) The information in this chapter.

b) The meaning and proper use of Aircraft Equipment/Navigation Suffixes.

c) Procedure characteristics as determined from chart depiction and textual description.

d) Depiction of waypoint types (fly-over and fly-by) and path terminators (provided in section 3.4.3.4 AIRINC 424 path terminators) and any other types used by the operator) as well as associated aircraft flight paths.

e) Required navigation equipment for operation on Basic-RNP 1 SIDs, and STARs.

f) RNP system-specific information:

   i) Levels of automation, mode annunciations, changes, alerts, interactions, reversions, and degradation.

   ii) Functional integration with other aircraft systems.

   iii) The meaning and appropriateness of route discontinuities as well as related flight crew procedures.

   iv) Pilot procedures consistent with the operation (for example, monitor PROG or LEGS page).

   v) Types of navigation sensors utilized by the RNP system and associated system prioritization/weighting/logic.

   vi) Turn anticipation with consideration to speed and altitude effects.

   vii) Interpretation of electronic displays and symbols

   viii) Understanding of the aircraft configuration and operational conditions required to support Basic-RNP 1 operations, i.e appropriate selection of CDI scaling (lateral deviation display scaling)

g) RNP equipment operating procedures, as applicable, including how to perform the following actions:

   i) Verify currency and integrity of aircraft navigation data.

   ii) Verify successful completion of RNP system self-tests.

   iii) Initialize navigation system position.

   iv) Retrieve and fly a SID or a STAR with appropriate transition.

   v) Adhere to speed and/or altitude constraints associated with a SID or STAR.

   vi) Select the appropriate STAR or SID for the active runway in use and be familiar with procedures to deal with a runway change.

   vii) Verify waypoints and flight plan programming.

   viii) Fly direct to a waypoint.

   ix) Fly a course/track to a waypoint.

   x) Intercept a course/track.

   xi) Flying radar vectors and rejoining an RNP route from ‘heading’ mode.

   xii) Determine cross-track error/deviation. More specifically, the maximum deviations allowed to support Basic-RNP 1 must be understood and respected.

   xiii) Insert and delete route discontinuity.

   xiv) Remove and reselect navigation sensor input.

   xv) When required, confirm exclusion of a specific navigation aid or navigation aid type.

   xvi) Change arrival airport and alternate airport.

   xvii) Perform parallel offset function if capability exists. Pilots should know how offsets are applied, the functionality of their particular RNP system and the need to advise ATC if this functionality is not available.

xviii) Perform RNAV holding function.

h) Operator-recommended levels of automation for phase of flight and workload, including methods to minimize cross-track error to maintain route centerline.

i) R/T phraseology for RNAV/RNP applications

j) Contingency procedures for RNAV/RNP failures.

3.3.6. Database

The navigation database should be obtained from a supplier that complies with RTCA DO-200A/EUROCAE document ED 76, Standards for Processing Aeronautical Data. A Letter of Acceptance (LOA) issued by the appropriate regulatory authority demonstrates compliance with this requirement (e.g., FAA LOA issued in accordance with FAA AC 20-153 or EASA LOA issued in accordance with EASA IR 21 subpart G.

Discrepancies that invalidate a SID or STAR must be reported to the navigation database supplier and affected SID or STAR must be prohibited by an operator's notice to its flight crew.

Aircraft operators should consider the need to conduct ongoing checks of the operational navigation databases in order to meet existing quality system requirements.

Note: To minimize path definition error, the database should comply with DO 200A, or an equivalent operational means must be in place to ensure database integrity for the Basic-RNP 1 SIDs or STARs.

3.3.7. Oversight of Operators

A regulatory authority may consider any navigation error reports in determining remedial action. Repeated navigation error occurrences attributed to a specific piece of navigation equipment may result in cancellation of the approval for use of that equipment.

Information that indicates the potential for repeated errors may require modification of an operator's training program. Information that attributes multiple errors to a particular pilot crew may necessitate remedial training or license review.

3.4. REFERENCES

Copies of EUROCONTROL documents may be requested from EUROCONTROL, Documentation Centre, GS4, Rue de la Fusee, 96, B-1130 Brussels, Belgium; (Fax: 32 2 729 9109). Web site: http://www.ecacnav.com

Copies of EUROCAE documents may be purchased from EUROCAE, 17 rue Hamelin, 75783 PARIS Cedex 16, France, (Fax : 33 1 45 05 72 30). Web site: http://www.eurocae.org

Copies of FAA documents may be obtained from Superintendent of Documents,

Government Printing Office, Washington, DC 20402-9325, USA. Web site: http://www.faa.gov/certification/aircraft/ (Regulation and Guidance Library)

Copies of RTCA documents may be obtained from RTCA Inc., 1140 Connecticut Avenue, N.W., Suite 1020, Washington, DC 20036-4001, USA, (Tel: 1 202 833 9339). Web site www.rtca.org.

Copies of ARINC documents may be obtained from Aeronautical Radio Inc., 2551 Riva Road, Annapolis, Maryland 24101-7465, USA. Web site: http://www.arinc.com

Copies of JAA documents are available from JAA's publisher Information Handling Services (IHS). Information on prices, where and how to order, is available on the JAA web site, http://www.jaa.nl , and on the IHS web sites http://www.global.his.com , and http://www.avdataworks.com .

Copies of EASA documents may be obtained from EASA (European Aviation Safety Agency), 101253, D-50452 Koln, Germany.

Copies of ICAO documents may be purchased from Document Sales Unit, International Civil Aviation Organization, 999 University Street, Montreal, Quebec, Canada H3C 5H7, (Fax: 1 514 954 6769, or e-mail: sales_unit@icao.org) or through national agencies.

CHAPTER 4

IMPLEMENTING ADVANCED-RNP 1

To be developed

CHAPTER 5

IMPLEMENTING RNP APP

5.1. INTRODUCTION

5.1.1. Background

RNP approach (RNP APP) procedures are characterized by existing RNAV (GNSS) approach procedures designed with straight segment. RNP APP procedures are expected to be authorized by a number of State regulatory agencies including the European Aviation Safety Agency (EASA) and U.S. Federal Aviation Administration (FAA). The FAA has issued airworthiness criteria, AC20-138A, for GNSS equipment and systems that are eligible for such operations. EASA is developing certification material (AMC20 series) for airworthiness and operational approval for RNAV GNSS approach operations. While similar in functional requirements, there are slight differences between these two sets of airworthiness criteria. In order to achieve a global standard, the two sets of criteria were harmonized into a single navigation standard.

This chapter addresses non-precision approach applications based on GNSS and are named RNP APP thanks to the ability of the airborne system/installation to reach a high level of integrity supported by an on board performance monitoring and alerting function.

Overlay procedures and procedures designed with Radius to Fix (RF) leg are not addressed in this chapter.

5.1.2. Purpose

This chapter provides guidance to States implementing RNP APP operations (excluding RNP AR APP operations). For the Air Navigation Service Provider, it provides a consistent ICAO recommendation on what to implement. For the operator, it provides a combination of European and U.S. RNAV airworthiness and operational criteria. For existing single and multi-sensor RNAV systems using GNSS, compliance with both European (EASA AMC 20) and U.S. (FAA AC 20-138A, AC 20-130A or TSO C115b) is compliance with this ICAO standard, obviating the need for further assessment or AFM documentation. In addition, an operational approval to this standard allows an operator to conduct RNP APP operations globally.

> *Note: The multi-sensor systems may use other sensor combinations such as DME/DME or DME/DME/IRU that provide the navigation performance acceptable for RNP APPROACH. However, such cases are limited due to the increased complexity in the NAVAID infrastructure requirements and assessment, and are not practical or cost effective for widespread application.*

This chapter addresses only the requirement for the lateral navigation aspect (2D navigation). The vertical navigation aspect is discussed in PBN VOL II Attachment A.

5.1.3. Terminology

Consistent with TSO-C129a performance, RNP APP procedures require a total system error of ± 1.0 NM in the initial, intermediate and missed approach segments of the instrument approach procedure, and a total system error of ± 0.3 NM in the final approach segment.

5.2. ANSP CONSIDERATIONS

5.2.1. Navaid Infrastructure

GNSS is the primary navigation system to support RNP APP procedures.

Under certain circumstances, the missed approach segment may be based upon the conventional navaid (e.g VOR, DME, NDB).

The acceptability of the risk of loss of RNP APP capability for multiple aircraft due to satellite failure or loss of on board monitoring and alerting function (e.g. RAIM holes), must be considered by the responsible airspace authority.

5.2.2. Communication & ATS Surveillance

RNP APP does not include specific requirements for communication or ATS surveillance. Adequate obstacle clearance is achieved through aircraft performance and operating procedures.

5.2.3. Obstacle Clearance

Detailed guidance on obstacle clearance is provided in PANS-OPS (Doc 8168, Volume II). The general criteria in Part 1 and Part 3 apply, together with the approach criteria from Doc 8168, Volume II, Part III, Section 1, Chapter 2 and Section 3, Chapter 3 regarding Basic GNSS. The criteria in Part 3, Section 1, Chapter 7 shall not be used. If Barometric VNAV is applied (see attachment A), then also PANS-OPS, Volume II, Section 3, Chapter 4 applies.

Missed approach procedure may be supported by either RNAV or conventional (e.g. based on NDB, VOR, DME) segments.

Procedures design must take account of the absence of a vertical navigation capability on the aircraft.

5.2.4. Additional Considerations

Many aircraft have the capability to execute a holding pattern manoeuvre using their RNAV system.

Guidance in this chapter does not supersede appropriate State operating requirements for equipage.

5.2.5. Publication

The instrument approach chart should clearly identify the RNP APP application as $\text{RNAV}_{\text{(GNSS)}}$ or equivalent.

The procedure design should rely on normal descent profiles and the chart should identify minimum segment altitude requirements, to include an LNAV OCA(H)/MDA.

If the missed approach segment is based on conventional means, navaid facilities that are necessary to conduct the approach must be identified in the relevant publications.

The navigation data published in the State AIP for the procedures and supporting navigation aids must meet the requirements of ICAO Annex 15 and Annex 4 (as appropriate).

All procedures must be based upon WGS 84 coordinates.

5.2.6. Controller Training

Air traffic controllers providing approach control services in an ATS unit where RNP APP is implemented, should have completed training in the following:

a) RNP APP procedures;

   i) The title of the procedure and phraseology to be used to clear aircraft for the approach

   ii) Radar vectoring techniques particular to aircraft executing a RNP APP. When Radar vectoring to final approach, controllers need to ensure the capture of the final approach occurs sufficiently prior to the final approach fix.

b) RNP APP equipment airworthiness requirements and operational approvals;

c) Waypoint fly-by vs. fly-over concept;

d) Effect of interference on signal coverage,

e) GNSS receiver, RAIM integrity concept, integrity alerts, and Fault Detection and Exclusion (FDE).

5.2.7. Status monitoring

The NAVAID infrastructure should be monitored and, where appropriate, maintained by the service provider. Timely warnings of outages (NOTAM) should be issued.

Status information should be provided in accordance with ICAO Annex 11 for navigation facilities or services that may be used to support the operation.

5.2.8. ATS System Monitoring

If an observation/analysis indicates that a loss of obstacle clearance has occurred, the reason for the apparent deviation from track or altitude should be determined and steps taken to prevent a recurrence.

5.3. NAVIGATION SPECIFICATION

5.3.1. Background

This section identifies the airworthiness and operational requirements for RNP APP operations. Operational compliance with these requirements must be addressed through national operational regulations, and may require a specific operational approval in some cases. For example, certain operational regulation requires operators to apply to their national authority (State of registry) for operational approval.

This chapter addresses only the lateral part of the navigation system. If the system is approved for APV-Baro VNAV operation, the installation must be compliant with requirements of VOL II Attachment A “Baro VNAV”.

5.3.2. Approval Process

The following steps must be completed before conducting RNP APP operations:

a) Aircraft equipment eligibility must be determined and documented;

b) Operating procedures for the navigation systems to be used and the operator navigation database process must be documented;

c) Flight crew training based upon the operating procedures must be documented if necessary;

d) The above material must be accepted by the State regulatory authority; and

e) Operational approval must then be obtained in accordance with national operating rules.

Following the successful completion of the above steps, a RNP APP operational approval, letter of authorization or appropriate operations specification (Ops Spec), if required, should then be issued by the State.

5.3.2.1 Aircraft Eligibility

Eligibility airworthiness documents. Relevant documentation acceptable to the State of operation must be available to establish that the aircraft is equipped with an RNAV systems meeting RNP APP requirements. To avoid unnecessary regulatory activity, the determination of eligibility for existing systems should consider acceptance of manufacturer documentation of compliance e.g. as with EASA AMC 20 series document. RNP AR APP Systems are considered qualified for RNP APP operations. No further examination of aircraft capability, operator training, maintenance, operating procedures, databases, etc is necessary.

5.3.2.2 Operational Approval

The assessment of a particular operator is made by the State of Registry for that operator and in accordance with national operating rules (e.g., JAR-OPS 1, 14 CFR Part 121) supported through appropriate advisory and guidance material. The assessment should take into account:

a) Evidence of aircraft eligibility

b) Assessment of the operating procedures for the navigation systems to be used

c) Control of those procedures through acceptable entries in the Operations Manual

d) Identification of flight crew training requirements

e) Where required, control of navigation database process

The operational approval will likely be documented through the State endorsing the Air Operators Certificate (AOC) through issue of a letter of authorisation, appropriate operations specification (Ops Spec) or amendment to the operations manual.

5.3.2.2.1 Description of aircraft equipment

The operator must have a configuration list detailing pertinent components and equipment to be used for RNP APP operation.

5.3.2.2.2 Training documentation

Commercial operators must have a training program addressing the operational practices, procedures and training items related to RNP APP operations (e.g. initial, upgrade or recurrent training for flight crew, dispatchers or maintenance personnel).

NOTE: It is not required to establish a separate training program or regimen if RNAV training is already an integrated element of a training program. However, it should be possible to identify what aspects of RNAV are covered within a training program.

Private operators must be familiar with the practices and procedures identified in paragraph 5.3.5 “Pilot Knowledge/Training” of this chapter.

5.3.2.2.3 Operations manuals and checklists

Operations manuals and checklists for commercial operators must address information/guidance on the standard operating procedures detailed in the “Operating procedures” section of this chapter. The appropriate manuals should contain navigation operating instructions and contingency procedures where specified. Manuals and checklists must be submitted for review as part of the application process.

Private operators must operate using the practices and procedures identified in paragraph 5.3.5 “Pilot Knowledge/Training” of this chapter.

5.3.2.2.4 Minimum Equipment List (MEL) considerations

Any minimum equipment list (MEL) revisions necessary to address RNP APP provisions must be approved.

Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions.

5.3.3. Aircraft Requirements

The following systems meet the accuracy, integrity and continuity requirements of these criteria:

a) GNSS stand-alone systems, equipment should be approved in accordance with TSO-C129a/ ETSO-C129a Class A1 or E/TSO-C146A Class Gamma and operational class 1, 2 or 3.

b) GNSS sensors used in multi-sensor system (e.g. FMS) equipment should be approved in accordance with TSO C129 ( )/ ETSO-C129 ( ) Class B1, C1, B3, C3 or E/TSO C145A class 1, 2 or 3 or E/TSO C146A class 1, 2 or 3.

NOTE: For GNSS receiver approved in accordance with E/TSO-C129(), capability for satellite Fault detection and Exclusion (FDE) is recommended to improve Continuity of function.

c) Multi-sensor systems using GNSS should be approved accordance with AC20-130A or TSO-C115b, as well as having been demonstrated for RNP capability.

If the missed approach procedure is based on conventional means (e.g. NDB, VOR, DME), related navigation equipment must be installed and be serviceable.

5.3.3.1 System Accuracy

The Lateral Total System Error (TSE) of the on-board navigation system must be equal to or better than:

a) +/- 1 NM for 95% of the flight time for the initial, intermediate segment and for the RNAV missed approach. *Note: There is no specific RNAV accuracy requirement if the missed approach is based on conventional means (VOR, DME, NDB) or on dead reckoning.*

b) +/- 0.3 NM for 95% of the flight time for the final approach.

The Lateral Total System Error (TSE) is dependent on the Navigation System Error (NSE) (a combination of path definition error, position estimation error and display error) and Flight Technical Error (FTE). In order to satisfy the +/- 0.3 NM accuracy, FTE (95%) should not exceed 0.25 NM whatever the operating mode (manual, Flight Director or Autopilot). An FTE (95%) of ± 0.25NM is assumed for the approach when coupled to a flight director and 0.125 NM when coupled to an autopilot. For manual mode, it should be demonstrated that an FTE of 0.25 NM could be maintained under all foreseeable condition through a dedicated flight test evaluation except if a standardized CDI is installed (compliant with full-scale deflection sensitivity requirement of TSO-C129a paragraph (a).3.(viii)). In that case, no specific flight test is requested. Outside of the FAF, an FTE of 0.5 NM may be assumed.

Positioning data from other types of navigation sensors may be integrated with the GNSS data provided it does not cause position errors exceeding the Total System Error (TSE) budget**,** or if means are provided to deselect the other navigation sensor types.

An acceptable means of complying with these accuracy requirements is to have an RNAV system approved for RNAV approaches in accordance with 2D navigation accuracy criteria of FAA AC 20-138, AC 20-138A or AC 20-130A.

5.3.3.2 Performance Monitoring and Alerting

The installation must meet the following on-board performance monitoring and alerting requirements.

Integrity

The system shall provide integrity performance as specified in Table 2-1 of RTCA/DO-208 for terminal and approach phases of flight as appropriate.

Malfunction of the aircraft navigation equipment is considered a major failure condition under airworthiness regulations (i.e. 10-5 per hour).

The system must provide an alert if the accuracy requirement is not met, or if the probability that the total system error exceeds 0.6 NM (for the final approach segment) or 2NM (for initial, intermediate and missed approach segment) is greater than 10-5.

Continuity

The probability of loss navigation shall be no worse than 10-5 per flight hour.

Loss of function is considered a minor failure condition if the operator can revert to a different navigation system and proceed to a suitable airport. For RNP APP operation at least one RNAV system is required.

Note: From an operational point of view, the operator should develop contingency procedure in order to react safely following the loss of the RNP APP capability during the approach.

Bounding FTE for equipment not monitoring TSE performance

For operational consistency, it is desirable to use the same flight crew procedures on all RNP APP procedures. The following mitigations may be considered as operational means to limit FTE.

a) Systems with automatic CDI scaling: The performance requirements shall be satisfied by means of one or more of the following:
   i) Crew procedure: requires remaining within half scale allowable deflection (unless there is other substantiated FTE data)
   ii) Flight director: must be tied to cross track deviation (Roll stabilization systems do not qualify)
   iii) Auto-pilot: must be tied to cross track deviation (Roll stabilization systems do not qualify)
b) The preceding guidance also applies to systems without automatic scalable CDIs, which must be manually selected to 0.3 NM prior to commencing the RNP APP.

Aircraft using only an Electronic map display are not authorized to manually fly the final approach unless it has been demonstrated to meet the TSE requirements.

An automatic monitoring of the flight technical error is not required. The on board monitoring and alerting function should consist at least of a Navigation System Error (NSE) monitoring and alerting algorithm and a lateral navigation display indicator enabling the crew to monitor the Flight Technical Error (FTE). Path Definition Error (PDE) is considered negligible if quality assurance process is applied at the navigation data base level (paragraph 5.3.6) and if crew procedures (paragraph 5.3.4) are applied.

NSE Monitoring and Alerting

The Navigation System Error (NSE) monitoring and alerting algorithm must be provided at least by an ABAS or an equivalent algorithm.

The probability of signal in space errors causing a horizontal NSE greater than 0.6 NM (for the final approach segment) or 2NM (for initial, intermediate and missed approach segment) without alert, shall be less than 10-7 per hour.

FTE Monitoring and Alerting

The lateral deviation display must have a full-scale deflection suitable for the phase of flight and consistent with the Total System Error (TSE) requirement. It is recognized that a scaling of +/- 1NM for the initial, intermediate and missed approach segments and of +/- 0.3 NM for the final segment are an acceptable means to satisfy this objective.

5.3.3.1. Functional Requirements

Navigation Displays and Required Functions

Navigation data, including a to/from indication, and a failure indicator, must be displayed on a lateral deviation display (CDI, (E)HSI) and/or a navigation map display. These must be used as primary flight instruments for the navigation of the aircraft, for manoeuvre anticipation and for failure/status/integrity indication.

a) The displays must be visible to the pilot and located in the primary field of view (± 15 degrees from pilot's normal line of sight) when looking forward along the flight path.

b) The lateral deviation display scaling should agree with any alerting and annunciation limits

c) The lateral deviation display must also have a full-scale deflection suitable for the current phase of flight and must be based on the Total System Error requirement. Scaling is +/- 1NM for the initial and intermediate segments and +/- 0.3 NM for the final segment.

   Note: Use of electronic map displays and occasional reference to the RNAV Control Display Unit information has been shown to be acceptable.

d) The display scaling may be set automatically by default logic or set to a value obtained from a navigation database. The full-scale deflection value must be known or must be available for display to the pilot commensurate with approach values.

e) As an alternate means, a navigation map display must give equivalent functionality to a lateral deviation display with appropriate map scales (scaling may be set manually by the pilot), and giving equivalent functionality to a lateral deviation display. To be approved, the navigation map display must be shown to meet the TSE requirements.

f) It is highly recommended that the course selector of the deviation display is automatically slaved to the RNAV computed path. Note: this does not apply for installations where an electronic map display contains a graphical display of the flight path and path deviation.

g) Flight director and/or autopilot is not required for this type of operation however if the lateral Total System Error cannot be demonstrated without these systems, it becomes mandatory. In this case coupling to the flight director and/or automatic pilot from the RNAV system must be clearly indicated at the cockpit level.

h) Enhanced navigation display (e.g. electronic map display or enhanced EHSI) to improve lateral situational awareness, navigation monitoring and approach verification (flight plan verification) could become mandatory if the RNAV installation doesn't support the display of information necessary for the accomplishment of these crew tasks.

The following system functions are required as a minimum:

a) The capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft (primary navigation display), the RNAV computed desired path and aircraft position relative to the path. For aircraft where the minimum flight crew is two pilots, the means for the pilot not flying to verify the desired path and the aircraft position relative to the path must also be provided

b) A navigation database, containing current navigation data officially promulgated for civil aviation, which can be updated in accordance with the Aeronautical Information Regulation and Control (AIRAC) cycle and from which approach procedures can be retrieved and loaded into the RNAV system. The stored resolution of the data must be sufficient to achieve the required track keeping accuracy. The database must be protected against pilot modification of the stored data.

c) The means to display the validity period of the navigation data to the pilot.

d) The means to retrieve and display data stored in the navigation database relating to individual waypoints and navigation aids, to enable the pilot to verify the procedure to be flown.

e) Capacity to load from the database into the RNAV system the whole approach to be flown. The approach must be loaded from the database, into the RNAV system, by its name.

f) The means to display the following items, either in the pilot's primary field of view, or on a readily accessible display page:

(i)The identification of the active (To) waypoint

(ii)The distance and bearing to the active (To) waypoint

(iii)The ground speed or time to the active (To) waypoint

g) The means to display the following items on a readily accessible display page:

(i)The display of distance between flight plan waypoints

(ii)The display of distance to go

(iii)The display of along track distances

(iv)The active navigation sensor type if there is other sensor in addition to the GNSS one.

h) The capability to execute a "Direct to" function.

i) The capability for automatic leg sequencing with the display of sequencing to the pilot.

j) The capability to execute procedures extracted from the onboard database including the capability to execute fly-over and fly-by turns.

k) The capability to automatically execute leg transitions and maintain tracks consistent with the following ARINC 424 path terminators, or their equivalent.

ARINC 424 Path Terminators
Initial Fix (IF)
Track to Fix (TF)
Direct to Fix (DF)

Note : Path terminators are defined in ARINC Specification 424, and their application is described in more detail in RTCA documents DO-236B and DO-201A.

l) The capability to display an indication of the RNAV system failure, including the associated sensors, in the pilot's primary field of view

m) The capability to indicate to the crew when NSE Alert Limit is exceeded (alert provided by the "on board performance monitoring and alerting function").

5.3.4. Operating Procedures

Airworthiness certification alone does not authorise operator to conduct RNP APP operation. Operational approval is also required to confirm the adequacy of the operator's normal and contingency procedures for the particular equipment installation.

5.3.4.1 Pre-flight Planning

Operators and pilots intending to conduct operations on RNP APP procedure must file the appropriate flight plan suffixes and the on board navigation data must be current and include appropriate procedures.

NOTE: Navigation databases are expected to be current for the duration of the flight. If the AIRAC cycle is due to change during flight, operators and pilots should establish procedures to ensure the accuracy of navigation data, including suitability of navigation facilities used to define the routes and procedures for flight.

In addition to the normal pre-flight planning checks the following must be included:

a) The pilot must ensure that approaches which may be used for the intended flight (including alternates aerodromes) are selectable from a valid navigation data base (current AIRAC cycle), have been verified by the appropriate process (navigation data base integrity process) and are not prohibited by a company instruction or NOTAM.

b) Subject to state's regulations, during the pre-flight phase, the pilot should ensure sufficient means are available to navigate and land at the destination or at an alternate aerodrome in the case of loss of RNP APP airborne capability.

c) Operators and flight-crews must take account of any NOTAMs or operator briefing material that could adversely affect the aircraft system operation, or the availability or suitability of the procedures at the airport of landing, or any alternate airport.

d) For missed approach procedures based on conventional means (VOR,NDB) the appropriate airborne equipment required to fly this procedure is installed in the aircraft and is operational. Also, the associated ground-based navaids are operational.

ABAS Availability

When using GNSS for navigation, SBAS or ABAS fault detection (e.g., RAIM) functionality is required to meet Annex 10 navigation performance. Therefore, the availability of the NAVAID infrastructure, required for the RNP APP, including any non-RNAV contingencies, must be confirmed for the period of intended operations using all available information. The pilot must also confirm availability of the onboard navigation equipment necessary for the procedure to be flown.

The availability of SBAS or ABAS fault detection can be determined through NOTAMs (if available) or through prediction for the intended RNP APP operation. Operators using TSO-C145/C146 receivers should check GPS RAIM availability in areas where SBAS is not usable or available. RAIM availability prediction services may be provided by the ANSP, avionics manufacturer or other entities. Operators should be familiar with the prediction information provided by any State within which they operate. Receiver RAIM prediction capability can also be used. Any prediction should take into account the latest GPS constellation NOTAMs.

In the event of a predicted, continuous loss of fault detection of more than five (5) minutes for any part of the RNP APP operation, the flight planning should be revised (e.g., delaying the departure or planning a different departure procedure). If the prediction service is temporarily unavailable, ANSPs may still allow RNP APP operations to be conducted.

RAIM availability prediction software does not guarantee the service, they are rather tools to asses the expected capability to meet the required navigation performances. Because of unplanned failure of some GNSS elements, pilots/ANSP must realize that RAIM (or GNSS navigation) altogether may be lost while airborne which may require to revert to an alternative means of navigation. Therefore, pilots should assess their capability to navigate (potentially to an alternate destination) in case of failure of GNSS navigation.

5.3.4.2 Prior to Commencing the Procedure

In addition to normal procedure prior to commencing the approach (before the IAF and in compatibility with crew workload), the flight crew must verify the correct procedure was loaded by comparison with the approach charts. This check must include:

a) The waypoint sequence.

b) Reasonableness of the tracks and distances of the approach legs, and the accuracy of the inbound course and mileage of the final approach segment.

Note: As a minimum, this check could be a simple inspection of a suitable map display that achieves the objectives of this paragraph.

Crew must also check from the published charts, map display or Control Display Unit (CDU), which waypoints are fly-by and which are fly-over.

For multi-sensor systems, crew must verify during the approach that GNSS sensor is used for position computation.

For an RNAV system with ABAS requiring barometric corrected altitude, the current airport barometric altimeter setting, should be input at the appropriate time and location, consistent with the performance of the flight operation.

When the operation is predicated on the availability of a GNSS approach, the flight crew should perform a new RAIM availability check if ETA is more than 15 minutes different from the ETA used during the preflight planning. This check is also processed automatically 2 NM before the FAF for E/TSO-C129a Class A1 receiver

ATC tactical interventions in the terminal area may include radar headings, ‘direct to’ clearances which by-pass the initial legs of an approach, interception of an initial or intermediate segment of an approach, or the insertion of waypoints loaded from the database. In complying with ATC instructions, the flight crew should be aware of the implications for the RNAV system.

a) The manual entry of coordinates into the RNAV system by the flight crew for operation within the terminal area is not permitted.

b) ‘Direct to’ clearances may be accepted to the Intermediate Fix (IF) provided that the resulting track change at the IF does not exceed 45^{o}.

Note: Direct to clearance to FAF is not acceptable.

The lateral definition of the flight path between the FAF and the Missed Approach Point (MAPt) must not be revised by the flight-crew under any circumstances.

5.3.4.3 During the Procedure

The final approach trajectory must be intercepted no later than the FAF in order for the aircraft to be correctly established on the final approach course before starting the descent (to ensure terrain and obstacle clearance).

The crew must check the RNAV approach mode annunciator (or equivalent) is properly indicating approach-mode integrity within 2 NM before the FAF.

Note: This will not apply for certain RNAV system (e.g. aircraft already approved with demonstrated RNP capability). For such systems, other means are available including electronic map displays, flight guidance mode indications, etc. which clearly indicate to the crew that the approach mode is activated.

The appropriate displays must be selected so that the following information can be monitored:

a) The RNAV computed desired path (DTK), and

b) Aircraft position relative to the path (Cross-track deviation) for FTE monitoring.

The procedure must be discontinued:
a) If the NSE alarm is triggered,
b) Or in case of loss of NSE alerting function,
c) Or if NSE alerting function is annunciated not available before passing the FAF.

Note: Discontinuing the procedure may not be necessary for a multi-sensor RNAV system that includes demonstrated RNP capability without GNSS. Manufacturer documentation should be examined to determine the extent the system may be used in such configuration.

d) Or if FTE is excessive**.**

The missed approach must be flown in accordance with the published procedure. Use of the RNAV system during the missed approach is acceptable provided:
a) The RNAV system is operational (e.g no loss of function, no NSE alert, no failure indication,..).
b) The whole procedure (including the missed approach) is loaded from the navigation data-base.

During the RNP APP procedure, pilots must use a lateral deviation indicator, flight director and/or autopilot in lateral navigation mode. Pilots of aircraft with a lateral deviation indicator (e.g., CDI) must ensure that lateral deviation indicator scaling (full-scale deflection) is suitable for the navigation accuracy associated with the various segments of the procedure (i.e., ±1.0 nm for the Initial and Intermediate segments, ±0.3 nm for the Final Approach segment, and ±1.0 nm for the Missed Approach segment). All pilots are expected to maintain procedure centerlines, as depicted by onboard lateral deviation indicators and/or flight guidance during all the approach procedure unless authorized to deviate by ATC or under emergency conditions. For normal operations, cross-track error/deviation (the difference between the RNAV system computed path and the aircraft position relative to the path) should be limited to +/- ½ the navigation accuracy associated with the procedure (i.e., 0.5 nm for the Initial and Intermediate segments, 0.15 nm for the Final Approach segment, and 0.5 nm for the Missed Approach segment). Brief deviations from this standard (e.g., overshoots or undershoots) during and immediately after turns, up to a maximum of 1 times the navigation accuracy (i.e., 1.0 nm for the Initial and Intermediate segments), are allowable.

NOTE: Some aircraft do not display or compute a path during turns. As such, pilots of these aircraft may not be able to adhere to the ±½ lateral navigation accuracy during turns but are still expected to satisfy the standard during intercepts following turns and on straight segments.

When Baro-VNAV is used for vertical path guidance during the final approach segment, deviations above and below the Baro-VNAV path must not respectively exceed +100/-50 feet.

Pilots must execute a Missed Approach if the lateral deviations or vertical deviations (if provided) exceed the criteria above, unless the pilot has in sight the visual references required to continue the approach.

Use by the crew of GNSS altitude information is prohibited during the approach

5.3.4.4 General Operating Procedures

Operators and pilots must not request an RNP APP procedure unless they satisfy all the criteria in the relevant State documents. If an aircraft not meeting these criteria receives a clearance from ATC to conduct an RNP APP procedure, the pilot must advise ATC that he/she is unable to accept the clearance and must request alternate instructions.

The pilot must comply with any instructions or procedures identified by the manufacturer as necessary to comply with the performance requirements in this chapter.

While operating on RNAV segments, pilots are encouraged to use flight director and/or autopilot in lateral navigation mode, if available.

5.3.4.5 Contingency Procedures

The pilot must notify ATC of any loss of the RNP APP capability, together with the proposed course of action. If unable to comply with the requirements of an RNP APP procedure, pilots must advise Air Traffic Service as soon as possible. For example, "....[Aircraft call sign], failure of GNSS system, unable RNP APP, request amended clearance." The loss of RNP APP capability includes any failure or event causing the aircraft to no longer satisfy the RNP APP requirements of the procedure.

In the event of communications failure, the flight crew must continue with the RNP APP in accordance with the published lost communication procedure.

5.3.5. Pilot Knowledge and Training

The training program must provide sufficient training (for example, simulator, training device, or aircraft) on the aircraft’s RNAV system to the extent that the pilots are not just task oriented.

a) The information in this chapter.

b) The meaning and proper use of aircraft systems.

c) Procedure characteristics as determined from chart depiction and textual description.

Knowledge regarding depiction of waypoint types (fly-over and fly-by), required path terminators (IF, TF, DF) and any other types used by the operator as well as associated aircraft flight paths.

Knowledge on the required navigation equipment in order to conduct RNP APP operation (at least one RNAV system based on GNSS).

Knowledge of RNAV system-specific information:

a) Levels of automation, mode annunciations, changes, alerts, interactions, reversions, and degradation.

b) Functional integration with other aircraft systems.

c) The meaning and appropriateness of route discontinuities as well as related flight crew procedures.

d) Monitoring procedures for each phase of flight (for example, monitor “PROGRESS” or “LEGS” page).

e) Types of navigation sensors utilized by the RNAV system and associated system prioritization/weighting/logic.

f) Turn anticipation with consideration to speed and altitude effects.

g) Interpretation of electronic displays and symbols.

Knowledge of RNAV equipment operating procedures, as applicable, including how to perform the following actions:

a) Verify currency of aircraft navigation data.

b) Verify successful completion of RNAV system self-tests.

c) Initialize RNAV system position.

d) Retrieve and fly an RNP APP.

e) Adhere to speed and/or altitude constraints associated with an approach procedure.

f) Fly interception of an initial or intermediate segment of an approach following ATC notification. .

g) Verify waypoints and flight plan programming.

h) Fly direct to a waypoint.

i) Determine cross-track error/deviation.

j) Insert and delete route discontinuity.

k) When required by the State aviation authority, perform gross navigation error check using conventional navigation aids.

l) Change arrival airport and alternate airport.

Knowledge of Operator-recommended levels of automation for phase of flight and workload, including methods to minimize cross-track error to maintain procedure centerline.

Knowledge of R/T phraseology for RNAV applications

Ability to conduct contingency procedures following RNAV system failures

5.3.6. Navigation Database

The navigation database should be obtained from a supplier that complies with RTCA DO-200A/EUROCAE document ED 76, Standards for Processing Aeronautical Data. A Letter of Acceptance (LOA) issued by the appropriate regulatory authority demonstrates compliance with this requirement (e.g., FAA LOA issued in accordance with FAA AC 20-153 or EASA LOA issued in accordance with EASA IR 21 subpart G.

Discrepancies that invalidate a procedure must be reported to the navigation database supplier and affected procedures must be prohibited by an operator's notice to its flight crew.

Aircraft operators should consider the need to conduct ongoing checks of the operational navigation databases in order to meet existing quality system requirements.

5.3.7. Oversight of Operators

A regulatory authority may consider any navigation error reports in determining remedial action. Repeated navigation error occurrences attributed to a specific piece of navigation equipment may result in cancellation of the approval for use of that equipment.

Information that indicates the potential for repeated errors may require modification of an operator's training program. Information that attributes multiple errors to a particular pilot crew may necessitate remedial training or license review.

5.4. REFERENCES

Copies of EUROCONTROL documents may be requested from EUROCONTROL, Documentation Centre, GS4, Rue de la Fusee, 96, B-1130 Brussels, Belgium; (Fax: 32 2 729 9109). Web site: http://www.ecacnav.com

Copies of EUROCAE documents may be purchased from EUROCAE, 17 rue Hamelin, 75783 PARIS Cedex 16, France, (Fax : 33 1 45 05 72 30). Web site: http://www.eurocae.org

Copies of FAA documents may be obtained from Superintendent of Documents,

Government Printing Office, Washington, DC 20402-9325, USA. Web site: http://www.faa.gov/certification/aircraft/ (Regulation and Guidance Library)

Copies of RTCA documents may be obtained from RTCA Inc., 1140 Connecticut Avenue, N.W., Suite 1020, Washington, DC 20036-4001, USA, (Tel: 1 202 833 9339). Web site www.rtca.org.

Copies of ARINC documents may be obtained from Aeronautical Radio Inc., 2551 Riva Road, Annapolis, Maryland 24101-7465, USA. Web site: http://www.arinc.com

Copies of JAA documents are available from JAA's publisher Information Handling Services (IHS). Information on prices, where and how to order, is available on the JAA web site, http://www.jaa.nl , and on the IHS web sites http://www.global.his.com , and http://www.avdataworks.com .

Copies of EASA documents may be obtained from EASA (European Aviation Safety Agency), 101253, D-50452 Koln, Germany.

Copies of ICAO documents may be purchased from Document Sales Unit, International Civil Aviation Organization, 999 University Street, Montreal, Quebec, Canada H3C 5H7, (Fax: 1 514 954 6769, or e-mail: sales_unit@icao.org) or through national agencies.

CHAPTER 6

IMPLEMENTING RNP AR APP

6.1. INTRODUCTION

6.1.1 Background

The Federal Aviation Administration (FAA) published *Approval Guidance for RNP Procedures with Special Aircraft and Aircrew Authorization Required* on 15 December 2005 through AC 90-101. RNP Authorization Required Approaches (RNP AR APP) represent the ICAO equivalent to FAA RNP Special Aircraft and Aircrew Authorization Required (SAAAR) operations. The European Aviation Safety Agency is developing equivalent guidance.

6.1.2 Purpose

This chapter provides a consistent ICAO recommendation and method of compliance with RNP (AR) instrument approach procedure (IAP) requirements. The goal of this document is to avoid the proliferation of national standards and the need for multiple regional approvals.

This chapter addresses operational and airworthiness issues. It does *not* address all requirements that may be specified for operation on a procedure. These requirements are specified in other documents such as operating rules, aeronautical information publications (AIPs) and the ICAO *Regional Supplementary Procedures* (Doc 7030). While operational approval primarily relates to the navigation requirements of the airspace, operators and flight crew are still required to take account of all operational documents relating to the airspace that are required by the appropriate State authority before conducting flights into that airspace.

6.1.3 Terminology

RNP Authorization Required (AR). Comprised of three parts: aircraft qualified to this navigation specification, operator approved to this navigation specification, and operator authorized to conduct the specific RNP AR procedure by the State regulatory authority responsible for that procedure.

6.2 ANSP CONSIDERATIONS

6.2.1 Navaid Infrastructure Considerations

RNP AR APPs are only authorized based on GNSS as the primary NAVAID infrastructure. The use of DME/DME as a reversionary capability may be authorized for individual operators where the infrastructure supports the required performance. RNP AR APP shall not be used in areas of known navigation signal (GNSS) interference.

NOTE: Most modern RNAV systems will prioritize inputs from GNSS and then DME/DME positioning. Although VOR/DME positioning is usually performed within a flight management computer when DME/DME positioning criteria does not exist, avionics and infrastructure variability pose serious challenges to standardization.

6.2.2 Communication & ATS Surveillance Considerations

RNP AR APPs do not require any unique communication or ATS Surveillance considerations.

6.2.3 Obstacle Clearance and Route Spacing

Guidance for the application of RNP(AR) Approach is provided in the ICAO Manual *Procedure Design for RNP(AR) Approach Procedures.*

Terrain and obstacle data in the vicinity of the approach should be published, in accordance with ICAO Annex 15.

RNP AR APP only has application for obstacle clearance and not route spacing.

6.2.4 Additional Considerations

Guidance in this chapter does not supersede appropriate State operating requirements for equipage.

Current local pressure setting must be provided to support RNP AR APPs, where the aircraft's achieved vertical path is dependent on that setting. Failure to report a correct setting can lead to aircraft leaving the obstacle clearance area.

The Safety Assessment items listed in paragraph 6.4 must be considered prior to implementation.

Flight Evaluation

As RNP AR APPs do not have a specific underlying navigation facility, there is no requirement for flight inspection of navigation signals. However, due to the importance of publishing correct data, it is recommended that flight evaluation be used prior to publication for procedure validation and obstacle validation. Flight evaluation can be accomplished through ground evaluation (eg, simulator assessment) and actual flight.

Procedure validation includes confirmation of the basic flyability of the procedure in accordance with the procedure design. A thorough flyability assessment is not required prior to publication, since flyability is individually assessed by the operator as part of their database updating and maintenance process due to the unique nature of RNP AR APPs. The flight evaluation prior to publication should confirm track lengths, bank angles, descent gradients, runway alignment and compatibility with predictive terrain hazard warning functions (e.g., Terrain Awareness and Warning Systems). A truth system is typically not required. Due to variations in aircraft speeds, flight control system design, and navigation system design this flight evaluation does not confirm flyability for all of the various aircraft conducting RNP AR APPs.

Obstacle validation through flight evaluation may used to validate the obstacle data used to design the procedure. An obstacle flight evaluation may not be necessary if obstacle validation can be accomplished through ground inspection or validated survey techniques to the appropriate accuracy.

6.2.5 Publication

The AIP should clearly indicate the navigation application is RNP AR APP and specific authorization is required.

All routes must be based upon WGS 84 coordinates.

The navigation data published in the State AIP for the procedures and supporting navigation aids must meet the requirements of ICAO Annex 15 and Annex 4 (as appropriate). The original data defining the procedure should be available to the operators in a manner suitable to enable the operator to verify their navigation data. The navigation accuracy for all RNP AR APP procedures should be clearly published in the AIP.

6.2.6 Controller Training

Controllers should be familiar with the characteristics of RNP AR APPs. In particular:

a) the title of the procedure and phraseology to be used to clear aircraft for the approach .

b) radar vectoring techniques particular to aircraft executing an RNP AR APP; including not clearing an aircraft direct to a fix at the start of the curved path. If vectoring aircraft to intercept the procedure prior to a turn, the intercept must be early enough to ensure the aircraft is established on course prior to initiating the turn.

c) Importance of airspeed on curved paths. Aircraft cannot exceed the maximum airspeeds listed in Table 0-1 in any segment, or a procedure-specified limit (when a speed restriction is required through the procedure design).

6.2.7 Status monitoring

The NAVAID infrastructure should be monitored and, where appropriate, maintained by the service provider. Timely warnings of outages (NOTAM) should be issued.

Status information should be provided in accordance with ICAO Annex 11 for navigation facilities or services that may be used to support the operation.

6.2.8 ATS System Monitoring

When available, radar observations of each aircraft's proximity to track and altitude are typically noted by Air Traffic Service (ATS) facilities and aircraft track-keeping capabilities are analyzed. If an observation/analysis indicates that a loss of separation or obstacle clearance has occurred, the reason for the apparent deviation from track or altitude should be determined and steps taken to prevent a recurrence.

6.3 NAVIGATION SPECIFICATION

6.3.1 Background

This chapter identifies the operational requirements for RNP AR APP operations. Operational compliance with these requirements shall be addressed through national operational regulations. In addition, authorization is required from the State responsible for the specific RNP AR APP procedure.

6.3.2 Approval Process

Any operator with an appropriate operational approval may conduct RNP (AR) instrument approach procedures, in a similar manner that operators with the proper authorization may conduct CAT II and CAT III ILS operations.

Due to the unique requirements for RNP AR APP operations and the need for crew procedures that are specific to each particular aircraft and navigation system, RNP AR APP operational support documentation is required from the manufacturer. The document should describe the navigation capabilities of applicant's aircraft in the context of RNP AR APP operations, and provide all the assumptions, limitations and supporting information necessary for the safe conduct of RNP AR APP operations. This document is primarily intended for use by operators to support operational approval by the appropriate Regulatory Authorities.

Operators should use the manufacturer recommendations when developing their procedures and application for approval. Installation of equipment is not sufficient by itself to obtain approval for use on RNP AR APPs.

The following steps must be completed before conducting RNP AR APP operations:

6.3.2.1 Aircraft Eligibility

The aircraft eligibility has to be determined through demonstration of compliance against the relevant airworthiness criteria. Aircraft Flight Manual (AFM) entries are not required provided the State accepts manufacturer documentation. Aircraft equipment eligibility must include:

a) Aircraft qualification

b) Established maintenance procedures

c) MEL revision

6.3.2.2 Operational Approval

The assessment of a particular operator is made by the State of Registry for that operator and in accordance with national operating rules (e.g., JAR-OPS 1, 14 CFR Part 121) supported through appropriate advisory and guidance material. The assessment should take into account:

a) Evidence of aircraft eligibility

b) Operating procedures for the navigation systems to be used and the operator navigation database process must include:

i) Navigation database validation program (see paragraph 6.3.6 for additional information)

ii) Operational procedure requirements

iii) RNP monitoring program (see paragraph 6.3.7 for additional information)

iv) Dispatch/flight following procedures

c) Control of those procedures through acceptable entries in the Operations Manual

d) Identification of flight crew training requirements

e) Where required, control of navigation database process

f) Flight crew and dispatch training based upon the operating procedures must be documented;

The operational approval will likely be documented through the State endorsing the Air Operators Certificate (AOC) through issue of a letter of authorisation, appropriate operations specification (Ops Spec) or amendment to the operations manual.

6.3.2.2.1 Description of aircraft equipment

The operator must have a configuration list detailing pertinent components and equipment to be used for RNP AR APP.

6.3.2.2.2 Training documentation

Commercial operators should have a training program addressing the operational practices, procedures and training items related to RNP AR APP operations (e.g. initial, upgrade or recurrent training for flight crew, dispatchers or maintenance personnel).

NOTE: It is not required to establish a separate training program or regimen if these items are already an integrated element of a training program. The operator should identify which aspects of RNP are covered within a training program.

Private operators should be familiar with the practices and procedures identified in section 6.3.5, Pilot Knowledge/Training.

6.3.2.2.3 Operations manuals and checklists

Operations manuals and checklists for commercial operators must address information/guidance on the standard operating procedures detailed in section 6.3.4 of this chapter. The appropriate manuals should contain navigation operating instructions and contingency procedures where specified. Manuals and checklists must be submitted for review as part of the application process.

Private operators should operate using the practices and procedures identified in section 6.3.5, Pilot Knowledge/Training.

6.3.2.2.4 Minimum Equipment List (MEL) considerations

Any minimum equipment list (MEL) revisions necessary to address RNP AR APP provisions must be approved. Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions.

6.3.2.3 Approval Submittal

Following the successful completion of the above steps, the above material must be accepted by the State regulatory authority; for operational approval (subject to any conditions or limitations) to be obtained in accordance with national operating rules.

The Safety Assessment items listed in paragraph 6.4 should be considered prior to implementation.

An RNP AR APP operational approval (letter of authorization, appropriate operations specification (Ops Spec), or amendment to the Operations Manual), should then be issued by the State.

Once approval is received from the State of Registry, operators desiring to perform RNP AR APP operations in other States will require authorization from that State authority.

The approval should identify the type of procedures for which the operator is approved: the lowest navigation accuracy, procedures with RF legs, and procedures with required accuracy in the missed approach less than 1.0 NM. Equipment configurations, selected modes and crew procedures must be defined for each approved approach.

6.3.3 Aircraft Requirements

This section describes the aircraft performance and functional criteria for aircraft to qualify for RNP AR APP. In addition to the specific guidance in this chapter, the aircraft must comply with FAA AC 20-129 and either FAA AC 20-130 or AC 20-138, or equivalent.

6.3.3.1 System Accuracy

System accuracy is addressed in performance requirements and criteria for specific navigation services.

6.3.3.1.1 Performance Requirements

This section defines the general performance requirements for aircraft qualification.

Path Definition. Aircraft performance is evaluated around the path defined by the published procedure and RTCA/DO-236B Section 3.2. All vertical paths used in conjunction with the final approach segment will be defined by a Flight Path Angle (RTCA/DO-236B Section 3.2.8.4.3) as a straight line emanating to a fix and altitude.

Lateral Accuracy. All aircraft operating on RNP AR APP procedures must have a cross-track navigation error no greater than the applicable accuracy value (0.1 NM to 0.3 NM) for 95 per cent of the flight time. This includes positioning error, flight technical error (FTE), path definition error (PDE) and display error. Also, the aircraft along-track positioning error must be no greater than the applicable accuracy value for 95 per cent of the flight time.

Vertical Accuracy. The vertical system error includes altimetry error (assuming the temperature and lapse rates of the International Standard Atmosphere), the effect of along-track error, system computation error, data resolution error, and flight technical error. The 99.7% of system error in the vertical direction must be less than the following (in feet):

$$\sqrt{\left((6076.115)(1.225)\mathbf{RNP}\cdot \tan\theta\right)^2 + (60\tan\theta)^2 + 75^2 + \left(\left(-8.8\cdot 10^{-8}\right)(\mathbf{h}+\Delta\mathbf{h})^2 + \left(6.5\cdot 10^{-3}\right)(\mathbf{h}+\Delta\mathbf{h}) + 50\right)^2}$$

where θ is the vertical navigation (VNAV) path angle, h is the height of the local altimetry reporting station and Δh is the height of the aircraft above the reporting station.

6.3.3.2 Performance Monitoring and Alerting

System Monitoring. A critical component of RNP are the RNP requirements of the approach, the ability of the aircraft navigation system to monitor its achieved navigation performance, and to identify for the pilot whether the operational requirement is or is not being met during an operation (e.g., ‘Unable RNP’, ‘Nav Accur Downgrad’).

Airspace Containment. RNP AR APPs require a level of performance and appropriate monitoring of that performance.

a) RNAV and Barometric VNAV aircraft. This chapter provides a detailed acceptable means of compliance for aircraft that use an area navigation (RNAV) system based primarily on GNSS and a VNAV system based on barometric altimetry. Aircraft and operations complying with these paragraphs provide the requisite airspace containment through a variety of monitoring and alerting (e.g., ‘Unable RNP’, GNSS alert limit, path deviation monitoring).

b) Other systems or alternate means of compliance. For other systems or alternate means of compliance, the probability of the aircraft exiting the lateral and vertical extent of the obstacle clearance volume (defined in ICAO Manual *Procedure Design for RNP(AR) Approach Procedures*) must not exceed 10^{-7} per approach, including the approach and missed approach. This requirement may be satisfied by an operational safety assessment applying (a) appropriate quantitative numerical methods, (b) qualitative operational and procedural considerations and mitigations, or (c) an appropriate combination of both quantitative and qualitative methods.

NOTE 1: This requirement applies to the total probability of excursion outside the obstacle clearance volume, including events caused by latent conditions (integrity) and by detected conditions (continuity) if the aircraft does not remain within the obstacle clearance volume after the failure is annunciated (considering the aircraft wingspan). The monitor limit of the alert, the latency of the alert, the crew reaction time, and the aircraft response should all be considered when ensuring that the aircraft does not exit the obstacle clearance volume. The requirement applies to a single approach, considering the exposure time of the operation and the NAVAID geometry and navigation performance available for each published approach.

NOTE 2: This containment requirement derives from the operational requirement. This requirement is notably different than the containment requirement specified in RTCA/DO-236B. The requirement in RTCA/DO-236B was developed to facilitate airspace design and does not directly equate to obstacle clearance.

6.3.3.3 Criteria For Specific Navigation Services

The navigation system must estimate the aircraft's position. This section identifies unique issues for the navigation sensors within the context of RNP AR APPs.

Global Positioning System (GPS).

a) The sensor must comply with the guidelines in AC 20-138(). For systems that comply with AC 20-138(), the following sensor accuracies can be used in the total system accuracy analysis without additional substantiation: GPS sensor accuracy is better than 36 meters (95%), and augmented GPS (GBAS or SBAS) sensor accuracy is better than 2 meters (95%).

b) In the event of a latent GPS satellite failure and marginal GPS satellite geometry (e.g., Horizontal Integrity Limit (HIL) equal to the horizontal alert limit), the probability that the aircraft remains within the obstacle clearance volume used to evaluate the procedure must be greater than 95% (both laterally and vertically).

NOTE: GNSS-based sensors output a HIL, also known as a Horizontal Protection Level (HPL) (see AC 20-138A Appendix 1 and RTCA/DO-229C for an explanation of these terms). The HIL is a measure of the position estimation error assuming a latent failure is present. In lieu of a detailed analysis of the effects of latent failures on the total system error, an acceptable means of compliance for GNSS-based systems is to ensure the HIL remains less than twice the navigation accuracy, minus the 95% of FTE, during the RNP AR APP operation.

Inertial Reference System (IRS). An inertial reference system must satisfy the criteria of US 14 CFR part 121, Appendix G, or equivalent. While Appendix G defines the requirement for a 2 NM per hour drift rate (95%) for flights up to 10 hours, this rate does not apply to an RNAV system after loss of position updating. Systems that have demonstrated compliance with part 121, Appendix G can be assumed to have an initial drift rate of 8 NM/hour for the first 30 minutes (95%) without further substantiation. Aircraft manufacturers and applicants can demonstrate improved inertial performance in accordance with the methods described in appendix 1 or 2 of FAA Order 8400.12A.

NOTE: Integrated GPS/INS position solutions reduce the rate of degradation after loss of position updating. For "tightly coupled" GPS/IRUs, RTCA/DO-229C, Appendix R, provides additional guidance.

Distance Measuring Equipment (DME). Initiation of all RNP AR APP procedures is based on GNSS updating. Except where specifically designated on a procedure as Not Authorized, DME/DME updating can be used as a reversionary mode during the approach or missed approach when the system complies with the navigation accuracy. The manufacturer should identify any constraints on the DME infrastructure or the procedure for a given aircraft to comply with this requirement.

VHF Omni-directional Range station (VOR). For the initial RNP AR APP implementation, the RNAV system may not use VOR updating. The manufacturer should identify any constraints on the VOR infrastructure or the procedure for a given aircraft to comply with this requirement.

NOTE: This requirement does not imply an equipment capability must exist providing a direct means of inhibiting VOR updating. A procedural means for the flight crew to inhibit VOR updating or executing a missed approach if reverting to VOR updating may meet this requirement.

For multi-sensor systems, there must be automatic reversion to an alternate RNAV sensor if the primary RNAV sensor fails. Automatic reversion from one multi-sensor system to another multi-sensor system is not required.

The 99.7% aircraft altimetry system error for each aircraft (assuming the temperature and lapse rates of the International Standard Atmosphere) must be less than or equal to the following with the aircraft in the approach configuration:

$$\mathbf{ASE} = -8.8 \cdot 10^{-8} \cdot \mathbf{H}^2 + 6.5 \cdot 10^{-3} \cdot \mathbf{H} + 50 \text{ (ft)}$$

Where H is the true altitude of the aircraft.

Temperature compensation systems. Systems that provide temperature-based corrections to the barometric VNAV guidance must comply with RTCA/DO-236B, Appendix H.2. This applies to the final approach segment. Compliance to this standard should be documented to allow the operator to conduct RNP approaches when the actual temperature is below or above the published procedure design limit. Appendix H also provides guidance on operational issues associated with temperature compensated systems, such as intercepting the compensated path from uncompensated procedure altitudes.

6.3.3.4 Functional Requirements

NOTE: Additional guidance and information concerning many of the required functions is provided in RTCA/DO-236B.

General Requirements (applicable to all approaches)

Path Definition and Flight Planning.

a) Maintaining Track and Leg Transitions. The aircraft must have the capability to execute leg transitions and maintain tracks consistent with the following paths:

   i) A geodesic line between two fixes;

   ii) A direct path to a fix;

   iii) A specified track to a fix, defined by a course; and

   iv) A specified track to an altitude.

NOTE 1: Industry standards for these paths can be found in RTCA/DO-236B and ARINC Specification 424, which refer to them as TF, DF, CF, and FA path terminators. Also, certain procedures require RF legs. EUROCAE ED-75A/ RTCA DO-236B and ED-77/ DO-201A describe the application of these paths in more detail.

NOTE 2: The navigation system may accommodate other ARINC 424 path terminators (e.g., Heading to manual terminator (VM)); and the missed approach procedure may use these types of paths when there is no requirement for RNP containment.

b) Fly-By and Fly-Over Fixes. The aircraft must have the capability to execute fly-by and fly-over fixes. For fly-by turns, the navigation system must limit the path definition within the theoretical transition area defined in RTCA/DO-236B under the wind conditions identified in the ICAO Manual *Procedure Design for RNP(AR) Approach Procedures.* The fly-over turn is not compatible with RNP flight tracks and will only be used when there is no requirement for repeatable paths.

c) Waypoint Resolution Error. The navigation database must provide sufficient data resolution to ensure the navigation system achieves the required accuracy. Waypoint resolution error must be less than or equal to 60 feet, including both the data storage resolution and the RNAV system computational resolution used internally for construction of flight plan waypoints. The navigation database must contain vertical angles (flight path angles) stored to a resolution of hundredths of a degree, with computational resolution such that the system-defined path is within 5 ft of the published path.

d) Capability for a "Direct-To" Function. The navigation system must have a "Direct-To" function the flight crew can activate at any time. This function must be available to any fix. The navigation system must also be capable of generating a geodesic path to the designated "To" fix, without "S-turning" and without undue delay.

e) Capability to define a vertical path. The navigation system must be capable of defining a vertical path by a flight path angle to a fix. The system must also be capable of specifying a vertical path between altitude constraints at two fixes in the flight plan. Fix altitude constraints must be defined as one of the following:

i) An "AT or ABOVE" altitude constraint (for example, 2400A, may be appropriate for situations where bounding the vertical path is not required);

ii) An "AT or BELOW" altitude constraint (for example, 4800B, may be appropriate for situations where bounding the vertical path is not required);

iii) An "AT" altitude constraint (for example, 5200); or

iv) A "WINDOW" constraint (for example, 2400A3400B).

NOTE: For RNP AR APP procedures, any segment with a published vertical path will define that path based on an angle to the fix and altitude.

f) Altitudes and/or speeds associated with published terminal procedures must be extracted from the navigation database.

g) The system must be able to construct a path to provide guidance from current position to a vertically constrained fix.

h) Capability to Load Procedures from the Navigation Database. The navigation system must have the capability to load the entire procedure(s) to be flown into the RNAV system from the onboard navigation database. This includes the approach (including vertical angle), the missed approach and the approach transitions for the selected airport and runway.

i) Means to Retrieve and Display Navigation Data. The navigation system must provide the ability for the flight crew to verify the procedure to be flown through review of the data stored in the onboard navigation database. This includes the ability to review the data for individual waypoints and for navigation aids.

j) Magnetic Variation. For paths defined by a course (CF and FA path terminators), the navigation system must use the magnetic variation value for the procedure in the navigation database.

k) Changes in Navigation accuracy. RNP changes to lower navigation accuracy must be complete by the fix defining the leg with the lower navigation accuracy, considering the alerting latency of the navigation system. Any operational procedures necessary to accomplish this must be identified.

l) Automatic Leg Sequencing. The navigation system must provide the capability to automatically sequence to the next leg and display the sequencing to the flight crew in a readily visible manner.

m) A display of the altitude restrictions associated with flight plan fixes must be available to the pilot. If there is a specified navigation database procedure with a flight path angle associated with any flight plan leg, the equipment must display the flight path angle for that leg.

Demonstration of Path Steering Performance. The demonstration of path steering performance (flight technical error) must be completed in a variety of operational conditions, rare-normal conditions and non-normal conditions (e.g., see FAA AC 120-29A, paragraphs 5.19.2.2 and 5.19.3.1). Realistic and representative procedures should be used (e.g. Number of waypoints, placement of waypoints, segment geometry, leg types, etc.) The non-normal assessment should consider the following :

a) An acceptable criteria to be used for assessing probable failures and engine failure during the aircraft qualification is to demonstrate that the aircraft trajectory is maintained within a 1xRNP corridor, and 75 feet vertical. Proper documentation of this demonstration in the Aircraft Flight Manual (AFM), AFM extension, or appropriate aircraft operational support document alleviates the operational evaluations.

b) RNP-significant Improbable failure cases should be assessed to show that under these conditions the aircraft can be safely extracted from the procedure. Failure cases might include dual system resets, flight control surface runaway and complete loss of flight guidance function while in NAV.

c) The aircraft performance demonstration during the operational evaluations can be based on a mix of analysis and flight technical evaluation using expert judgement.

Displays.

a) Continuous Display of Deviation. The navigation system must provide the capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft, the aircraft position relative to the RNAV defined path (both lateral and vertical deviation). The display must allow the pilot to readily distinguish if the cross-track deviation exceeds the navigation accuracy (or a smaller value) or if the vertical deviation exceeds 75 feet (or a smaller value).

It is recommended that an appropriately-scaled non-numeric deviation display (i.e., lateral deviation indicator and vertical deviation indicator) be located in the pilot's primary optimum field of view. A fixed-scale CDI is acceptable as long as the CDI demonstrates appropriate scaling and sensitivity for the intended navigation accuracy and operation. With a scalable CDI, the scale should derive from the selection of RNP, and not require the separate selection of a CDI scale. Alerting and annunciation limits must also match the scaling values. If the equipment uses default navigation accuracy to describe the operational mode (e.g., en route, terminal area and approach), then displaying the operational mode is an acceptable means from which the flight crew may derive the CDI scale sensitivity.

Numeric display of deviation or graphic depiction on a map display, without an appropriately scaled deviation indicator, is generally not considered acceptable for monitoring deviation. The use of numeric display and map display may be feasible depending on the flight crew workload, the display characteristics, the flight crew procedures and training. Additional initial and recurrent flight crew training (or line experience) is necessary, so such a solution increase flight crew workload during the approach and imposes additional costs to the operator to support the training requirements.

b) Identification of the Active (To) Waypoint. The navigation system must provide a display identifying the active waypoint either in the pilot's primary optimum field of view, or on a readily accessible and visible display to the flight crew.

c) Display of Distance and Bearing. The navigation system must provide a display of distance and bearing to the active (To) waypoint in the pilot's primary optimum field of view. Where not viable, a readily accessible page on a control display unit, readily visible to the flight crew, may display the data.

d) Display of Groundspeed and Time. The navigation system must provide the display of groundspeed and time to the active (To) waypoint in the pilot's primary optimum field of view. Where not viable, a readily accessible page on a control display unit, readily visible to the flight crew, may display the data.

e) Display of To/From the active fix. The navigation system must provide a To/From display in the pilot's primary optimum field of view.

f) Desired Track Display. The navigation system must have the capability to continuously display to the pilot flying the aircraft the RNAV desired track. This display must be on the primary flight instruments for navigation of the aircraft.

g) Display of Aircraft Track. The navigation system must provide a display of the actual aircraft track (or track angle error) either in the pilot's primary optimum field of view, or on a readily accessible and visible display to the flight crew.

h) Failure Annunciation. The aircraft must provide a means to annunciate failures of any aircraft component of the RNAV system, including navigation sensors. The annunciation must be visible to the pilot and located in the primary optimum field of view.

i) Slaved Course Selector. The navigation system must provide a course selector automatically slaved to the RNAV computed path.

j) RNAV Path Display. Where the minimum flight crew is two pilots, the navigation system must provide a readily visible means for the pilot monitoring to verify the aircraft's RNAV defined path and the aircraft's position relative to the defined path.

k) Display of Distance to Go. The navigation system must provide the ability to display distance to go to any waypoint selected by the flight crew.

l) Display of Distance Between Flight Plan Waypoints. The navigation system must provide the ability to display the distance between flight plan waypoints.

m) Display of Deviation. The navigation system must provide a numeric display of the vertical deviation with a resolution of 10 feet or less, and the lateral deviation with a resolution of 0.01 NM or less.

n) Display of Barometric Altitude. The aircraft must display barometric altitude from two independent altimetry sources, one in each pilots' primary optimum field of view.

NOTE 1: This display supports an operational cross-check (comparator monitor) of altitude sources. If the aircraft altitude sources are automatically compared, the output of the independent altimetry sources, including independent aircraft static air pressure systems, must be analyzed to ensure that they can provide an alert in the pilot's primary optimum field of view when deviations between the sources exceed ±75 feet. Such comparator monitor function should be documented as it may eliminate the need for an operational mitigation.

NOTE 2: The altimeter setting input must be used simultaneously by the aircraft altimetry system and by the RNAV system. A single input is necessary to prevent possible crew error. Separate altimeter setting for the RNAV system is prohibited.

o) Display of Active Sensors. The aircraft must display the current navigation sensor(s) in use. It is recommended that this display be provided in the primary optimum field of view.

NOTE: This display is used to support operational contingency procedures. If such a display is not provided in the primary optimum field of view, crew procedures may mitigate the need for this display if the workload is determined to be acceptable.

Design Assurance. The system design assurance must be consistent with at least a major failure condition for the display of misleading lateral or vertical guidance on an RNP AR APP.

NOTE: The display of misleading lateral or vertical RNP guidance is considered a hazardous (severe-major) failure condition for RNP AR APPs with an navigation accuracy less than RNP-0.3. Systems designed consistent with this effect should be documented as it may eliminate the need for some operational mitigations for the aircraft.

Navigation Database. The aircraft navigation system must use an on-board navigation database which can receive updates in accordance with the AIRAC cycle; and allow retrieval and loading of RNP AR APP procedures into the RNAV system. The onboard navigation database must be protected against flight crew modification of the stored data.

NOTE: When a procedure is loaded from the database, the RNAV system must fly the procedure as published. This does not preclude the flight crew from having the means to modify a procedure or route already loaded into the RNAV system. However, the procedures stored in the navigation database must not be modified and must remain intact within the navigation database for future use and reference.

The aircraft must provide a means to display the validity period for the onboard navigation database to the flight crew.

Requirements for RNP (AR) Approaches with RF Legs

The navigation system must have the capability to execute leg transitions and maintain tracks consistent with an RF leg between two fixes.

The aircraft must have an electronic map display of the selected procedure.

The FMC, the flight director system and autopilot must be capable of commanding a bank angle up to 25 degrees above 400 feet AGL and up to 8 degrees below 400 feet AGL.

Upon initiating a go-around or missed approach (through activation of TOGA or other means), the flight guidance mode should remain in LNAV to enable continuous track guidance during an RF leg.

When evaluating flight technical error on RF legs, the effect of rolling into and out of the turn should be considered. The procedure is designed to provide 5 degrees of manoeuvrability margin, to enable the aircraft to get back on the desired track after a slight overshoot at the start of the turn.

Requirements for RNP (AR) Approaches to less than RNP-0.3

No single-point-of-failure. No single-point-of-failure can cause the loss of guidance compliant with the navigation accuracy associated with the approach. Typically, the aircraft must have at least the following equipment: dual GNSS sensors, dual flight management systems, dual air data systems, dual autopilots, and a single inertial reference unit (IRU).

Design Assurance. The system design assurance must be consistent with at least a major failure condition for the loss of lateral or vertical guidance on an RNP AR APP where RNP less than 0.3 is required to avoid obstacles or terrain while executing an approach.

> *NOTE: For RNP AR APP operations requiring less than 0.3 to avoid obstacles or terrain, the loss of the display of lateral guidance is considered a hazardous (severe-major) failure condition. The AFM should document systems designed consistent with this effect. This documentation should describe the specific aircraft configuration or mode of operation that achieves navigation accuracy less than 0.3. Meeting this requirement can substitute for the general requirement for dual equipment described above*

Go-around guidance. Upon initiating a go-around or missed approach (through activation of TOGA or other means), the flight guidance mode should remain in LNAV to enable continuous track guidance during an RF leg. If the aircraft does not provide this capability, the following requirements apply:

a) If the aircraft supports RF legs, the lateral path after initiating a go-around (TOGA), (given a minimum 50 second straight segment between the RF end point and the DA), must be within 1 degree of the track defined by the straight segment through the DA point. The prior turn can be of arbitrary angular extent and radius as small as 1 NM, with speeds commensurate with the approach environment and the radius of the turn.

b) The flight crew must be able to couple the autopilot or flight director to the RNAV system (engage LNAV) by 400 feet AGL.

Loss of GNSS. After initiating a go-around or missed approach following loss of GNSS, the aircraft must automatically revert to another means of navigation that complies with the navigation accuracy.

Requirements for Approaches with Missed Approach less than RNP 1.0

Single-point-of-failure. No single-point-of-failure can cause the loss of guidance compliant with the navigation accuracy associated with a missed approach procedure. Typically, the aircraft must have at least the following equipment: dual GNSS sensors, dual flight management systems, dual air data systems, dual autopilots, and a single inertial reference unit (IRU).

Design Assurance. The system design assurance must be consistent with at least a major failure condition for the loss of lateral or vertical guidance on an RNP AR APP where RNP less than 1.0 is required to avoid obstacles or terrain while executing a missed approach.

NOTE: For RNP AR APP missed approach operations requiring less than 1.0 to avoid obstacles or terrain, the loss of the display of lateral guidance is considered a hazardous (severe-major) failure condition. The AFM should document systems designed consistent with this effect. This documentation should describe the specific aircraft configuration or mode of operation that achieves navigation accuracy less than 1.0. Meeting this requirement can substitute for the general requirement for dual equipment described above

Go-Around Guidance. Upon initiating a go-around or missed approach (through activation of TOGA or other means), the flight guidance mode should remain in LNAV to enable continuous track guidance during an RF leg. If the aircraft does not provide this capability, the following requirements apply:

a) If the aircraft supports RF legs, the lateral path after initiating a go-around (TOGA), (given a minimum 50 second straight segment between the RF end point and the DA), must be within 1 degree of the track defined by the straight segment through the DA point. The prior turn can be of arbitrary angular extent and radius as small as 1 NM, with speeds commensurate with the approach environment and the radius of the turn.

b) The flight crew must be able to couple the autopilot or flight director to the RNAV system (engage LNAV) by 400 feet AGL.

Loss of GNSS. After initiating a go-around or missed approach following loss of GNSS, the aircraft must automatically revert to another means of navigation that complies with the navigation accuracy.

6.3.4 Operating Procedures

Pre-flight Considerations

Minimum Equipment List. Operators minimum equipment list should be developed /revised to address the equipment requirements for RNP AR APP instrument approaches. Guidance for these equipment requirements is available from the aircraft manufacturer. The required equipment may depend on the intended navigation accuracy and whether or not the missed approach requires RNP less than 1.0. For example, GNSS and autopilot are typically required for small navigation accuracy. Dual equipment is typically required for approaches when using a line of minima less than RNP-0.3 and/or where the missed approach has an RNP less than 1.0. An operable Class A Terrain Awareness Warning System (TAWS) is required for all RNP AR APP procedures. It is recommended that the TAWS use altitude that is compensated for local pressure and temperature effects (e.g., corrected barometric and GNSS altitude), and include significant terrain and obstacle data. The flight crew must be cognizant of the required equipment.

Autopilot and Flight Director. RNP AR APP procedures with navigation accuracy less than RNP-0.3 or with RF legs require the use of autopilot or flight director driven by the RNAV system in all cases. Thus, the autopilot/flight director must operate with suitable accuracy to track the lateral and vertical paths required by a specific RNP AR APP procedure. When the dispatch of a flight is predicated on flying an RNP AR APP requiring the autopilot at the destination and/or alternate, the dispatcher must determine that the autopilot is installed and operational.

Dispatch RNP Assessment. The operator must have a predictive performance capability, which can forecast whether or not the specified RNP will be available at the time and location of a desired RNP AR APP operation. This capability can be a ground service and need not be resident in the aircraft's avionics equipment. The operator must establish procedures requiring use of this capability as both a preflight dispatch tool and as a flight-following tool in the event of reported failures. The RNP assessment must consider the specific combination of the aircraft capability (sensors and integration).

a) RNP assessment when GNSS updating. This predictive capability must account for known and predicted outages of GNSS satellites or other impacts on the navigation system's sensors. The prediction program should not use a mask angle below 5 degrees, as operational experience indicates that satellite signals at low elevations are not reliable. The prediction must use the actual GPS constellation with the (RAIM) (or equivalent) algorithm identical to that used in the actual equipment. For RNP AR APPs with high terrain, use a mask angle appropriate to the terrain.

b) Initially, RNP AR APP procedures require GNSS updating.

NAVAID Exclusion. The operator must establish procedures to exclude NAVAID facilities in accordance with NOTAMs (e.g., DMEs, VORs, localizers). Internal avionics reasonableness checks may not be adequate for RNP AR APP operations.

Navigation Database Currency. During system initialization, pilots of aircraft equipped with an RNAV-certified system, must confirm that the navigation database is current. Navigation databases are expected to be current for the duration of the flight. If the AIRAC cycle will change during flight, operators and pilots must establish procedures to ensure the accuracy of navigation data, including suitability of navigation facilities used to define the routes and procedures for flight. Traditionally, this has been accomplished by verifying electronic data against paper products. One acceptable means is to compare aeronautical charts (new and old) to verify navigation fixes prior to dispatch. If an amended chart is published for the procedure, the database must not be used to conduct the operation.

In-Flight Considerations

Modification of Flight Plan. Pilots are not authorized to fly a published RNP AR APP procedure unless it is retrievable by the procedure name from the aircraft navigation database and conforms to the charted procedure. The lateral path must not be modified; with the exception of accepting a clearance to go direct to a fix in the approach procedure that is before the FAF and that does not immediately precede an RF leg. The only other modification to the loaded procedure is to change altitude and/or airspeed waypoint constraints on the initial, intermediate, or missed approach segments (e.g., to apply cold temperature corrections or comply with an ATC clearance/instruction).

Required List of Equipment. The flight crew must have a required list of equipment for conducting RNP AR APPs or alternate methods to address in flight equipment failures prohibiting RNP AR APPs (e.g. quick reference handbook).

RNP Management. The flight crew's operating procedures must ensure the navigation system uses the appropriate navigation accuracy throughout the approach. If multiple lines of minima associated with different navigation accuracy are shown on the approach chart, the crew must confirm that the desired navigation accuracy is entered in the RNAV system. If the navigation system does not extract and set the navigation accuracy from the on-board navigation database for each leg of the procedure, then the flight crew's operating procedures must ensure that the smallest navigation accuracy required to complete the approach or the missed approach is selected before initiating the approach (e.g., before the initial approach fix (IAF)). Different IAF's may have different navigation accuracy, which are annotated on the approach chart.

GNSS Updating. Initially all RNP AR APP instrument approach procedures require GNSS updating of the navigation position solution. The flight crew must verify GNSS updating is available prior to commencing the RNP AR APP. During the approach, if at any time GNSS updating is lost and the navigation system does not have the performance to continue the approach, the flight crew must abandon the RNP AR APP unless the pilot has in sight the visual references required to continue the approach.

Radio Updating. Initiation of all RNP AR APP procedures is based on GNSS updating. Except where specifically designated on a procedure as Not Authorized, DME/DME updating can be used as a reversionary mode during the approach or missed approach when the system complies with the navigation accuracy. VOR updating is not authorized at this time. The flight crew must comply with the operator's procedures for inhibiting specific facilities.

Approach Procedure Confirmation. The flight crew must confirm that the correct procedure has been selected. This process includes confirmation of the waypoint sequence, reasonableness of track angles and distances, and any other parameters that can be altered by the pilot, such as altitude or speed constraints. A procedure must not be used if validity of the navigation database is in doubt. A navigation system textual display or navigation map display must be used.

Track Deviation Monitoring. Pilots must use a lateral deviation indicator, flight director and/or autopilot in lateral navigation mode on RNP AR APP approach procedures. Pilots of aircraft with a lateral deviation indicator must ensure that lateral deviation indicator scaling (full-scale deflection) is suitable for the navigation accuracy associated with the various segments of the RNP AR approach procedure. All pilots are expected to maintain procedure centerlines, as depicted by onboard lateral deviation indicators and/or flight guidance during all RNP operations described in this manual unless authorized to deviate by ATC or under emergency conditions. For normal operations, cross-track error/deviation (the difference between the RNAV system computed path and the aircraft position relative to the path) should be limited to +/- ½ the navigation accuracy associated with the procedure segment. Brief lateral deviations from this standard (e.g., overshoots or undershoots) during and immediately after turns, up to a maximum of 1 times the navigation accuracy of the procedure segment, are allowable.

The vertical deviation must be within 75 feet during the final approach segment. Vertical deviation should be monitored above and below the glidepath; while being above the glidepath provides margin against obstacles on the final approach, it can result in a go-around decision closer to the runway and reduce the margin against obstacles in the missed approach.

Pilots must execute a Missed Approach if the lateral deviation exceeds 1xRNP or the vertical deviation exceeds 75 feet, unless the pilot has in sight the visual references required to continue the approach.

a) Some aircraft navigation displays do not incorporate lateral and vertical deviations scaled for each RNP AR APP operation in the primary optimum field of view. Where a moving map, low-resolution vertical deviation indicator (VDI), or numeric display of deviations are to be used, flight crew training and procedures must ensure the effectiveness of these displays. Typically, this involves demonstration of the procedure with a number of trained crews and inclusion of this monitoring procedure in the recurrent RNP AR APP training program.

b) For installations that use a CDI for lateral path tracking, the aircraft flight manual (AFM) or aircraft qualification guidance should state which navigation accuracy and operations the aircraft supports and the operational effects on the CDI scale. The flight crew must know the CDI full-scale deflection value. The avionics may automatically set the CDI scale (dependent on phase of flight) or the flight crew may manually set the scale. If the flight crew manually selects the CDI scale, the operator must have procedures and training in place to assure the selected CDI scale is appropriate for the intended RNP operation. The deviation limit must be readily apparent given the scale (e.g., full-scale deflection).

System Crosscheck. For approaches with navigation accuracy less than RNP 0.3, the flight crew must monitor the lateral and vertical guidance provided by the navigation system by ensuring it is consistent with other available data and displays provided by an independent means.

NOTE: This crosscheck may not be necessary if the lateral and vertical guidance systems have been developed consistent with a hazardous (severe-major) failure condition for misleading information (see paragraph on Design Assurance) and if the normal system performance supports airspace containment.

Procedures with RF Legs. An RNP AR APP procedure may require the ability to execute an RF leg to avoid terrain or obstacles. As not all aircraft have this capability, flight crews must be aware of whether or not they can conduct these procedures. When flying an RF leg, flight crew compliance with the desired path is essential to maintain the intended ground track.

a) If initiating a go-around during or shortly after the RF leg, the flight crew must be aware of the importance of maintaining the published path as closely as possible. Operational procedures are required for aircraft that do not stay in LNAV when a go-around is initiated to ensure the RNP AR APP ground track is maintained.

b) Pilots must not exceed the maximum airspeeds shown in Table 0-1 throughout the RF leg segment. For example, a Category C A320 must slow to 140 KIAS at the FAF or may fly as fast as 165 KIAS if using Category D minima. A missed approach prior to DA may require the segment speed for that segment be maintained.

Table 0-1: Maximum Airspeed by Segment and Category

Indicated Airspeed (Knots)					
Segment	Indicated Airspeed by Aircraft Category				
	Cat A	Cat B	Cat C	Cat D	Cat E
Initial & Intermediate (IAF to FAF)	150	180	240	250	250
Final (FAF to DA)	100	130	160	185	As Specified
Missed Approach (DA to MAHP)	110	150	240	265	As Specified
Airspeed Restriction*	As specified				

*Airspeed restrictions may be used to reduce turn radius regardless of aircraft category.

Temperature Compensation. For aircraft with temperature compensation capability, flight crews may disregard the temperature limits on RNP AR APP procedures if the operator provides pilot training on the use of the temperature compensation function. Temperature compensation by the system is applicable to the VNAV guidance and is not a substitute for the flight crew compensating for the cold temperature effects on minimum altitudes or the decision altitude. Flight crews should be familiar with the effects of the temperature compensation on intercepting the compensated path described in RTCA/DO-236B Appendix H.

Altimeter Setting. Due to the reduced obstruction clearance inherent in RNP (AR) instrument approach procedures, the flight crew must verify current airport local altimeter is set prior to the final approach fix (FAF). Execution of an RNP (AR) instrument approach procedure requires the current altimeter setting for the airport of intended landing. Remote altimeter settings are not allowed.

Altimeter Crosscheck. The flight crew must complete an altimetry crosscheck ensuring both pilots' altimeters agree within ±100 feet prior to the final approach fix (FAF) but no earlier than the IAF. If the altimetry crosscheck fails then the procedure must not be continued. If the avionics systems provide a comparator warning system for the pilots' altimeters, the flight crew procedures should also address actions to take if a comparator warning for the pilots' altimeters occurs while conducting an RNP AR APP procedure.

NOTE: This operational crosscheck is not necessary if the aircraft automatically compares the altitudes to within 75 feet (see also paragraph 6.3.3.4, Displays, (n) Display of Barometric Altitude).

VNAV Altitude Transitions. The aircraft barometric VNAV system provides fly-by vertical guidance, and may result in a path that starts to intercept the glidepath prior to the FAF to ensure a smooth transition. The small vertical displacement which may occur at a vertical constraint (e.g., the final approach fix) is considered operationally acceptable, and desirable, to ensure asymptotic capture of a new (next) vertical segment. This momentary deviation below the published minimum procedure altitude is acceptable provided the deviation is limited to no more than 100 ft. and is a result of a normal VNAV capture. This applies to both "level off" or "altitude acquire" segments following a climb or descent, or vertical climb or descent segment initiation, or joining of climb or descent paths with different gradients.

Non-Standard Climb Gradient. When the operator plans to use the DA associated with a non-standard missed approach climb gradient, he must ensure the aircraft will be able to comply with the published climb gradient for the planned aircraft loading, atmospheric conditions and operating procedures before conducting the operation. Where operators have performance personnel that determine if their aircraft can comply with published climb gradients, information should be provided to the pilots indicating the climb gradient they can expect to achieve.

Engine-Out Procedures. Aircraft may demonstrate acceptable flight technical error with one engine inoperative to conduct RNP AR APPs. Otherwise, flight crews are expected to take appropriate action in event of engine failure during an approach so that no specific aircraft qualification is required. The aircraft qualification should identify any performance limits in event of engine failure to support definition of appropriate flight crew procedures.

Go-Around or Missed Approach. Where possible, the missed approach will require RNP 1.0. The missed approach portion of these procedures is similar to a missed approach of an RNAV (GNSS) approach. Where necessary, navigation accuracy less than RNP 1.0 will be used in the missed approach. To be approved to conduct these approaches, equipage and procedures must meet criteria in paragraph 6.3.3.4 (Requirements for Approaches with Missed Approach less than RNP 1.0).

In many aircraft when executing a go-around or missed approach activating Take-off/Go-around (TOGA) may cause a change in lateral navigation. In many aircraft, activating TOGA disengages the autopilot and flight director from LNAV guidance, and the flight director reverts to track-hold derived from the inertial system. LNAV guidance to the autopilot and flight director should be re-engaged as quickly as possible.

The flight crew procedures and training must address the impact on navigation capability and flight guidance if the pilot initiates a go-around while the aircraft is in a turn. When initiating an early go-around, the flight crew should follow the rest of the approach track and missed approach track unless issued a different clearance by ATC. The flight crew should also be aware that RF legs are designed based on the maximum true airspeed at normal altitudes, and initiating an early go-around will reduce the manoeuvrability margin and potentially even make holding the turn impractical at missed approach speeds.

Upon loss of GNSS updates, the RNAV guidance may begin to “coast” on IRU, if installed, and drift, degrading the navigation position solution. Thus, when the RNP AR APP missed approach operations rely on IRU “coasting” the inertial guidance can only provide RNP guidance for a specified amount of time.

Contingency Procedures **-** *Failure while En Route***.** The aircraft RNP capability is dependent on operational aircraft equipment and GNSS satellites. The flight crew must be able to assess the impact of equipment failure on the anticipated RNP AR APP and take appropriate action. As described in paragraph 6.3.4, Preflight Considerations (Dispatch RNP Assessment), the flight crew also must be able to assess the impact of changes in the GNSS constellation and take appropriate action.

Contingency Procedures - Failure on Approach. The operator’s contingency procedures need to address at least the following conditions: Failure of the RNP system components, including those affecting lateral and vertical deviation performance (e.g., failures of a GPS sensor, the flight director or automatic pilot); and Loss of navigation signal-in-space (loss or degradation of external signal).

6.3.5 Pilot/Dispatch/Operator Knowledge and Training

The operator must provide training for key personnel (e.g., flight crewmembers and dispatchers) in the use and application of RNP AR APP procedures. A thorough understanding of the operational procedures and best practices is critical to the safe operation of aircraft during RNP AR APP operations. This program must provide sufficient detail on the aircraft’s navigation and flight control systems to enable the pilots to identify failures affecting the aircrafts RNP capability and the appropriate abnormal/emergency procedures. Required training must include both knowledge and skill assessments of the crewmembers and dispatchers duties.

Operator Responsibilities.

a) Each operator is responsible for the training of flight crews for the specific RNP AR APP operations exercised by the operator. The operator must include training on the different types of RNP AR APP procedures and required equipment. Training must include discussion of RNP AR APP regulatory requirements. The operator must include these requirements and procedures in their flight operations and training manuals (as applicable). This material must cover all aspects of the operator’s RNP AR APP operations including the applicable operational authorization (e.g. Operations Specifications). An individual must have completed the appropriate ground and or flight training segment before engaging in RNP AR APP operations.

b) Flight training segments must include training and checking modules representative of the type of RNP AR APP operations the operator conducts during line flying activities. Many operators may train for RNP AR APP procedures under the established training standards and provisions for Advanced Qualification Programs (AQP). They may conduct evaluations in Line Oriented Flight Training (LOFT) scenarios, Selected Event Training (SET) scenarios or in a combination of both. The operator may conduct required flight-training modules in Flight Training Devices, Aircraft

Simulators, and other enhanced training devices as long as these training mediums accurately replicate the operator's equipment and RNP AR APP operations.

c) Operators must address initial RNP AR APP training and qualifications during initial, transition, upgrade, recurrent, differences, or stand-alone training and qualification programs in a respective qualification category. The qualification standards assess each pilot's ability to properly understand and use RNP AR APP procedures (RNP AR APP Initial Evaluation). The operator must also develop recurrent qualification standards to ensure their flight crews maintain appropriate RNP AR APP knowledge and skills (RNP AR APP Recurrent Qualification).

d) Operators may address RNP AR APP operation topics separately or integrate them with other curriculum elements. For example, an RNP AR APP flight crew qualification may focus on a specific aircraft during transition, upgrade, or differences courses. General training may also address RNP AR APP qualification (e.g., during recurrent training or checking events such as recurrent proficiency check/proficiency training, line oriented evaluation or special purpose operational training). A separate, independent RNP AR APP qualification program may also address RNP AR APP training (e.g., by completion of a special RNP AR APP curriculum at an operator's training center or at designated crew bases).

e) Operators intending to receive credit for RNP training, when their proposed program relies on previous training (e.g., Special RNP IAP's) must receive specific authorization from their Principal Operations Inspector/Flight Operations Inspector. In addition to the current RNP training program the air carrier will need to provide differences training between existing training program and the RNP AR APP training requirements.

f) Training for flight dispatchers must include: the explanation of different types of RNP AR APP procedures, the importance of specific navigation equipment and other equipment during RNP AR APP operations and the RNP AR APP regulatory requirements and procedures. Dispatcher procedure and training manual's must include these requirements (as applicable). This material must cover all aspects of the operator's RNP AR APP operations including the applicable authorizations (e.g. Ops Specs, Operations Manual, MSpecs or LOA). An individual must have completed the appropriate training course before engaging in RNP AR APP operations. Additionally, the dispatchers' training must address how to determine: RNP AR APP availability (considering aircraft equipment capabilities), MEL requirements, aircraft performance, and navigation signal availability (e.g., GPS RAIM/predictive RNP capability tool) for destination and alternate airports.

Ground training segments content

Ground training segments must address the following subjects as training modules in approved RNP AR APP academic training during the initial introduction of a crewmember to RNP AR APP systems and operations. For recurrent programs, the curriculum need only review initial curriculum requirements and address new, revised, or emphasized items.

General Concepts of RNP (AR) Approach Operation. RNP AR APP academic training must cover RNP AR APP systems theory to the extent appropriate to ensure proper operational use. Flight crews must understand basic concepts of RNP AR APP systems operation, classifications, and limitations. The training must include general knowledge and operational application of RNP (AR) instrument approach procedures. This training module must address the following specific elements:

a) Definitions of RNAV, RNAV (GPS), RNP, RNP (AR), and RAIM.

b) The differences between RNAV and RNP.

c) The types of RNP AR APP procedures and familiarity with the charting of these procedures.

d) The programming and display of RNP and aircraft specific displays (e.g., Actual Navigation Performance).

e) How to enable and disable the navigation updating modes related to RNP.

f) Navigation accuracy appropriate for different phases of flight and RNP AR APP procedures and how to select (if required).

g) The use of GPS RAIM (or equivalent) forecasts and the effects of RAIM availability on RNP AR APP procedures (flight crew and dispatchers).

h) When and how to terminate RNP navigation and transfer to traditional navigation due to loss of RNP and/or required equipment.

i) How to determine FMC database currency and whether it contains required navigational data for use of GPS waypoints.

j) Explanation of the different components that contribute to the total system error and their characteristics (e.g., effect of temperature on baro-VNAV, drift characteristics when using IRU with no radio updating).

k) Temperature Compensation. Flight crews operating avionics systems with compensation for altimetry errors introduced by deviations from ISA may disregard the temperature limits on RNP AR APP procedures, if pilot training on use of the temperature compensation function is provided by the operator and the compensation function is utilized by the crew. However, the training must also recognize the temperature compensation by the system is applicable to the VNAV guidance and is not a substitute for the flight crew compensating for the cold temperature effects on minimum altitudes or the decision altitude.

ATC Communication and Coordination for Use of RNP (AR) Approach. Ground training must instruct the flight crews on proper flight plan classifications and any Air Traffic Control (ATC) procedures applicable to RNP AR APP operations. The flight crews must receive instruction on the need to advise ATC immediately when the performance of the aircraft's navigation system is no longer suitable to support continuation of an RNP AR APP procedure. Flight crews must also know what navigation sensors form the basis for their RNP AR APP compliance, and they must be able to assess the impact of failure of any avionics or a known loss of ground systems on the remainder of the flight plan.

RNP AR APP Equipment Components, Controls, Displays, and Alerts. Academic training must include discussion of RNP terminology, symbology, operation, optional controls, and display features including any items unique to an operator's implementation or systems. The training must address applicable failure alerts and limitations. The flight crews and dispatchers should achieve a thorough understanding of the equipment used in RNP operations and any limitations on the use of the equipment during those operations.

AFM Information and Operating Procedures. The AFM or other aircraft eligibility evidence must address normal and abnormal flight crew operating procedures, responses to failure alerts, and any limitations, including related information on RNP modes of operation. Training must also address contingency procedures for loss or degradation of RNP capability. The flight operations manuals approved for use by the flight crews (e.g., Flight Operations Manual (FOM) or Pilot Operating Handbook (POH)) should contain this information.

MEL Operating Provisions. Flight crews must have a thorough understanding of the MEL requirements supporting RNP AR APP operations.

Flight Training Segments - Content

Training programs must cover the proper execution of RNP AR APP procedures in concert with the OEM's documentation. The operational training must include RNP AR APP procedures and limitations; standardization of the set-up of the cockpit's electronic displays during an RNP AR APP procedure; recognition of the aural advisories, alerts and other annunciations that can impact compliance with an RNP AR APP procedure; and the timely and correct responses to loss of RNP AR APP capability in a variety of scenarios embracing the breadth of the RNP AR APP procedures the operator plans to complete. Such training may also use approved flight training devices or simulators. This training must address the following specific elements:

a) Procedures for verifying that each pilot's altimeter has the current setting before beginning the final approach of an RNP AR APP procedure, including any operational limitations associated with the source(s) for the altimeter setting and the latency of checking and setting the altimeters approaching the FAF.

b) Use of aircraft RADAR, TAWS, GPWS, or other avionics systems to support the flight crew's track monitoring and weather and obstacle avoidance.

c) The effect of wind on aircraft performance during RNP AR APP procedures and the need to remain within RNP containment area, including any operational wind limitation and aircraft configuration essential to safely complete an RNP AR APP procedure.

d) The effect of groundspeed on compliance with RNP AR APP procedures and bank angle restrictions impacting the ability to remain on the course centreline. For RNP AR APP procedures, aircraft are expected to maintain the standard speeds associated with applicable category.

e) Relationship between RNP and the appropriate approach minima line on an approved published RNP AR APP procedure and any operational limitations if the available RNP degrades or is not available prior to an approach (this should include flight crew procedures outside the FAF versus inside the FAF).

f) Concise and complete flight crew briefings for all RNP AR APP procedures and the important role Cockpit Resource Management (CRM) plays in successfully completing an RNP AR APP procedure.

g) Alerts from the loading and use of improper navigation accuracy for a desired segment of an RNP AR APP procedure.

h) The performance requirement to couple the autopilot/flight director to the navigation system's lateral guidance on RNP AR APP procedures requiring an RNP of less than RNP 0.3.

i) The importance of aircraft configuration to ensure the aircraft maintains any required speeds during RNP AR APP procedures.

j) The events triggering a missed approach when using the aircraft's RNP capability.

k) Any bank angle restrictions or limitations on RNP AR APP procedures.

l) The potentially detrimental effect of reducing the flap setting, reducing the bank angle or increasing airspeeds on the ability to comply with an RNP AR APP procedure.

m) Flight crew knowledge and skills necessary to properly conduct RNP AR APP operations.

n) Programming and operating the FMC, autopilot, auto throttles, RADAR, GPS, INS, EFIS (including the moving map), and TAWS in support of RNP AR APP procedures.

o) Effect of activating TOGA while in a turn,

p) FTE monitoring and impact on go-around decision and operation,

q) GPS loss during a procedure,

r) Performance issues associated with reversion to radio updating and limitations on the use of DME and VOR updating.

s) Flight crew contingency procedures for a loss of RNP capability during a missed approach. Due to the lack of navigation guidance, the training should emphasize the flight crew contingency actions that achieve separation from terrain and obstacles. The operator should tailor these contingency procedures to their specific RNP AR APP procedures.

t) As a minimum, each pilot must complete two RNP approach procedures that employ the unique RNP AR APP characteristics of the operator's approved procedures (i.e., RF legs, RNP missed). One procedure must culminate in a transition to landing and one procedure must culminate in execution of an RNP missed approach procedure.

Evaluation Module

Initial Evaluation of RNP AR APP Knowledge and Procedures. The operator must evaluate each individual flight crewmember on their knowledge of RNP AR APP procedures prior to employing RNP AR APP procedures. As a minimum, the review must include a thorough evaluation of pilot procedures and specific aircraft performance requirements for RNP AR APP operations. An acceptable means for this initial assessment includes one of the following:

a) An evaluation by an authorized instructor evaluator or check airman using an approved simulator or training device.

b) An evaluation by an authorized instructor evaluator or check airman during line operations, training flights, PC/PT events, operating experience, route checks, and/or line checks.

c) Line Oriented Flight Training (LOFT)/Line Oriented Evaluation (LOE). LOFT/LOE programs using an approved simulator that incorporates RNP operations that employ the unique RNP AR APP characteristics (i.e., RF legs, RNP missed) of the operator's approved procedures.

Evaluation Content. Specific elements that must be addressed in this evaluation module are:

a) Demonstrate the use of any RNP limits/minimums that may impact various RNP AR APPs.

b) Demonstrate the application of radio-updating procedures, such as enabling and disabling ground-based radio updating of the FMC (i.e., DME/DME and VOR/DME updating) and knowledge of when to use this feature. If the aircraft's avionics do not include the capability to disable radio updating, then the training must ensure the flight crew is able to accomplish the operational actions that mitigate the lack of this feature.

c) Demonstrate the ability to monitor the actual lateral and vertical flight paths relative to programmed flight path and complete the appropriate flight crew procedures when exceeding a lateral or vertical FTE limit.

d) Demonstrate the ability to read and adapt to a RAIM (or equivalent) forecast including forecasts predicting a lack of RAIM availability.

e) Demonstrate the proper setup of the FMC, the weather RADAR, TAWS, and moving map for the various RNP AR APP operations and scenarios the operator plans to implement.

f) Demonstrate the use of flight crew briefings and checklists for RNP AR APP operations with emphasis on CRM.

g) Demonstrate knowledge of and ability to perform an RNP (AR) missed approach procedure in a variety of operational scenarios (i.e., loss of navigation or failure to acquire visual conditions).

h) Demonstrate speed control during segments requiring speed restrictions to ensure compliance with an RNP AR APP procedure.

i) Demonstrate competent use of RNP AR APP plates, briefing cards, and checklists.

j) Demonstrate the ability to complete a stable RNP AR APP: bank angle, speed control, and remain on the procedure's centreline.

k) Know the operational limit for deviation below the desired flight path on an RNP AR APP and how to accurately monitor the aircraft's position relative to vertical flight path.

Recurrent Training

The operator should incorporate recurrent RNP training that employs the unique (AR) approach characteristics of the operator's approved procedures as part of the overall program.

A minimum of two RNP AR APPs must be flown by each pilot for each duty position (pilot flying and pilot monitoring), with one culminating in a landing and one culminating in a missed approach, and may be substituted for any required "precision-like" approach.

NOTE: Equivalent RNP approaches may be credited toward this requirement.

6.3.6 Navigation Database

The procedure stored in the navigation database defines the lateral and vertical guidance. Navigation database updates occur every 28 days, and the navigation data in every update is critical to the integrity of every RNP AR APP operation. Given the reduced obstacle clearance associated with these approaches, validation of navigation data warrants special consideration. This paragraph provides guidance for the operator's procedures for validating the navigation data associated with RNP AR APPs.

Data Process

The operator must identify the responsible manager for the data updating process within their procedures.

The operator must document a process for accepting, verifying and loading navigation data into the aircraft.

The operator must place their documented data process under configuration control.

Initial Data Validation. The operator must validate every RNP AR APP procedure before flying the procedure in instrument meteorological conditions (IMC) to ensure compatibility with their aircraft and to ensure the resulting path matches the published procedure. As a minimum, the operator must:

a) Compare the navigation data for the procedure(s) to be loaded into the flight management system with the published procedure.

b) Validate the loaded navigation data for the procedure, either in a simulator or in the actual aircraft in visual meteorological conditions (VMC). The depicted procedure on the map display must be compared to the published procedure. The entire procedure must be flown to ensure the path is flyable, does not have any apparent lateral or vertical path disconnects, and is consistent with the published procedure.

c) Once the procedure is validated, retain and maintain a copy of the validated navigation data for comparison to subsequent data updates.

Data Updates. Upon receipt of each navigation data update, and before using the navigation data in the aircraft, the operator must compare the update to the validated procedure. This comparison must identify and resolve any discrepancies in the navigation data. If there are significant changes (any change affecting the approach path or performance) to any portion of a procedure and source data verifies the changes, the operator must validate the amended procedure in accordance with Initial Data Validation.

Data Suppliers. Data suppliers must have a Letter of Acceptance (LOA) for processing navigation data (e.g., FAA AC 20-153, EASA Conditions for the issuance of Letters of Acceptance for navigation database Suppliers by the Agency, or equivalent). An LOA recognizes the data supplier as one whose data quality, integrity and quality management practices are consistent with the criteria of DO-200A/ED-76. The operator's supplier (e.g., FMS company) must have a Type 2 LOA, and their respective suppliers must have a Type 1 or 2 LOA.

Aircraft Modifications. If an aircraft system required for RNP AR APP is modified (e.g., software change), the operator is responsible for validation of RNP AR APP procedures with the navigation database and the modified system. This may be accomplished without any direct evaluation if the manufacturer verifies that the modification has no effect on the navigation database or path computation. If no such assurance from the manufacturer is available, the operator must conduct initial data validation with the modified system.

6.3.7 Oversight of Operators

A regulatory authority may consider any anomaly reports in determining remedial action. Repeated navigation error occurrences attributed to a specific piece of navigation equipment may result in cancellation of the approval for use of that equipment.

Information that indicates the potential for repeated errors may require modification of an operator's training program. Information that attributes multiple errors to a particular pilot crew may necessitate remedial training or license review.

The operator must have an RNP monitoring program to ensure continued compliance with the guidance of this chapter and to identify any negative trends in performance. At a minimum, this program must address the following information. During the interim approval, the operator must submit the following information every 30 days to the authority granting their authorization. Thereafter, the operator must continue to collect and periodically review this data to identify potential safety concerns, and maintain summaries of this data.

a) Total number of RNP (AR) procedures conducted.

b) Number of satisfactory approaches by aircraft/system (Satisfactory if completed as planned without any navigation or guidance system anomalies).

c) Reasons for unsatisfactory approaches, such as:

(i) UNABLE REQ NAV PERF, NAV ACCUR DOWNGRAD, or other RNP messages during approaches.

(ii) Excessive lateral or vertical deviation.

(iii) TAWS warning.

(iv) Autopilot system disconnect.

(v) Nav data errors.

(vi) Pilot report of any anomaly.

d) Crew comments.

6.4 SAFETY ASSESSMENT

The safety objective for RNP AR APP operations is to provide for safe flight operations. Traditionally, operational safety has been defined by a target level of safety and specified as a risk of collision of 10^{-7} per approach. For RNP AR APP a flight operational safety assessment (FOSA) methodology is used. The FOSA is intended to provide a level of flight safety that is equivalent to the traditional TLS, but using methodology oriented to performance-based flight operations. Using the FOSA, the operational safety objective is met by considering more than the aircraft navigation system alone. The FOSA blends quantitative and qualitative analyses and assessments for navigation systems, aircraft systems, operational procedures, hazards, failure mitigations, normal, rare-normal and abnormal conditions, hazards, and the operational environment. The FOSA relies on the detailed criteria for aircraft qualification, operator approval and instrument procedure design to address the majority of general technical, procedure and process factors. Additionally, technical and operational expertise and experience are essential to the conduct and conclusion of the FOSA.

An overview of the hazards and mitigations is provided to assist States in applying this criteria. Safety of RNP AR APP operations rests with the operator and the air navigation service provider as described in this chapter.

A FOSA should conducted for each RNP AR APP procedure to ensure that for each specific set of operating conditions, aircraft, and environment that all failure conditions are assessed and where necessary mitigations implemented to meet the operational safety objective. The assessment should give proper attention to the inter-dependence of the elements of design, aircraft capability, crew procedures and operating environment.

The following hazard conditions are examples of some of the more significant hazards and mitigations addressed in the aircraft, operational and procedure criteria:

Normal performance: Lateral and vertical accuracy are addressed in the aircraft requirements, aircraft and systems operate normally in standard configurations and operating modes, and individual error components are monitored/truncated through system design or crew procedure.

Rare-Normal and Abnormal Performance: Lateral and vertical accuracy are evaluated for aircraft failures as part of the determination of aircraft qualification. Additionally, other rare-normal and abnormal failures and conditions for ATC operations, crew procedures, NAVAID infrastructure and operating environment are also assessed, Where the failure or condition results are not acceptable for continued operation, mitigations are developed or limitations established for the aircraft, crew and/or operation.

Aircraft failures

1. System Failure: Failure of a navigation system, flight guidance system, flight instrument system for the approach, missed approach or departure (e.g., loss of GNSS updating, receiver failure, autopilot disconnect, FMS failure etc.) Depending on the aircraft, this may be addressed through aircraft design or operational procedure to cross-check guidance (e.g., dual equipage for lateral errors, use of terrain awareness and warning system).
2. Malfunction of air data system or altimetry: Crew procedure cross-check between two independent systems mitigates this risk.

Aircraft Performance

1. Inadequate performance to conduct the approach: the aircraft qualification and operational procedures ensure the performance is adequate on each approach, as part of flight planning and in order to begin or continue the approach. Consideration should be given to aircraft configuration during approach and any configuration changes associated with a go-around (e.g., engine failure, flap retraction).
2. Loss of engine: Loss of an engine while on an RNP AR APP approach is a rare occurrence due to high engine reliability and the short exposure time. Operators will take appropriate action to mitigate the effects of loss of engine, initiating a go-around and manually taking control of the aircraft if necessary.

Navigation Services

1. Use of a navigation aid outside of designated coverage or in test mode: Aircraft requirements and operational procedures have been developed to address this risk.
2. Navigation database errors: Procedures are validated through flight validation specific to the operator and aircraft, and the operator is required to have a process defined to maintain validated data through updates to the navigation database.

ATC Operations

1. Procedure assigned to incapable aircraft: Operators are responsible for declining the clearance.
2. ATC vectors aircraft onto approach such that performance cannot be achieved: ATC training and procedures must ensure obstacle clearance until aircraft is established on the procedure, and ATC should not intercept on or just prior to curved segments of the procedure.

Flight Crew Operations

1. Erroneous barometric altimeter setting: Crew entry and cross-check procedures mitigate this risk.
2. Incorrect procedure selection or loading: crew procedure to verify loaded procedure matches published procedure, aircraft requirement for map display.
3. Incorrect flight control mode selected: training on importance of flight control mode, independent procedure to monitor for excessive path deviation.
4. Incorrect RNP entry: crew procedure to verify RNP loaded in system matches the published value.
5. Go-Around/Missed Approach: Balked landing or rejected landing at or below DA (H).
6. Poor meteorological conditions: Loss or significant reduction of visual reference that may result in or require a go-around.

Infrastructure

1. GNSS satellite failure: This condition is evaluated during aircraft qualification to ensure obstacle clearance can be maintained, considering the low likelihood of this failure occurring.
2. Loss of GNSS signals: Relevant independent equipage (eg IRU) is required for RNP AR APP approaches with RF legs and approaches where the accuracy for the missed approach is less than 1

NM. For other approaches, operational procedures are used to approximate the published track and climb above obstacles.

3. Testing of ground Navaid in the vicinity of the approach: Aircraft and operational procedures are required to detect and mitigate this event.

Operating Conditions

1. Tailwind conditions: Excessive speed on RF legs will result in inability to maintain track. This is addressed through aircraft requirements on the limits of command guidance, inclusion of 5 degrees of bank manoeuvrability margin, consideration of speed effect and crew procedure to maintain speeds below the maximum authorized.

2. Wind conditions and effect on flight technical error: nominal flight technical error is evaluated under a variety of wind conditions, and crew procedure to monitor and limit deviations ensure safe operation.

3. Extreme temperature effects of barometric altitude (e.g. extreme cold temperatures, known local atmospheric or weather phenomena, high winds, severe turbulence etc.): The effect of this error on the vertical path is mitigated through the procedure design and crew procedures, with an allowance for aircraft that compensate for this effect to conduct procedures regardless of the published temperature limit. The effect of this error on minimum segment altitudes and the decision altitude are addressed in an equivalent manner to all other approach operations.

6.5 REFERENCES

Copies of EUROCAE documents may be purchased from EUROCAE, 17 rue Hamelin, 75783 PARIS Cedex 16, France, (Fax : 33 1 45 05 72 30). Web site: http://www.eurocae.org

Copies of FAA documents may be obtained from Superintendent of Documents, Government Printing Office, Washington, DC 20402-9325, USA. Web site: http://www.faa.gov/certification/aircraft/ (Regulation and Guidance Library)

- TSO-C115B, Airborne Area Navigation Equipment Using Multi-Sensor Inputs.
- TSO-C129A, Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS).
- TSO C145A, Airborne Navigation Sensors Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS).
- TSO C146A, Stand-Alone Airborne Navigation Equipment Using the Global Positioning System (GPS) Augmented by the Wide Area Augmentation System (WAAS).
- AC 20-129, Airworthiness Approval for Vertical Navigation (VNAV) Systems for Use in the U.S. National Airspace System (NAS) and Alaska
- AC 20-130A, Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors.
- AC 20-138A, Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for Use as a VFR and IFR Supplemental Navigation System.
- AC 20-153, Acceptance of Data Processes and Associated Navigation Databases.
- AC 25-1309-1A, System Design and Analysis.
- AC 25-15, Approval of Flight Management Systems in Transport Category Airplanes.
- AC 23-1309-1C, Equipment, Systems and Installations in Part 23 Airplanes
- AC 120-29A, Criteria for Approval of Category I and Category II Weather Minima for Approach.

Copies of RTCA documents may be obtained from RTCA Inc., 1140 Connecticut Avenue, N.W., Suite 1020, Washington, DC 20036-4001, USA, (Tel: 1 202 833 9339). Web site www.rtca.org.

- RTCA/DO-178B, Software Considerations in Airborne Systems and Equipment Certification.
- RTCA/DO-187, Minimum Operational Performance Standards for Airborne Area Navigation Equipment Using Multi-Sensor Inputs.
- RTCA/DO-189, Minimum Performance Standard for Airborne Distance Measuring Equipment (DME) Operating Within the Radio Frequency Range of 960-1215 Megahertz
- RTCA/DO-200A, Standards for Processing Aeronautical Data.
- RTCA/DO-201A, User Recommendations for Aeronautical Information Services.
- RTCA/DO-208, Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS).
- RTCA/DO-229C, Minimum Operations Performance Standards for Airborne GPS/Wide Area Augmentation System Equipment.
- RTCA/DO-236B, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation.
- RTCA/DO-283A, Minimum Operational Performance Standards for Required Navigation Performance for Area Navigation.

Copies of EASA documents may be obtained from EASA (European Aviation Safety Agency),101253, D-50452 Koln, Germany.

Copies of ICAO documents may be purchased from Document Sales Unit, International Civil Aviation Organization, 999 University Street, Montreal, Quebec, Canada H3C 5H7, (Fax: 1 514 954 6769, or e-mail: sales_unit@icao.org) or through national agencies.

ATTACHMENTS TO VOLUME II

Attachment A

BAROMETRIC VNAV

1.1. INTRODUCTION

1.1.1. Background

This navigation specification addresses those systems based upon the use of barometric altitude and RNAV information in the definition of vertical flight paths, and vertical tracking to a path. The final approach segment of VNAV instrument flight procedures are performed using vertical guidance to a glide path computed by the on-board RNAV system. The glide path is contained in the specification of the instrument procedure within the RNAV system navigation database. For other phases of flight, barometric VNAV provides vertical path information that can be defined by vertical angles or altitudes at fixes in the procedure.

1.1.2. Purpose

This specification provides guidance to States implementing instrument flight procedures where baro-VNAV is authorized for RNP APP approaches, and, RNP AR APP where approved. For the Air Navigation Service Provider, it provides a consistent ICAO recommendation on what to implement. For the operator, this reflects airworthiness guidance material that has existed for over 20 years. This specification is intended to facilitate operational approvals for existing baro-VNAV systems that have demonstrated their capabilities and obtained regulatory approval for usage. An operational approval based upon this standard allows an operator to conduct baro-VNAV operations globally.

This specification provides airworthiness and operational criteria for the approval of an RNAV system using barometric altimetry as a basis for its vertical navigation capability.

1.2. ANSP CONSIDERATIONS

1.2.1. Application of BARO-VNAV

Baro-VNAV is intended to be applied where vertical guidance and information is provided to the flight crew on instrument approach procedures containing a vertical flight path defined by a vertical path angle. Barometric VNAV may also be defined by altitude constraints but only for flight phases other than approach. Guidance for operational use is provided in PANS-OPS (Doc 8168, Volume 1).

1.2.2. Obstacle Clearance

Detailed guidance on obstacle clearance for the final approach segment is provided in PANS-OPS (Doc 8168, Volume II). The general criteria in Part 1 and Part 3 apply, together with the approach criteria from Doc 8168, Volume II, Part III, Section 1, Chapter 2 and Section 3, Chapter 4. The PANS-OPS criteria does not provide specific guidance for design of a Baro-VNAV overlay to a conventional non-precision procedure. In such cases, many other considerations must be made to ensure continued obstacle clearance, flyability, charting consistency and compatibility with airborne systems.

1.3. GENERAL CONSIDERATIONS FOR DEVELOPMENT OF BARO-VNAV SPECIFICATION

1.3.1. Navaid Infrastructure Considerations

The procedure design does not have unique infrastructure requirements. This criteria is based upon the use of barometric altimetry by an airborne RNAV system whose performance capability supports the required operation. The procedure design should take into account the functional capabilities required by this document.

1.3.2. Publication Considerations

Charting should follow the standards of Annex 4 for the designation of an RNAV procedure where the vertical flight path is specified by a glidepath angle. The charting designation will remain consistent with the current convention (for example if the lateral procedure is predicated on GNSS, the charting will indicate RNAV **(GNSS)** .

1.3.3. Monitoring and investigation of navigation and system errors

If an observation/analysis indicates that a loss of separation or obstacle clearance has occurred, the reason for the apparent deviation from track or altitude should be determined and steps taken to prevent a recurrence.

1.3.4. Navigation Error Reports

A regulatory authority may consider any navigation error reports in determining remedial action. Repeated navigation error occurrences attributed to a specific piece of navigation equipment may result in cancellation of the approval for use of that equipment.

Information that indicates the potential for repeated errors may require modification of an operator's training program. Information that attributes multiple errors to a particular pilot crew may necessitate remedial training or license review.

1.3.5. Service Provider Assumptions

It is expected that air navigation service provision will include data and information to enable correct and accurate altimeter setting on-board the aircraft, as well as local temperature. This data must be from measurement equipment at the airport where the approach is to take place. The specific medium for transmission of this data and information to the aircraft may include voice communication, ATIS or other media. In support of this, it is also expected that service providers will assure the accuracy, currency and availability of meteorological data supporting VNAV operations.

1.3.6. ATC Coordination

It is expected that ATC will be familiar with aircraft VNAV capability, as well as issues associated with altimeter setting and temperature data required by the aircraft.

1.4. NAVIGATION SPECIFICATION

1.4.1. Background

This section identifies the operational requirements for VNAV in conjunction with RNP APP operations. It assumes the airworthiness approval of the aircraft and systems have been completed. This means the basis for the VNAV function and performance have already been established and approved based upon appropriate levels of analysis, testing and demonstration. Additionally, as part of this activity the normal procedures, as well as any limitations for the function, have been documented as appropriate to aircraft flight and operations manuals. Compliance with the operational requirements herein should be addressed through national operational regulations, and may require a specific operational approval in some cases. For example, certain operational regulation requires operators to apply to their national authority (State of registry) for operational approval.

1.4.2. Approval Process

The following steps must be completed before the use of BARO-VNAV in the conduct of basic RNP approach operations:

a) Aircraft equipment eligibility must be determined and documented;
b) Operating procedures must be documented;
c) Flight crew training based upon the operating procedures must be documented;
d) The above material must be accepted by the State regulatory authority; and
e) Operational approval should then be obtained in accordance with national operating rules.

Following the successful completion of the above steps, operational approval for the use of VNAV, letter of authorization or appropriate operations specification (Ops Spec), or amendment to the Operations Manual, if required, should then be issued by the State.

1.4.3. Aircraft Requirements

1.4.3.1. Aircraft Eligibility

Relevant documentation acceptable to the State of operation must be available to establish that the aircraft is equipped with an RNAV system with a demonstrated VNAV capability. Eligibility may be established in two steps, one recognizing the qualities and qualifications of the aircraft and equipment, and the second determining the acceptability for operations. The determination of eligibility for existing systems should consider acceptance of manufacturer documentation of compliance e.g. as with AC20-129.

NOTE: RNP AR Systems: RNAV systems demonstrated and qualified for RNP AR operations including VNAV are considered qualified with recognition that the RNP approaches are expected to be performed consistent with the operators RNP AR approval. . No further examination of aircraft capability, operator training, maintenance, operating procedures, databases, etc is necessary.

a) Description of aircraft equipment. The operator must have a configuration list detailing pertinent components and equipment to be used for approach operation.

Note: Barometric altimetry and related equipment such as air data systems are a required basic capability and already subject to minimum equipment requirements for flight operations.

b) Training documentation. Commercial operators should have a training program addressing the operational practices, procedures and training items related to VNAV in approach operations (e.g. initial, upgrade or recurrent training for flight crew, dispatchers or maintenance personnel).

NOTE: It is not required to establish a separate training program or regimen if RNAV and VNAV training is already an integrated element of a training program. However, it should be possible to identify what aspects of VNAV are covered within a training program. Private operators should be familiar with the practices and procedures identified in paragraph 1.4.6, Pilot Knowledge/Training.

c) Operations manuals and checklists. Operations manuals and checklists for commercial operators must address information/guidance on the standard operating procedures detailed in section 1.2.1 of this chapter. The appropriate manuals should contain navigation operating instructions and contingency procedures where specified. Manuals and checklists must be submitted for review as part of the application process.

Private operators should operate using the practices and procedures identified in section 1.4.6, Pilot Knowledge/Training.

1.4.3.2. Minimum Equipment List (MEL) Considerations

Any unique minimum equipment list (MEL) revisions necessary to address VNAV for approach provisions must be approved. Operators must adjust the MEL, or equivalent, and specify the required dispatch conditions.

NOTE: Barometric altimetry and related systems are minimum equipment for all operations. Any unique dispatch or operational assumptions should be documented.

1.4.4. Aircraft System Requirements

1.4.4.1. Barometric Vertical Navigation (VNAV) System Performance

Barometric VNAV approach operations are based upon the use of RNAV equipment that automatically determines aircraft position in the vertical plane using inputs from equipment that can include:

a) FAA TSO-C106, Air Data Computer

b) Air data system, ARINC 706, Mark 5 Air Data System

c) Barometric altimeter system, DO-88 Altimetry, ED-26 MPS for Airborne Altitude Measurements and Coding Systems, ARP-942 Pressure Altimeter Systems, ARP-920 Design and Installation of Pitot Static Systems for Transport Aircraft.

d) Type certified integrated systems providing an Air Data System capability comparable to item b).

Note: Positioning data from other sources may be integrated with the barometric altitude information provided it does not cause position errors exceeding the track keeping accuracy requirements

System Accuracy

a) For instrument approach operations, the error of the airborne VNAV equipment, excluding altimetry, should have been demonstrated to be less than that shown below on a 99.7 percent probability basis:

Altitude Region	Level Flight Segments and Climb/Descent Intercept of Specified Altitudes (ft)	Climb/Descent Along Specified Vertical Profile (angle) (ft)
At or below 5,000 ft	50	100
5,000 ft to 10,000 ft	50	150
Above 10,000 ft	50	220

NOTES:

1. *Maximum operating altitudes to be predicated on a compliance with total accuracy tolerance.*

2. *VNAV guidance may be used in level flight en route as in the case of altitude hold control laws, which are integrated with speed control laws to provide an energy trade. The incremental error component contributed by the VNAV equivalent must be offset by a corresponding reduction in other error components, such as flight technical error, to ensure that the total error budget is not exceeded.*

3. *Altimetry Error. Refers to the electrical output and includes all errors attributable to the aircraft altimetry installation including position effects resulting from normal aircraft flight attitudes. In high performance aircraft, it is expected that altimetry correction will be provided. Such correction should be done automatically. In lower performance aircraft, upgrading of the altimetry system may be necessary.*

4. *VNAV Equipment Error. Includes all errors resulting from the vertical guidance equipment installation. Does not include errors of the altimeter system but does include any additional errors resulting from the addition of the VNAV equipment. This error component may be zero in level en route flight if the operation is limited to guidance by means of the altimeter only. It should not be disregarded in terminal and approach operations where the pilot is expected to follow the VNAV indications.*

b) Flight Technical (Pilotage) Errors. With satisfactory displays of vertical guidance information, flight technical errors should have been demonstrated to be less than the values shown below on a three-sigma basis.

Altitude Region	Level Flight Segments and Climb/Descent Intercept of Specified Altitudes (ft)	Climb/Descent Along Specified Vertical Profile (angle) (ft)
At or below 5,000 ft	150	200
5,000 ft to 10,000 ft	240	300
Above 10,000 ft	240	300

Sufficient flight tests of the installation should have been conducted to verify that these values can be maintained. Smaller values for flight technical errors may be achieved especially in the cases where the VNAV system is to be used only when coupled to an autopilot or flight director. However, at least the total system vertical accuracy shown below should be maintained.

If an installation results in larger flight technical errors, the total vertical error of the system (excluding altimetry) may be determined by combining equipment and flight technical errors using the root sum square (RSS) method. The result should be less than the values listed below.

	Level Flight Segments and Climb/Descent Intercept Altitude Region of Specified Altitudes (ft)	Climb/Descent Along Specified Vertical Profile (angle) (ft)
At or below 5,000 ft	158	224
5,000 ft to 10,000 ft	245	335
Above 10,000 ft	245	372

An acceptable means of complying with these accuracy requirements is to have an RNAV system approved for VNAV approaches in accordance with the criteria of FAA AC20-129.

Continuity of function

For operations predicated on the use of barometric VNAV capability, at least one RNAV system is required.

1.4.4.2. Vertical Navigation Functions

Path Definition

The requirements for defining the vertical path are governed by the two general requirements for operation; allowance for aircraft performance, and repeatability and predictability in path definition. This operational relationship leads to the specifications in the following sections that are based upon specific phases of flight and flight operations.

The navigation system must be capable of defining a vertical path by a flight path angle to a fix. The system must also be capable of specifying a vertical path between altitude constraints at two fixes in the flight plan. Fix altitude constraints must be defined as one of the following:

a) An “AT or ABOVE” altitude constraint (for example, 2400A, may be appropriate for situations where bounding the vertical path is not required);

b) An “AT or BELOW” altitude constraint (for example, 4800B, may be appropriate for situations where bounding the vertical path is not required);

c) An “AT” altitude constraint (for example, 5200); or

d) A “WINDOW” constraint (for example, 2400A3400B).

e) NOTE: For RNP AR approach procedures, any segment with a published vertical path will define that path based on an angle to the fix and altitude.

Vertical Constraints

Altitudes and/or speeds associated with published procedures must be automatically extracted from the navigation database upon selecting the approach procedure.

Path Construction

The system must be able to construct a path to provide guidance from current position to a vertically constrained fix.

Capability to Load Procedures from the Navigation Database

The navigation system must have the capability to load and modify the entire procedure(s) to be flown, based upon ATC instruction, into the RNAV system from the onboard navigation database. This includes the approach (including vertical angle), the missed approach and the approach transitions for the selected airport and runway. The navigation system should preclude modification of the procedure data contained in the navigation database.

Temperature Limits.

For aircraft using barometric vertical navigation without temperature compensation to conduct the approach, low-temperature limits are reflected in the procedure design and identified along with any high temperature limits on the charted procedure. Cold temperatures reduce the actual glidepath angle while high temperatures increase the actual glidepath angle. Aircraft using barometric vertical navigation with temperature compensation or aircraft using an alternate means for vertical guidance (e.g., SBAS) may disregard the temperature restrictions.

1.4.4.3. Guidance and Control

For the vertical performance requirements, the path steering error budget must reflect altitude reference as well as other factors such as roll compensation and speed protection, as applicable.

1.4.4.4. User Interface

Displays and Control

The display readout and entry resolution for vertical navigation information should be as follows:

Parameter	Display Resolution	Entry Resolution
Altitude	Flight level or 1 foot	Flight level or 1 foot
Vertical Path Deviation	10 feet	Not Applicable
Flight Path Angle	0.1 degree	0.1 degree
Temperature	1 degree	1 degree

Path Deviation and Monitoring

The navigation system must provide the capability to continuously display to the pilot flying, on the primary flight instruments for navigation of the aircraft, the aircraft position relative to the vertically defined path. The display must allow the pilot to readily distinguish if the vertical deviation exceeds +100/-50 feet. The deviation should be monitored, and action taken to minimize errors.

a) *It* is recommended that an appropriately-scaled non-numeric deviation display (i.e. vertical deviation indicator) be located in the pilot's primary optimum field of view. A fixed-scale deviation indicator is acceptable as long as it demonstrates appropriate scaling and sensitivity for the intended operation. Any alerting and annunciation limits must also match the scaling values. Note: Existing systems provide for vertical deviation scaling with a range of +/- 500 feet. Such deviation scaling should be assessed consistent with the above requirement on discernability.

b) In lieu of appropriately scaled vertical deviation indicators in the pilot's primary optimum field of view, a numeric display of deviation may be acceptable depending on the flight crew workload and the numeric display characteristics. A numeric display may require additional initial and recurrent flight crew training.

c) Since vertical deviation scaling and sensitivity varies widely, eligible aircraft must also be equipped with and operationally using either a flight director or autopilot capable of following the vertical path.

Barometric Altitude

The aircraft must display barometric altitude from two independent altimetry sources, one in each pilots' primary optimum field of view. Operator procedures should ensure current altimeter settings for the selected instrument procedure and runway.

1.4.5. Operating Procedures

Airworthiness certification alone does not authorise operator to utilize VNAV capability during the conduct of flight operations. Operational approval is required to confirm the adequacy of the operator's normal and contingency procedures for the particular equipment installation.

1.4.5.1. General Operating Procedures

The pilot should comply with any instructions or procedures identified by the manufacturer as necessary to comply with the performance requirements in this chapter.

Cold Temperature

When cold weather temperatures exist, the pilot should check the chart for the instrument approach procedure to determine the limiting temperature for the use of Baro-VNAV capability. If the airborne system contains a temperature compensation capability, manufacturer instructions should be followed for use of the Baro-VNAV function.

1.4.5.2. Contingency Procedures

Where the contingency procedure requires reversion to a conventional procedure, necessary preparation should be completed before commencing the RNAV procedure, consistent with operator practices.

1.4.6. Pilot Knowledge and Training

The training program should provide sufficient training (for example, simulator, training device, or aircraft) on the aircraft's VNAV capability to the extent that the pilots are not just task oriented.

a) The information in this chapter.
b) The meaning and proper use of aircraft systems.
c) Procedure characteristics as determined from chart depiction and textual description.

   i) Depiction of waypoint types (fly-over and fly-by) and path terminators and any other types used by the operator) as well as associated aircraft flight paths.

   ii) RNAV system-specific information:

   iii) Levels of automation, mode annunciations, changes, alerts, interactions, reversions, and degradation.

   iv) Functional integration with other aircraft systems.

   v) The meaning and appropriateness of vertical path discontinuities as well as related flight crew procedures.

   vi) Monitoring procedures for each phase of flight (for example, monitor "PROGRESS" or "LEGS" page).

   vii) Turn anticipation with consideration to speed and altitude effects.

   viii) Interpretation of electronic displays and symbols.

VNAV equipment operating procedures, as applicable, including how to perform the following actions:
a) Adhere to speed and/or altitude constraints associated with an approach procedure.
b) Verify waypoints and flight plan programming.

c) Fly direct to a waypoint.
d) Determine vertical-track error/deviation.
e) Insert and delete route discontinuity.
f) Change arrival airport and alternate airport.
g) Contingency procedures for VNAV failures

h) There should be a clear understanding for crew requirements for comparisons to primary altimeter information, altitude crosschecks (e.g. altimetry comparisons of 100 feet), temperature limitations for instrument procedures using VNAV, and procedures for altimeter settings for approach.

Additional operations guidance related to the considerations reflected in the procedure design are included in PANS-Ops Vol I.

1.4.7. Database

The navigation database should be obtained from a supplier holding an EASA or FAA Letter of Acceptance (LOA). This LOA demonstrates compliance with EUROCAE/RTCA document ED-76/DO-200A, Standards for Processing Aeronautical Data. FAA AC 20-153/EASA IR 21 sub-part G provides additional guidance on Type 1 and Type 2 LOA's.

Discrepancies that invalidate a procedure must be reported to the navigation database supplier and affected procedures must be prohibited by an operator's notice to its flight crew.

Aircraft operators should consider the need to conduct ongoing checks of the operational navigation databases in order to meet existing quality system requirements.

1.5. REFERENCES

Reserved