



Agenda Item 2: Review of Air Navigation Matters
2.2 Air Navigation specific activities:
2.2.1 Air Traffic Management (ATM)
• PBN implementation

PBN IMPLEMENTATION

(Presented by the Secretariat)

SUMMARY	
This working paper analyzes the follow-up actions for PBN implementation so as to increase airspace capacity, in accordance with aircraft capability and the gate-to-gate concept.	
References: • ICAO Doc 9613- <i>Performance-Based Navigation Manual</i> • Reports of GREPECAS/14 (San Jose, Costa Rica, 16 – 20 April 2007) and 15 (Río de Janeiro, Brasil, 13 – 17 October 2008) Meetings.	
Strategic Objectives	<i>This working paper is related to Strategic Objective E: Efficiency.</i>

1. Introduction

1.1 ICAO Assembly resolution A36-23 resolves that States and planning and implementation regional groups (PIRGs) complete a PBN implementation plan by 2009 to achieve, among others, implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and/or augmented GNSS) for all instrument runway ends at international aerodromes.

1.2 GREPECAS, through Conclusions 14/51, 15/1 and 15/38 addressed PBN regional strategies and a model to develop national action plans by the end of December 2009. The scenario of the CAR/SAM PBN Roadmap approved by GREPECAS is in accordance with ICAO Doc 9613- *Performance-Based Navigation Manual*.

2 Discussion

2.1 PBN helps to develop arrival and departure procedures that enhance service and safety, are environmentally friendly, and have a significant lower cost than available today. PBN precision and predictability can reduce route-structure track miles, minimize CO₂ emissions, and increase efficiency improving air operations such as implementation of continuous descent approaches (CDA).

2.2 It should be noted that many of the navigational advances enabled by PBN are compatible with the avionics technology currently installed in most of the world's major commercial aircraft fleets—meaning minimal or no new equipment requirements for major aircraft operators or Air Navigation Service Providers (ANSPs).

2.3 PBN represents a framework for defining a navigation performance specification along a route, during a procedure, or in an airspace within which an aircraft must comply with specific operational performance requirements.

2.4 For PBN implementation, a safety assessment should be conducted in accordance with the provisions contained in Annex 11 and PANS-ATM, Chapter 2; operating rules should be published in the aeronautical information publication (AIP) and the ICAO *Regional Supplementary Procedures* (Doc 7030). Once aircraft are certified by their State of manufacture, operators should be approved in accordance with their National Operating Rules.

2.5 ICAO Doc 9613 provides a basis for the development of automated flight paths, as well as for more efficient airspace design, aircraft separation and obstacle avoidance. Extracts from Doc 9613, Vol. II, related to application of RNAV or RNP navigation specification by flight phase, approval process and guidelines for safety assessment are included in the **Appendix** to this Working Paper.

2.6 Several lessons were learnt from the WATRS Plus project; one of them was the implementation of RNAV routes with navigation specifications according to the user requirements to increase ATS capacity. In addition several airports have implemented GNSS procedures in the CAR Region; however there are additional tasks that should be developed in the near future such as:

- a) methodologies for traffic forecast and cost benefit analysis;
- b) air operations simulation in different scenarios;
- c) ATC personnel training;
- d) uniform classification of adjacent and regional airspaces;
- e) RNAV/RNP application in SIDs and STARs;
- f) RNAV routes implementation;
- g) FPL processing;
- h) automation updates;
- i) WGS 84 implementation; and
- j) AIS support for PBN publications.

2.7 In accordance with ICAO Assembly resolution A36-23, it is expected that E/CAR States/Territories complete a PBN implementation plan by 2009 to achieve among others, implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and/or augmented GNSS) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 with intermediate milestones as follows: 30% by 2010, 70% by 2014.

2.8 It is expected that E/CAR States/Territories issue PBN regulations and procedures so as to allow operational enhancements to the airspace capacity and benefits for aircraft operators in the near term. It is necessary also to review the ATS routes network, assign particular RNAV or RNP navigation specification to the ones already implemented and publish related information in the AIP as soon as practicable.

2.9 Supporting regional activities, the ICAO NACC Regional Office coordinated a PBN Design Course to assist CAR States to pursue activities moving forward with the PBN implementation. Unfortunately, only Trinidad and Tobago was able to assist.

3 **Suggested action**

3.1 The Meeting is invited to:

- a) review the information provided in this working paper;
- b) urge E/CAR States and Territories to develop a national action plan for PBN implementation in the short term by **31 January 2010**;
- c) review the ATS route network within the Piarco FIR so as to achieve improvements in the airspace capacity; and
- d) urge E/CAR States/Territories to issue applicable PBN regulations and procedures for aircraft operators and air navigation providers.

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APPENDIX

APPLICATION OF RNAV OR RNP NAVIGATION SPECIFICATION BY FLIGHT PHASE

Navigation specification	Flight Phase							Departure
	En Route oceanic /remote	En Route continental	Arrival	Approach				
				Initial	Intermediate	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							
Basic RNP 1			1 ^{a,c}	1 ^a	1 ^a		1 ^{ab}	1 ^{a,c}
RNP APCH				1	1	0.3	1	
RNP AR APCH				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 (NM)

RNAV 5 is an en-route navigation specification which may be used for the initial part of the STAR outside 30NM and above MSA

RNP 2 and Advanced-RNP 1 are expected to be included in a future revision of the PBN Manual;

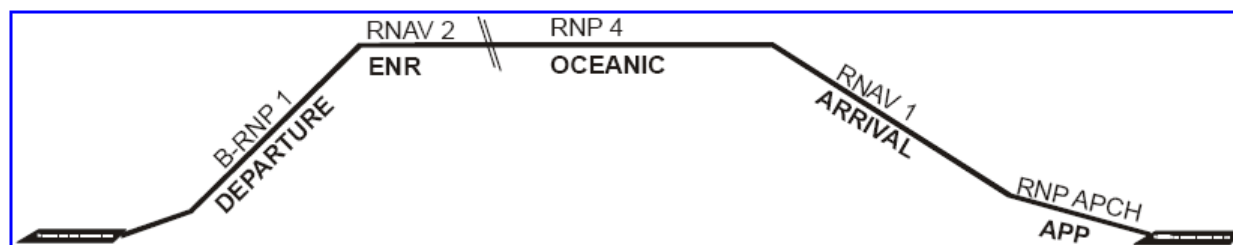
1a means that the navigation application is limited to use on STARs and SIDs only;

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. 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 APCH. An example of an Application of RNAV and RNP Specifications to ATS Routes and Instrument Procedures is as follows:



Navigation Specifications and the Approval process

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.

The Navigation Specification provides the technical and operational criteria, and does not imply a need for recertification. Therefore, with RNAV 2/ RNAV 1, for example, there is still a need to have an approval process. 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

Application of Performance Monitoring and Alerting to Risk Evaluations

The performance monitoring and alerting requirements for RNP 4, Basic-RNP 1 and RNP APCH 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 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 SASP (formerly RGCSP).

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.

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. ICAO Doc 9849, Global Navigation Satellite System (GNSS) Manual, provides guidance when GNSS is planned to be used. 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. 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.

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.

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 PRNAV Route Spacing and Aircraft Separation	
RNP 4	(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)	
RNP 2	To be developed	Navigation specification in development
Basic-RNP 1	ICAO Procedures for Air Navigation Services – Aircraft Operations (Doc 8168) (PANS-OPS), Volume II	
Advanced-RNP 1	To be developed	Navigation specification in development
RNP AR	ICAO Procedures for Air Navigation Services – Aircraft Operations (Doc 8168) (PANS-OPS), Volume II	
RNP AR APCH	Procedure Design for RNP AR APCH Procedures (Doc 9905; Draft)	