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TWELFTH AIR NAVIGATION CONFERENCE

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Agenda Item 1: Strategic issues that address the challenge of integration, interoperability and harmonization of systems in support of the concept of "One Sky" for international civil aviation
1.1: Global Air Navigation Plan (GANP) – framework for global planning
c) Navigation roadmap

NAVIGATION ROADMAP

(Presented by the Secretariat)

SUMMARY

The *Global Air Traffic Management Operational Concept* (Doc 9854) presents the ICAO vision of an integrated, harmonized and globally interoperable air traffic management (ATM) system. The ultimate goal of this system is to support airspace users' requirements to follow preferred trajectories on each flight, resulting in fuel savings and reduced emissions. This requires the ATM system to manage each flight in four dimensions (4D), the fourth being time. The system must also support approaches with the lowest possible minima and vertical guidance to all qualifying runways. Meeting these goals requires the implementation of performance-based navigation (PBN). The navigation roadmap encompasses navigation applications, infrastructure and avionics. The roadmap describes PBN migration paths for types of airspace and phases of flight.

The aviation system block upgrade (ASBU) process defines timelines for the operational use of various ATM capabilities. Some of the ASBUs depend on the implementation of PBN. As described in this document, PBN implementation timing will depend on State and regional requirements to meet airspace users' requirements for safety and efficiency, as well as on the pace of aircraft equipage.

1. INTRODUCTION

1.1 The *Global Air Traffic Management Operational Concept* (Doc 9854) presents the ICAO vision of an integrated, harmonized and globally interoperable air traffic management (ATM) system. The ultimate goal of this system is to support airspace users' requirements to follow the preferred trajectory on each flight, resulting in fuel savings and reduced emissions. This requires an ATM system that can manage each flight in four dimensions (4D), the fourth being time. The system must also support approaches with the lowest possible minima and vertical guidance to all qualifying runways.

1.2 Meeting these goals requires the progressive introduction of performance-based navigation (PBN) to ensure that aircraft follow defined paths with accuracy, reliability and improved predictability. Transitioning to PBN operations may also dictate the need to reassess the role of conventional navigation systems.

1.3 As the key enabler of PBN, global navigation satellite system (GNSS) currently supports a variety of PBN applications in many States and in oceanic airspace. Transitioning to PBN therefore requires that an appropriate GNSS navigation infrastructure and the majority of aircraft be equipped with suitable PBN avionics.

1.4 The navigation roadmap describes PBN migration paths for types of airspace and phases of flight. The aviation system block upgrade (ASBU) process defines timelines for the operational use of various ATM capabilities. Some of the ASBUs depend on the implementation of PBN. As described in this document, PBN implementation timing will depend on State and regional requirements to meet airspace users' requirements for safety and efficiency, as well as on the pace of aircraft equipage.

1.5 Ideally it would be possible to rely solely on GNSS-based PBN and eliminate the requirement for conventional terrestrial aids, but the vulnerability of GNSS signals to interference and the need to ensure continuous PBN operations during a GNSS outage requires the retention of suitable conventional systems to enable aircraft to proceed to a safe recovery and landing.

1.6 If a GNSS outage is experienced, the PBN airspace system may need to revert to a less capable level of performance. The transition period immediately after a GNSS outage will be most critical to ensure aircraft maintain safe separation, particularly in high volume traffic areas. Each air navigation service provider (ANSP) will therefore need to devise a navigation reversion strategy. (See AN-Conf/12-WP/22 for further discussion of the rationalization of terrestrial navigation aids).

2. NAVIGATION EVOLUTION

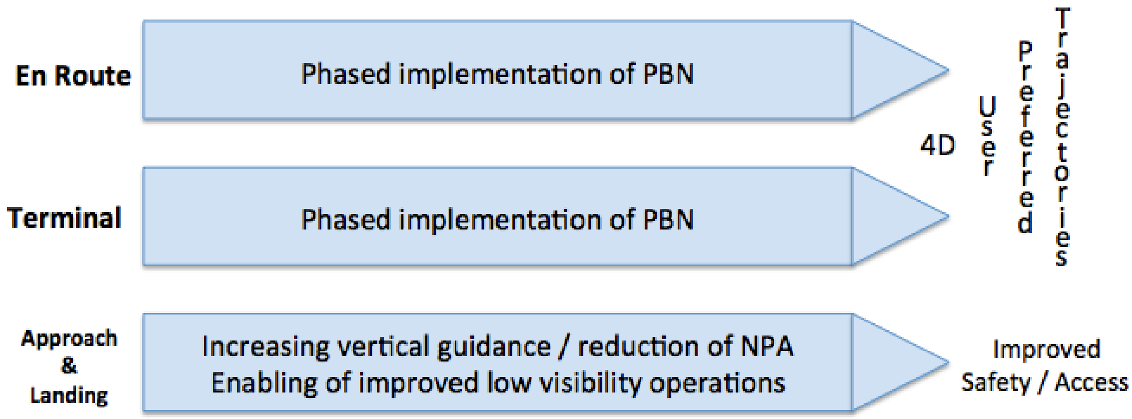
2.1 Achieving the benefits of increased capacity in en route and terminal airspace depends on implementing suitable communications, navigation, surveillance, air traffic control (ATC) automation, and related procedures to enable reduced aircraft separation. This results in improved traffic flow, increased operating efficiencies, and the realization of the potential benefits of PBN. Transitioning from conventional routes and procedures to PBN requires that nearly all operators equip with suitable PBN avionics and obtain the related operational approvals, and that ANSPs implement airspace changes and procedures.

2.2 Current en route and terminal operations rely on a combination of conventional terrestrial aids, an inertial navigation system (INS) and GNSS. There are PBN applications in place in some regions and large segments of the aircraft fleet are PBN capable, with more being added every day.

2.2.1 Current approach operations rely on conventional terrestrial aids and PBN applications. Approach minima determine airport accessibility in low ceiling and visibility conditions. GNSS-based PBN and ground-based augmentation system (GBAS) approach procedures can support lower minima to many runways with conventional non-precision approaches and provide new approaches to runways that currently have no procedure in place. Aircraft-based augmentation system (ABAS) with barometric-vertical navigation (Baro-VNAV), satellite-based augmentation system (SBAS) and GBAS support vertical guidance, which enhances safety. The flexibility inherent in PBN and GBAS approach design can be exploited to increase runway access and capacity.

2.2.2 Some States have developed the regulatory framework to support PBN operations and have sufficient aircraft equipped with avionics incorporating GNSS to start planning for the rationalization of conventional terrestrial aids.

2.3 The figure below depicts the evolution of navigation applications by phase of flight.



3. NAVIGATION APPLICATIONS – PBN AND PRECISION APPROACH

3.1 The *Performance-based Navigation (PBN) Manual* (Doc 9613) explains the PBN concept and includes navigation specifications for each navigation application, defining performance and functionality needed for the proposed operation in the context of a particular airspace concept. Navigation specifications also describe approval processes and requirements for aircraft, pilot knowledge and training as well as ANSP considerations. There are two kinds of navigation specification: area navigation (RNAV), with accuracy requirements (e.g. RNAV 5); and RNP, which adds the requirement for on-board performance monitoring and alerting (e.g. RNP 4, RNP APCH). The GNSS Standards and Recommended Practices (SARPs) support the use of GNSS signals to meet PBN specifications. The standards for avionics incorporating GNSS are identified in each PBN specification.

3.2 ICAO Assembly Resolution A37-11 resolves that:

"States complete a PBN implementation plan as a matter of urgency to achieve:

a) implementation of RNAV and RNP operations (where required) for en route and terminal areas according to established timelines and intermediate milestones;

b) implementation of approach procedures with vertical guidance (APV) (Baro-VNAV and/or augmented GNSS), including LNAV only minima, for all instrument runway ends, either as the primary approach or as a back-up for precision approaches by 2016 with intermediate milestones as follows: 30 per cent by 2010 and 70 per cent by 2014; and

c) implementation of straight-in LNAV only procedures, as an exception to 2) above, for instrument runways at aerodromes where there is no local altimeter setting available and where there are no aircraft suitably equipped for APV operations with a maximum certificated take-off mass of 5 700 kg or more;"

3.3 With reference to a) above, it should be noted that a transition to a total RNAV environment requires that virtually all aircraft be equipped in order to be beneficial as it is very difficult to design efficient airspace and manage a mixed fleet where some aircraft are not capable of RNAV operations. With reference to c) above, in some cases physical obstacles preclude the development of procedures with vertical guidance.

3.4 Precision approach operations based on instrument landing system (ILS), microwave landing system (MLS) and GBAS are outside the scope of the PBN concept. The *Global Navigation Satellite System (GNSS) Manual* (Doc 9849) and Annex 10 — *Aeronautical Telecommunications* provide guidance for the implementation of all GNSS-based operations, including those supported by GBAS.

4. NAVIGATION INFRASTRUCTURE

4.1 GNSS is the basis for PBN and future improvements in navigation services. The core constellations – global positioning system (GPS) and GLObal NAvigation Satellite System (GLONASS) – have been in operation for well over a decade and SARPs in support of aviation operations are in place. As a result, aviation usage of GNSS is currently widespread. GPS and GLONASS are being upgraded to provide service on multiple frequency bands. Other core constellations, namely the European Galileo and China's Beidou are being developed. Multi-constellation, multi-frequency GNSS has clear technical advantages that will support the provision of operational benefits. To realize these benefits, ICAO, States, ANSPs, standards bodies, manufacturers and aircraft operators need to coordinate activities to address and resolve related issues. (See AN-Conf/12-WP/21 for further discussion of multi-constellation, multi-frequency GNSS).

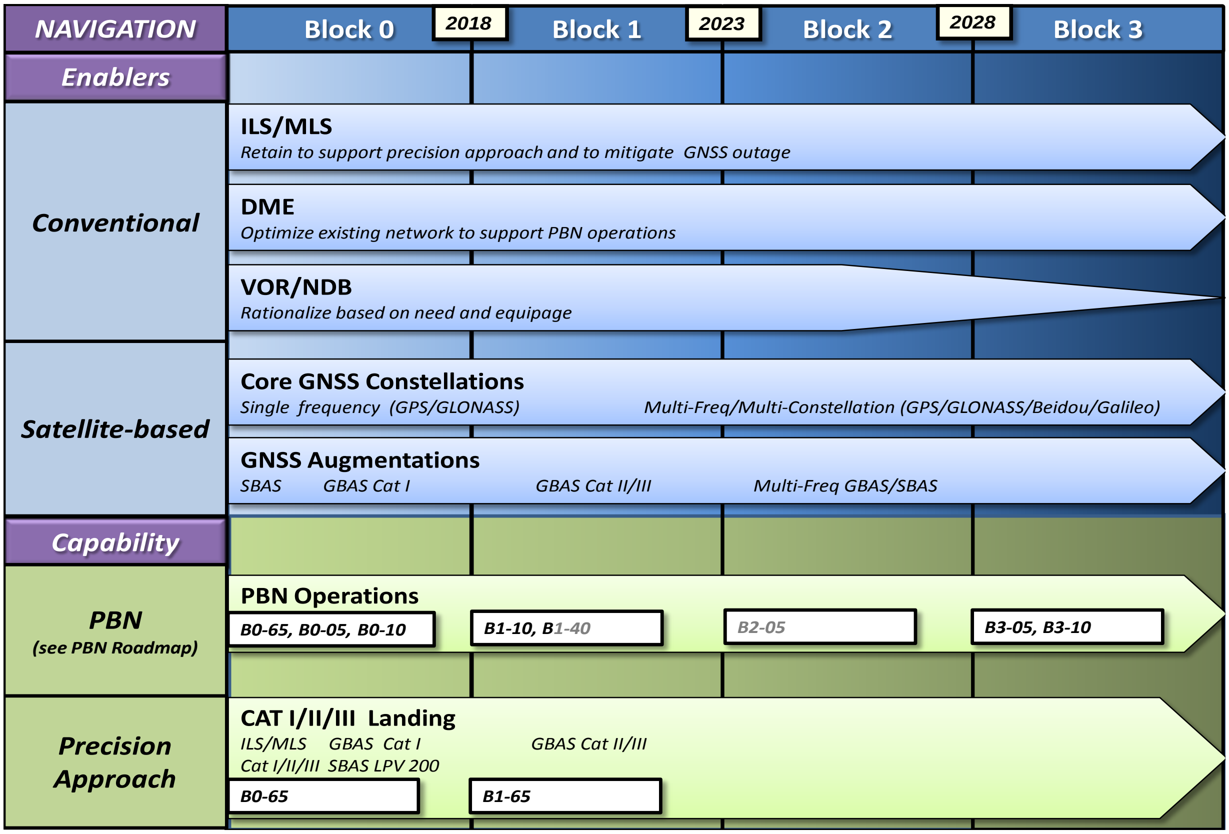
4.2 SBAS based on GPS is available in North America (WAAS), Europe (EGNOS) and Japan (MSAS) and will soon be available in India (GAGAN) and Russia (SDCM). Several thousands of SBAS approach procedures are now implemented, mostly in North America, while other regions have started publishing SBAS-based procedures. SBAS typically supports APV operations but can also support precision approach (Category I) operations. However, it is challenging for SBAS to support precision approach operations in equatorial regions using single-frequency GPS because of ionospheric effects.

4.3 GBAS CAT I based on GPS and GLONASS is available in Russia and, based on GPS, at some airports in several States. SARPS for GBAS CAT II/III are under operational validation. Related research and development activities are ongoing in different States. It is also challenging for GBAS to support a high availability of precision approach in equatorial regions.

4.4 Conventional navigation aids (VOR, DME, NDB and ILS) are in widespread use globally and most aircraft are equipped with the relevant avionics. As discussed above, the vulnerability of GNSS signals to interference has led to the conclusion that there is a need to retain some conventional aids as a backup to GNSS. (See AN-Conf/12-WP/21 for further discussion of GNSS vulnerability issues).

4.5 Mitigating the operational impact of a GNSS outage will depend on relying on another constellation, employing pilot and/or ATC procedural methods, and taking advantage of on-board inertial systems and specific conventional terrestrial aids. In the case of a general GNSS outage in an area, reversion to conventional systems and procedures would result in lower service levels and a possible decrease in capacity. In the case of loss of signals from a specific constellation, the reversion to another constellation could maintain the same PBN level. The implementation of PBN will make area navigation operations the norm. Distance measuring equipment (DME) is the most appropriate conventional aid to support area navigation operations since it currently is used in multi-sensor avionics for this purpose. This could result in an increase in the number of DME installations in some regions. Similarly, ILS is in widespread use, so where available would provide an alternate approach and landing service.

4.6 The figure below depicts the expected evolution of navigation infrastructure and avionics.



5. AVIONICS

5.1 GNSS avionics meeting Standards for ABAS and SBAS operations are now available off-the-shelf to support every level of PBN. GBAS avionics are available on a limited basis to support CAT I approaches.

5.2 The pace of avionics equipage by aircraft operators is primarily determined by their business case. Aircraft operators typically must be assured of a return on investment, benefit certainty, strategic fit and that they have the financial capacity to make the investment. Moreover, avionics and airframe manufacturers will develop new generations of avionics only if their analysis shows that this will be profitable.

5.3 The benefits of PBN in en route and terminal operations depend on the percentage of aircraft with the prescribed PBN capability. In the busiest airspaces, experience has proven that the percentage of homogeneous equipment with a given PBN capability should be larger than 90 per cent in order for tangible benefits to be obtained. Mixed equipage is difficult to manage from the ATC perspective. This can result in equipped aircraft not receiving all the anticipated benefits while non-equipped aircraft may receive some benefits. Therefore, the aviation community should develop processes to reach a common level of equipment and PBN procedures publication commensurate with the local requirements, and particularly for en route and the busiest terminal areas. On the other hand, in the case of PBN approach operations, equipped aircraft receive all the benefits of lower minima, thus satisfying the requirement for benefit certainty.

5.4 The slow progress over the past decade of PBN implementation in high traffic density areas shows that a synchronized implementation of the required avionics capabilities while procedures are published by ANSPs would considerably accelerate the pace of actual operational implementations and increase the benefits of the aviation community as a whole.

6. OPERATIONAL IMPLEMENTATION

6.1 As discussed in paragraph 3 above, the PBN manual provides the implementation guidance material to match PBN applications to airspace concepts. The implementation of advanced navigation services within a State or region requires the ANSP, regulator and aircraft operators to coordinate efforts in a number of areas, as described below.

6.2 When choosing avionics, aircraft operators must take account of all operational applications (e.g. PBN, ADS-B). Aircraft operators will be reluctant to equip with required avionics unless they participate in the development of concepts of operation and they validate the quantification of benefits and costs. States and aircraft operators should therefore coordinate investments to ensure that benefits are available without delay. The business case must account for a transition period during which not all aircraft will be equipped. Guidance for the development of business case elements may be found in Doc 9849 and various other ICAO documents. Realizing maximum benefits within a reasonable amount of time may require States to consider mandating equipage for operations in high-level, en route airspace and in the busiest terminal areas.

6.3 States must develop the regulatory framework and certification guidance for PBN. This includes operational approval of GNSS-based services which are the primary enabler for PBN implementation. Doc 9613 provides detailed guidance in this regard and States can refer to regulatory documentation from other States that have already implemented PBN operations. To expedite the transition to PBN, States should also consider sponsorship of avionics and operational approvals for operators who are willing to be the first to equip.

6.4 ANSPs must develop all implementation elements, including procedure design standards (which can be from the PANS-OPS, Doc 8168), ATC procedures and NOTAM requirements and training material. Guidance is provided in Docs 9613 and 9849. The ICAO PBN website provides links to States' websites to provide access to documentation that will assist States with implementation. ANSPs should encourage equipage by publishing procedures that will provide operational benefits.

6.5 Manufacturers can contribute to the potential of GNSS services further by extending their product range to accommodate the existing and future properties of GNSS and its augmentations.

7. PBN ROADMAP

7.1 Introduction

7.1.1 This section describes PBN migration paths that will meet the requirements of the relevant ASBUs (B0-05, B0-10, B0-65, B1-10, B1-40, B1-65, B2-05, B3-05 and B3-10).

7.1.2 In developing navigation implementation plans, regions and States are encouraged to comply with ICAO provisions and take advantage of the expertise and information available through the ICAO planning and implementation regional groups (PIRGs) and their subgroups. ICAO has a mandate to contribute to this process by: ensuring regional and interregional coordination; providing a forum for the exchange of expertise and information among States and international organizations; and identifying technical assistance needs in the region and arranging for the provision of such assistance.

7.2 **En route oceanic and remote continental**

7.2.1 Current en route oceanic and remote continental operations are served by two navigation applications, RNAV 10 and RNP 4. RNAV 10 retains the pre-existing “RNP 10” designation, despite not meeting the requirement for on-board performance monitoring and alerting, because the designation predates Doc 9613.

7.2.2 RNP 2 is a new navigation specification introduced in the March 2012 revision to Doc 9613. Since RNP 2 was developed without having to be restricted by existing specifications, it is an example of a navigation specification that stands on its own without referring to communication or surveillance requirements. This navigation specification allows for advantages to be taken from the accuracy and integrity requirements of existing technical standard order (TSO) GPS avionics when developing route and obstacle spacing.

7.2.3 North Atlantic (NAT) examples and plans. The NAT Air Traffic Management Group (ATMG) is developing a PBN transition plan for the North Atlantic. Consideration is being given to replacement of the current minimum navigation performance specification (MNPS) designation used within the airspace that has a stated RNAV performance requirement in lieu of an applicable PBN navigation specification(s). Desires to increase efficiency in the airspace through reduced lateral and longitudinal separation are also contributing to examination of a potential application of RNAV 10, RNP 4, and RNP 2.

7.2.4 Remote continental examples and plans. Canada has a significant volume of non-surveillance airspace over its northern territories which, owing to the scarcity of conventional navigation aids and aerodromes, would be considered remote. In this area consideration is being given to the development of RNP 2 routes joined to RNP 1 terminal procedures. The Asia/Pacific region is planning the implementation of RNP 4 and RNP 2.

7.3 **En route continental**

7.3.1 Current en route continental airspace concepts are supported by RNAV 5, RNAV 2 and RNP 2 applications. RNAV 5 is used in the Middle East and European regions, designated as B-RNAV (Basic-RNAV) in Europe and RNP 5 in the Middle East. An RNAV 2 application supports en route continental in the United States. These RNAV applications include radar surveillance and direct controller-pilot voice communications. Advanced-RNP applications will be developed for en route airspace. The use of RNP 2 routes in non-remote continental applications is under development in Canada to support closely spaced, unidirectional routes to allow efficient climb and descent profiles in congested airspace.

7.3.2 Europe plans to migrate to advanced RNP applications down to RNP 1 for en route.

7.3.3 USA plans to implement RNAV/RNP 2 in en route airspace above FL180 over the continental United States enabled by GPS, WAAS, and DME/DME.

7.3.4 Asia/Pacific plans to implement RNP 2, RNP 1 and RNP 0.3.

7.3.5 Canada plans en route application of RNAV 2 and RNP 2 for parallel routes, expansion of Q and T routes, and a revision of the current RNPC and CMNPS airspace designations to reflect current PBN navigation specifications.

7.4 Terminal airspace – arrival and departure

7.4.1 Current terminal airspace concepts are supported by RNAV applications in Europe, the United States and Canada. Precision RNAV, used in Europe, shares accuracy requirements with RNAV 1 but does not satisfy the full requirements of the RNAV 1 specification defined in Doc 9613. The United States application formerly known as US RNAV Type B, now called RNAV 1, is aligned with Doc 9613 specification. RNAV 1-based standard instrument departures (SIDs) are part of Canada's latest developments in its busiest domestic flight corridor between Toronto and Montreal. Basic-RNP 1 has been developed primarily for application in non-radar, low-density terminal airspace. Advanced RNP applications will be developed for terminal airspace.

7.4.2 Europe plans to migrate to advanced RNP applications, with RNP 1 down to RNP 0.3 for terminal airspace.

7.4.3 The United States plans to implement RNAV/RNP 1 in terminal airspace for standard arrivals, departures, and trajectory-based operations at the busiest terminal areas in the lower forty-eight States, enabled by GPS, wide area augmentation system (WAAS), and distance measuring equipment (DME)/DME.

7.4.4 Asia/Pacific plans to implement RNP 1 and RNP 0.3.

7.4.5 Canada's near-term (next 3 to 5 years) implementation envisages the following: terminal application of RNAV 1, RNAV 2 and Basic RNP 1 for SIDs and standard terminal arrivals (STARs); the addition of radius-to-fix legs associated with terminal and approach operations using RNP 1 or lower.

7.5 Approach

7.5.1 RNP APCH specifications provide requirements for approaches supported by basic GNSS avionics that provide lateral guidance only to lateral navigation (LNAV) minima; avionics that use GNSS Baro-VNAV to support lateral and vertical guidance to LNAV/VNAV minima; and SBAS avionics that support lateral and vertical guidance to lateral precision with vertical guidance (LPV) minima. LPV minima can equate to ILS Cat I minima given the proper physical environment. RNP approach (APCH) procedures include existing RNAV (GNSS) approach procedures. The implementation of RNP APCH procedures satisfies ICAO Assembly Resolution A37/11 described in paragraph 3.2.

7.5.2 The United States has published over 5 000 PBN approach procedures, over half with LNAV/VNAV and LPV minima; over 500 of the latter have a 200 ft height above threshold (HAT). Canada has published about 600 PBN approach procedures with LNAV minima. Of these, twenty-three have LNAV/VNAV minima and fifty-two have LPV minima. Canada plans to add PBN procedures, and to add LNAV/VNAV and LPV minima to those with LNAV-only minima based on demand from aircraft operators. Australia has published approximately 500 PBN approach procedures with LNAV minima, and has plans to add LNAV/VNAV minima to these procedures. Australia does not have SBAS; therefore none of the approaches has LPV minima. France has published eighty procedures with LNAV minima, ten LPV and one LNAV/VNAV. The objective is to have PBN procedures for 100 per cent of France's IFR runways with LNAV minima by 2016, and 100 per cent with LPV and LNAV/VNAV minima by 2020. Brazil has published 146 PBN procedures with LNAV minima; forty-five have LNAV/VNAV minima. There are 179 procedures being developed, 171 of which will have LNAV/VNAV minima.

7.5.3 RNP authorization-required approaches (RNP AR APCH), as the name suggests, require special aircraft and aircrew authorization to ensure that they may be flown safely. This type of approach is suited to large airline aircraft in which GNSS and inertial sensors are integrated to enhance lateral and vertical performance.

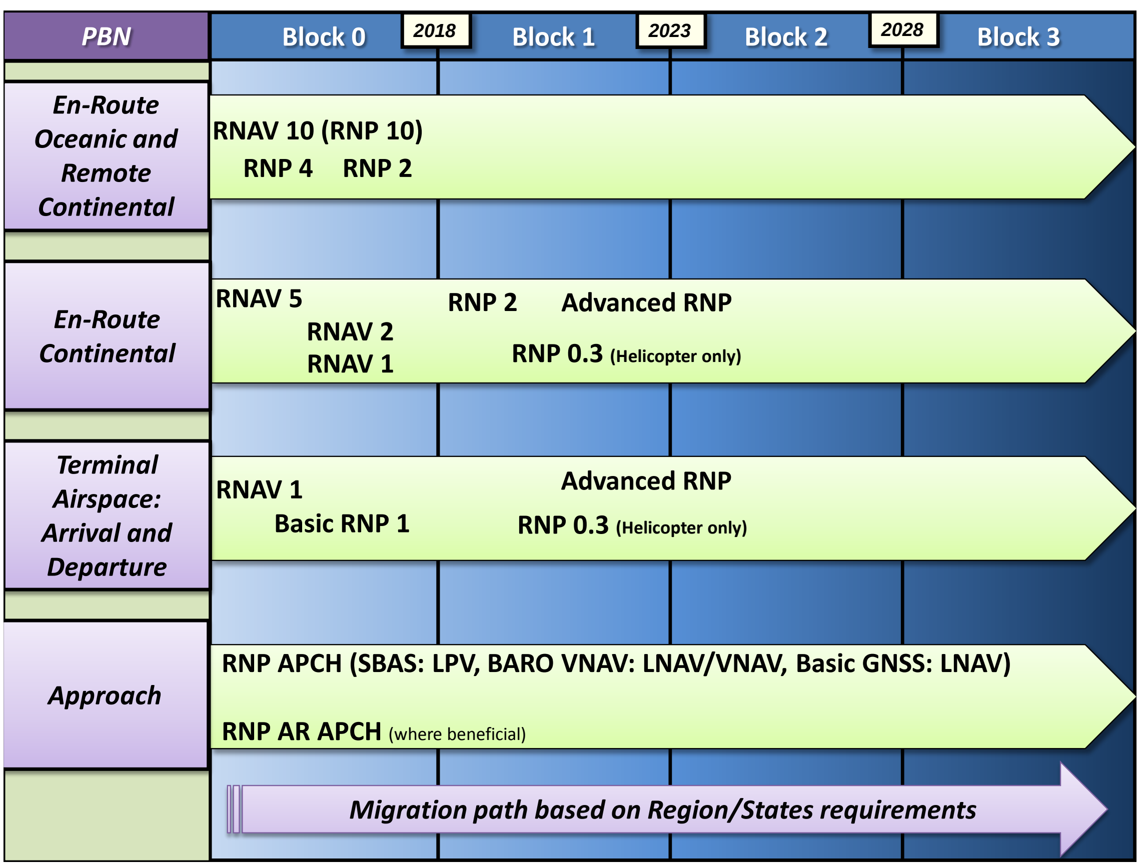
7.5.4 Several States are embarking on programs to provide CAT I service using GBAS. ICAO is validating Standards for CAT II/III GBAS and prototypes are under development. GBAS CAT I installations are deployed in Russia (>20), United States (2), Australia (1), Germany (1), Brazil (1) and Spain (1).

7.5.5 The United States plans to implement RNP approach (RNP-0.3, LNAV and LNAV/VNAV) and approach procedure with vertical guidance (APV), LPV or LP at all qualifying runways enabled by GPS and/or WAAS.

7.5.6 Asia/Pacific plans to implement Baro-VNAV, RNP, RNP AR and APV (SBAS).

8. ROADMAP SUMMARY

8.1 The figure below summarizes migration paths for the implementation of PBN levels and precision approach for the following operations: en route oceanic and remote continental, en route continental, TMA arrival/departure, and approach. There is no attempt to show detailed timelines because regions and States will have different requirements; some may need to move quickly to the most demanding PBN specification while others will be able to satisfy airspace users' requirements with a basic specification. The figures does not imply that States or regions have to implement each step along the path to the most demanding specification. Doc 9613 provides the background and detailed technical information required for operational implementation planning.



9. CONCLUSION

9.1 As summarized in this paper, the progressive introduction of PBN is underway, supported by worldwide implementation of a GNSS infrastructure complemented by appropriate means of backup to mitigate the potential vulnerabilities of GNSS.

9.2 The Conference is invited to take note of the information provided in this paper in connection with the navigation roadmap in the Global Air Navigation Plan.

— END —