PERFORMANCE-BASED NAVIGATION WILL ENABLE EFFICIENCY-ENHANCING OPERATIONS IN THE FUTURE.

Operational Benefits of Performance-Based Navigation

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Global airspace and airline operations are moving to performance-based navigation (PBN), which provides a basis for designing and implementing automated flight paths that will facilitate airspace design, traffic flow, and improved access to runways. This change offers a number of operational benefits, including enhanced safety, increased efficiency, reduced carbon footprint, and reduced costs. To fully realize these benefits, operators may need to make changes to their airplanes and operations.

Operators have already begun to experience the benefits of area navigation (RNAV) and required navigation performance (RNP). These benefits include safer, more efficient operations; greater capacity; and improved access. For instance, freeing airplanes from reliance on ground-based navigational aids (navaids) and allowing flexible and optimum routing with satellite navigation can create more direct routes, saving fuel and reducing CO_2 emissions and enroute flight time.

However, the definitions and concepts associated with RNAV and RNP, as well as some RNP naming conventions, are inconsistent both in the United States and in various regions of the world. The result has been confusion among operators, manufacturers, regulators, and air navigation service providers (such as the U.S. Federal Aviation Administration [FAA], United Kingdom National Air Traffic Services [NATS], and NavCanada) in the implementation of RNAV and RNP applications in different areas in the world.

PBN is the result of recent collaboration between industry, states, regulators, and service providers to understand the issues leading to this confusion, and to clarify and update the definitions and explanatory material about RNAV and RNP concepts and applications. To ensure harmonization and consistency, this effort was applied to all areas of flight, from oceanic/remote to terminal area and approach.

This article provides background about RNAV and RNP, reasons for the move to PBN, benefits of PBN, the industry's PBN strategy, and keys for airlines to move successfully to PBN.

RNAV AND RNP: GOOD CONCEPTS IN NEED OF STREAMLINING

Historically, commercial airplanes have navigated from a position relative to one ground-based navaid — such as very-high-frequency (VHF) omni-directional range (VOR), distance measurement equipment (DME), or non-directional beacon (NDB) — to a position relative to another navaid. Because airplanes are inhibited from flying the most direct possible routes, this method leads to inefficient routes and procedures. Adding to this inefficiency are large airspace separation buffers that commercial airplanes must use because of both the inherent inaccuracies of conventional navigation methods and the need to protect against operational errors.

RNAV began as a means of navigation on a flight path from any point, or fix, to another. These fixes could be defined by a latitude and longitude, and an airplane's position relative to them could be established using a variety of navaids. RNAV facilitated a type of flight operation and navigation in which the flight path no longer had to be tied directly to overflight of ground navigation stations.

RNP is built on RNAV. The International Civil Aviation Organization (ICAO) recognized that global navigation satellite systems, the navigation infrastructure, airline operations, and airplane systems were undergoing change faster than traditional processes for equipment, including RNAV, could support. RNP was developed to allow airspace designers to specify airspace and operation requirements without relying on specific equipment or systems. The original RNP concept was oriented toward enroute, remote, and oceanic airspace, and was primarily concerned with precise navigation and safe separation of routes. Both RNAV and RNP offer a number of advantages over conventional, ground-based navigation systems, including greater safety and efficiency (see fig. 1).

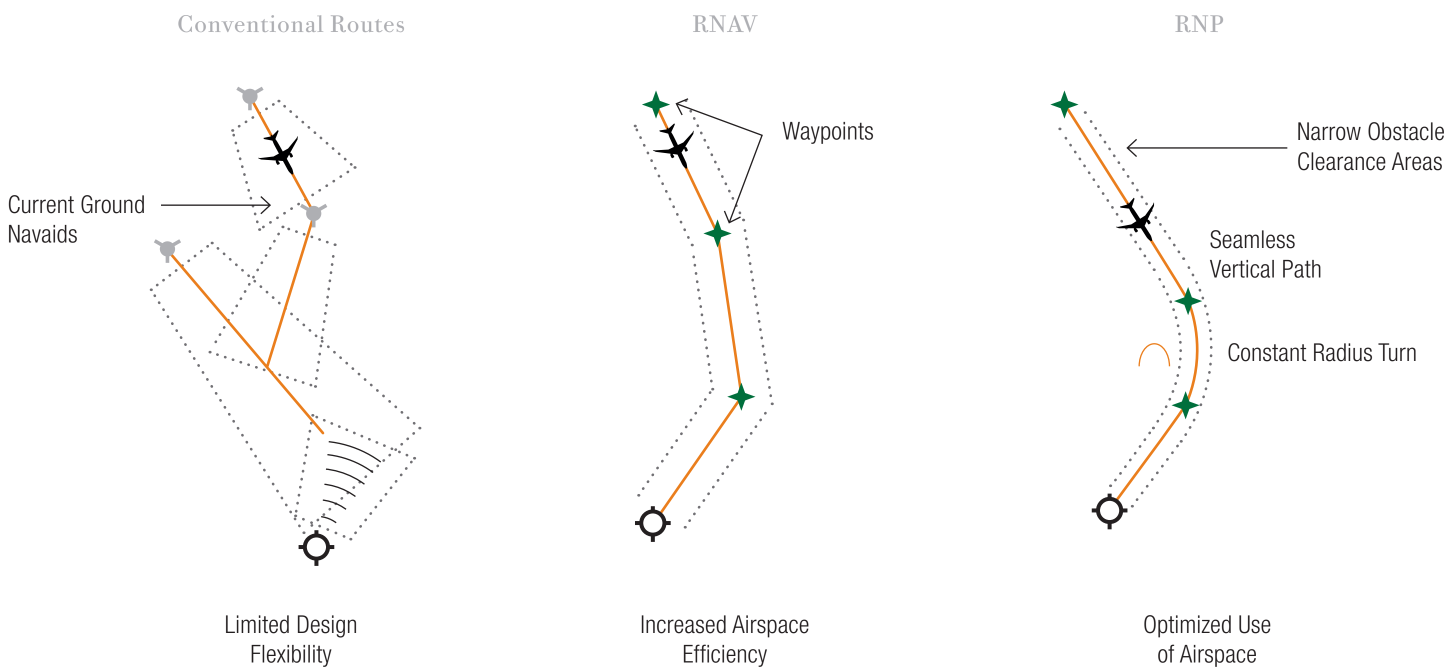
However, as RNP has evolved, some of its elements have been implemented inconsistently. Additionally, RNP applications lacked a common basis for interoperability, creating confusion and hampering adoption. At the same time, work had begun both within and outside ICAO to develop guidance for other phases of flight and operational environments. This work led to the understanding that it would be impossible to achieve global interoperability with these new concepts unless the assumptions on which they are based, such as RNP, were consistently applied. PBN is seen as the solution that will enable future efficiency-enhancing operations concepts.

THE MOVE TO PBN

The FAA defines PBN as "a framework for defining navigation performance requirements that can be applied to an air traffic route, instrument procedure, or defined airspace." PBN, which comprises both RNAV and RNP specifications, provides a basis for the design and implementation of automated flight paths that will facilitate airspace design, traffic flow, and improved access to runways.

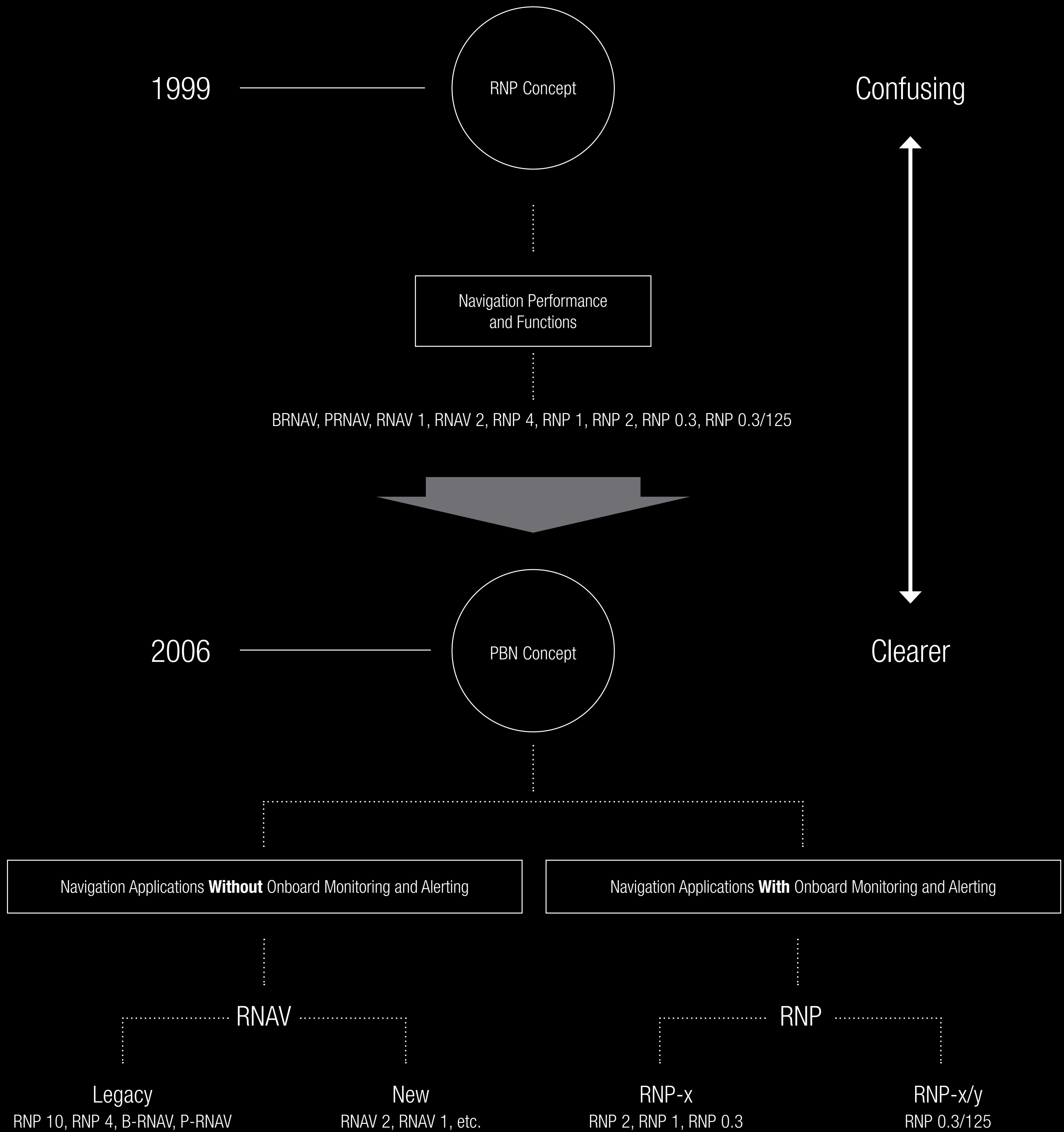
The PBN concept began with an assessment of all current and near-term implementations of RNAV and RNP, including basic RNAV (BRNAV) standards, precision RNAV (PRNAV), RNAV 1, RNAV 2, RNP < 1, RNP 1, RNP 2, RNP 4, and RNP 10. Part of the goal of PBN is to consolidate these various implementations to alleviate confusion and streamline operations (see fig. 2). RNAV now includes BRNAV, PRNAV, RNAV 1, RNAV 2 and RNP 10 (now RNAV 10), and RNP now includes RNP < 1, RNP 1, RNP 2, and RNP 4. This consolidation provides better guidance on how to apply RNAV and RNP and what it means to airspace, traffic management, air traffic control, and the commercial air service infrastructure.

Because RNAV and RNP are part of PBN, lateral navigation standards for performance, functionality, and capability are intrinsic to it. PBN has the potential to provide operators with more efficient airspace and instrument procedures that can improve safety, access, capacity, and efficiency, while minimizing environmental impacts. With PBN,



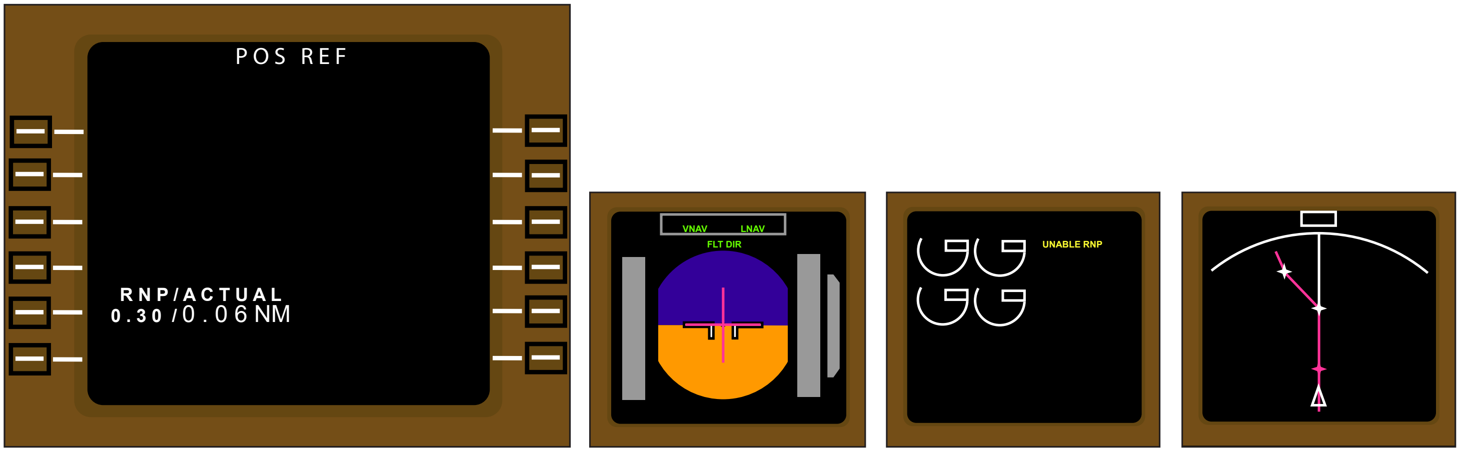
CONVENTIONAL ROUTES COMPARED TO PBN-BASED ROUTES
Figure 1

PBN comprises RNAV and RNP specifications to enable airspace designers to develop and implement new automated flight paths that increase airspace efficiency and optimize airspace use.



EVOLUTION OF PERFORMANCE-BASED NAVIGATION CONCEPT
Figure 2

PBN is an attempt to reduce confusion and streamline RNAV and RNP specifications and standards.



INCREASED OPERATIONAL SAFETY

Figure 3

PBN provides flight crews with an enhanced new interface designed to minimize manual insertion and control errors, enhanced situation awareness, better monitoring and RNP alerting, and improved indication of equipment failure.

all navigation aspects of operations — including terminal airspace — will be defined, developed, and implemented on the basis of operational requirements and the associated required performance.

More detailed information is provided in the PBN Manual, which is available on the ICAO Web site (www.icao.int). It will be issued as a major revision and replacement to the existing RNP Manual, Document 9613.

BENEFITS OF PBN

Aviation authorities anticipate a number of benefits when PBN becomes widely implemented. These benefits include:

Safety: Lateral and vertical track-keeping is much more accurate and reliable due to new three-dimensional guided arrival, approach, and departure procedures that cannot be defined by conventional navaids. No accidents have been reported to date associated with the use of RNP/RNAV procedures. In contrast, for all controlled-flight-into-terrain accidents, 60 percent occur on non-precision approaches using conventional navaids. PBN also reduces the flight crew's exposure to operational errors (see fig. 3).

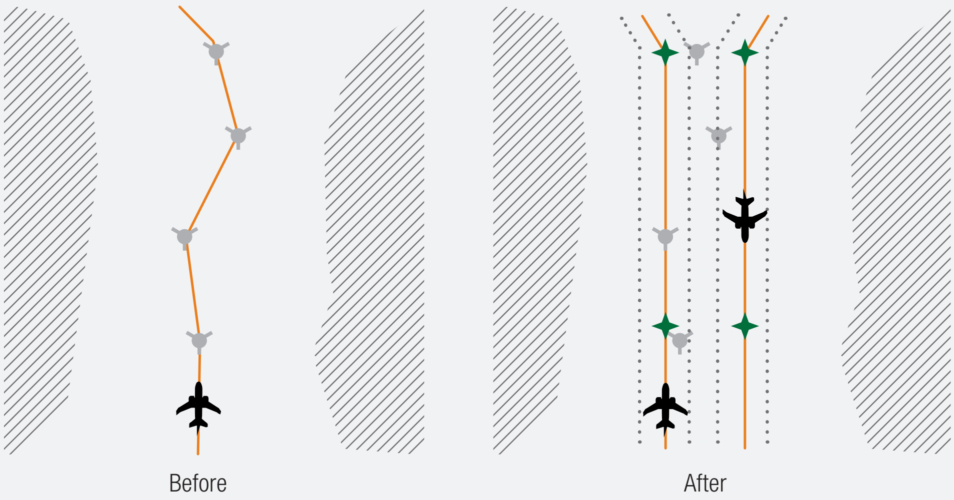
Capacity: Delays, congestion, and choke points at airports and in crowded airspace may be reduced because of new and parallel offset routes through terminal airspace, additional ingress/egress points around busy terminal areas, more closely spaced procedures for better use of airspace, and reduced or eliminated conflict in adjacent airport flows (see fig. 4).

Efficiency: Enhanced reliability, repeatability, and predictability of operations lead to increased air traffic throughput and smoother traffic flow.

Access: Obstacle clearance and environmental constraints can be better accommodated by applying optimized PBN tracks.

PBN promises economic benefits as well. For example, Hartsfield-Jackson Atlanta International Airport has streamlined operations by implementing 16 RNAV departures and three RNAV arrivals. The resulting earlier climb to enroute altitudes reduces fuel burn, and the reduced track distances enable fuel savings. For 2007, Hartsfield-Jackson Atlanta International Airport authorities are estimating $34 million in annual fuel savings for airlines as a result of RNAV. The airport is also reporting an additional 10 departures per hour. At Dallas-Fort Worth International Airport, RNAV departures are allowing between 11 and 20 additional operations per hour.

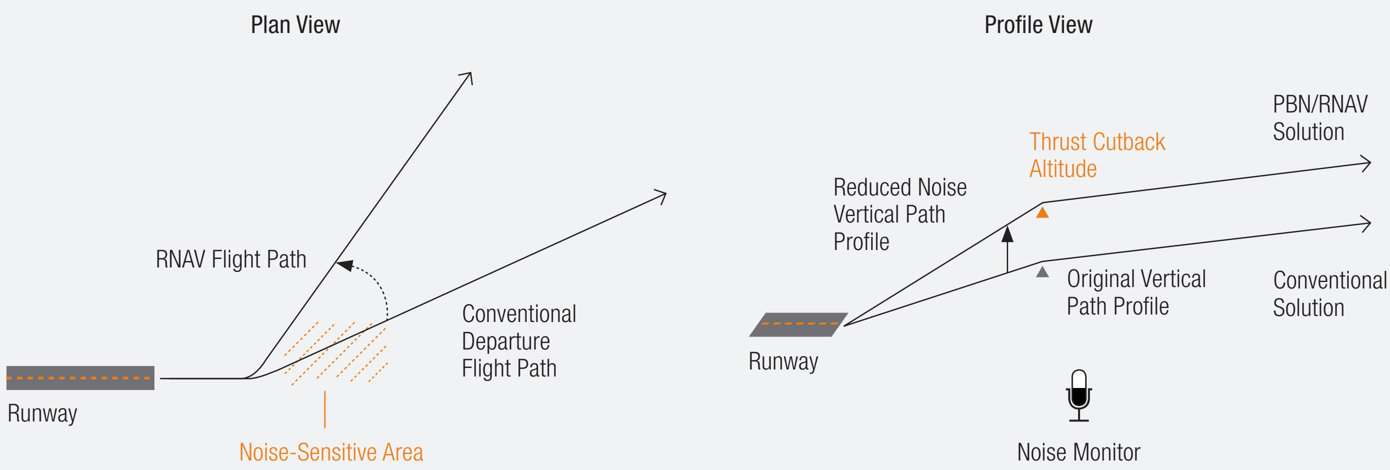
PBN also offers environmental benefits by saving fuel, reducing CO_2 emissions, and eliminating high-thrust go-arounds. Flying down the middle of a defined flight path means less throttle activity and better avoidance of noise-sensitive areas, so people on the ground perceive less jet noise and are exposed to fewer engine emissions (see fig. 5).



INCREASED CAPACITY

Figure 4

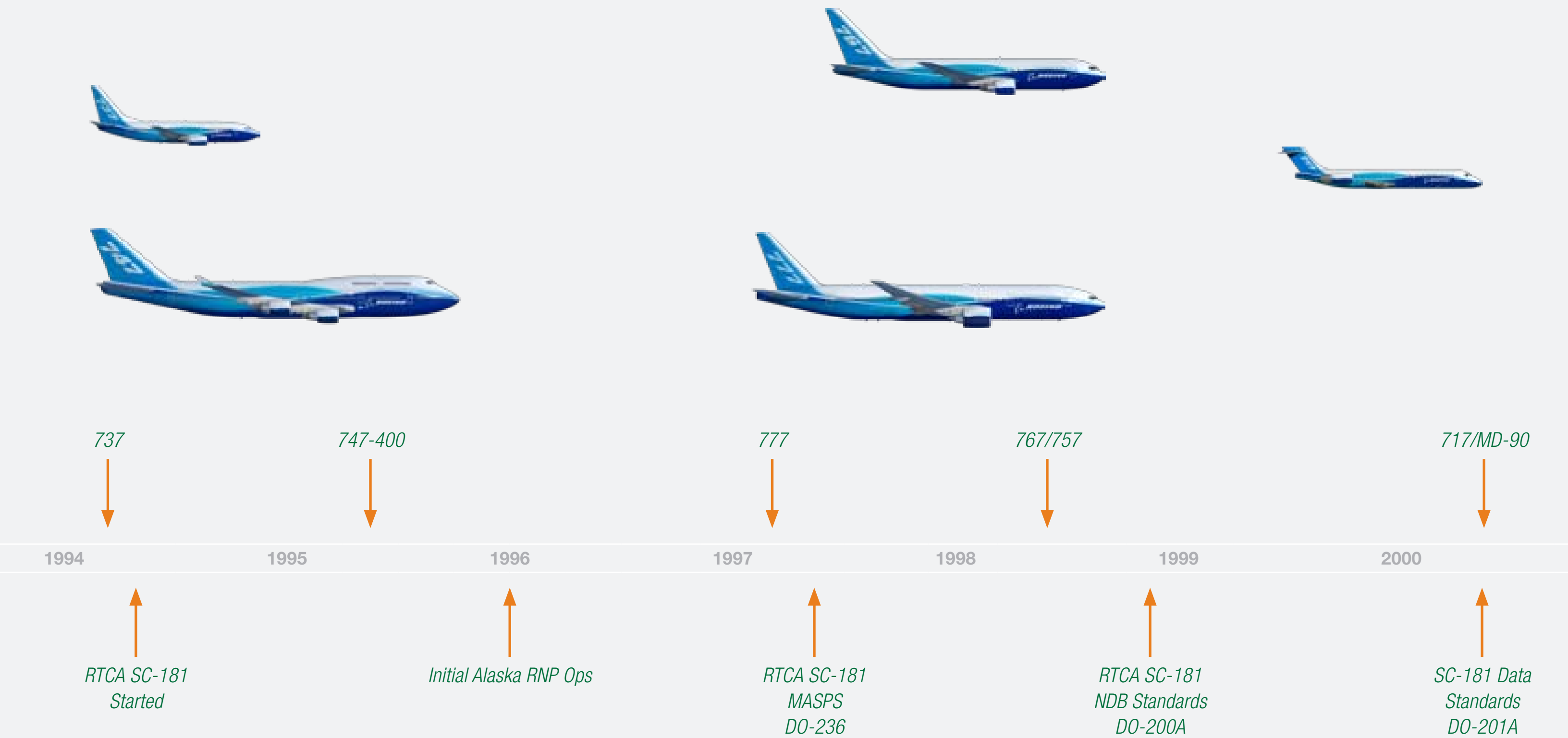
Conventional routes (left) have limited development and flexibility due to vertical separation requirements and implementation of routes based on ground navaids. RNAV and RNP routes (right) offer design flexibility and capacity from additional flight levels and parallel routes using latitude- and longitude-based fixes.



REDUCED ENVIRONMENTAL IMPACTS

Figure 5

Moving from ground-based flight procedures to RNAV latitude/longitude fix-referenced and performance-based procedures leads to flexibility in the specified location and profile of the flight path, making it easier to accommodate noise-sensitive areas.



INDUSTRY'S PBN STRATEGY

Boeing has helped shape the evolving PBN standards through close and ongoing involvement with the FAA and ICAO. Boeing has also worked with the Air Traffic Alliance with a goal of developing a strategy that a large number of industry participants can support to establish a clear, focused direction for the future.

In developing a strategy for PBN, Boeing started by observing industry developments, taking into account the trends and constraints of the various regions and technologies, and accommodating the business realities of the airlines and service providers.

All Boeing commercial airplanes manufactured since the 1980s include RNAV capabilities. Boeing began implementing RNP on airplanes in 1994. As of 2000, every Boeing commercial airplane included RNP capability (see fig. 6).

CONSIDERATIONS FOR AIRLINE OPERATIONS

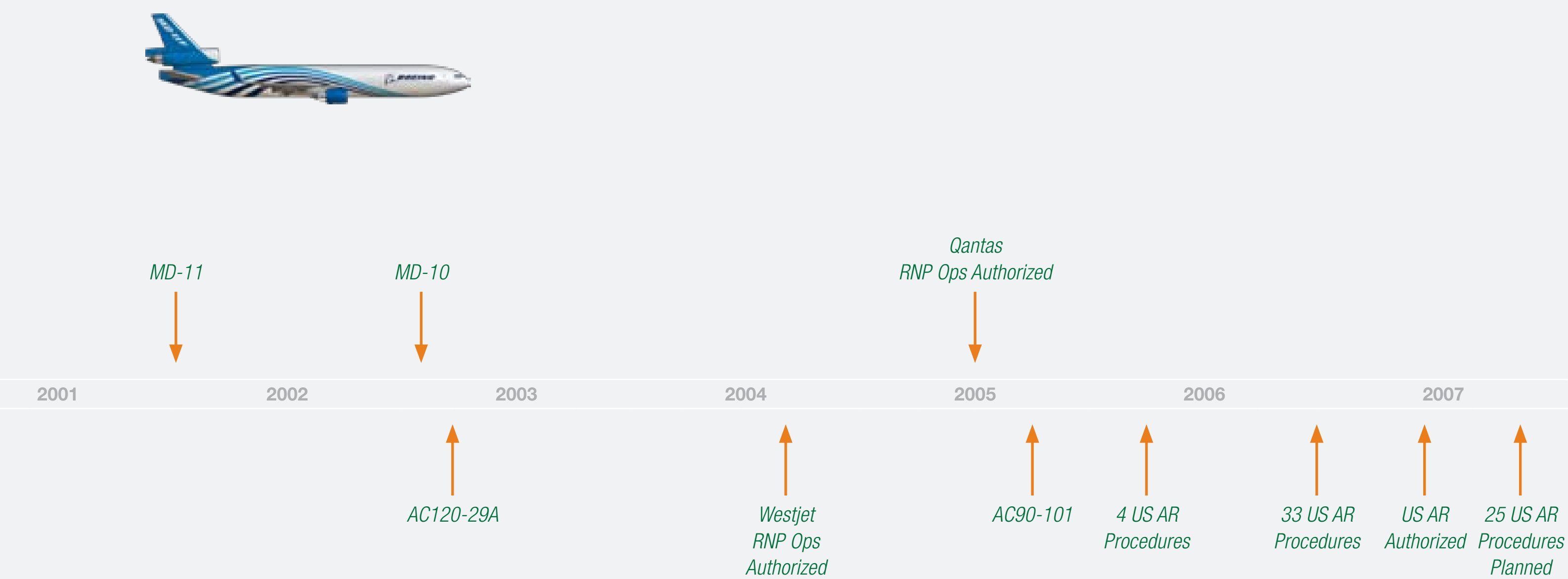
PBN is expected to be the foundation for a number of operational changes, including additional point-to-point routes, independent parallel runway operations, and coordinated departures and arrivals for adjacent airports. The degree of impact to requirements for crews, flight operations, maintenance, and dispatch could range from minimal to significant, depending on the current state of airports serviced and associated operating requirements.

Operators moving to PBN should begin coordination with their regulatory agency as soon as possible. When planning additions or modifications to a fleet, operators should carefully consider including RNP-related features such as navigation performance scales, a display feature that integrates lateral navigation and vertical navigation with actual navigation performance and RNP. Operators should also provide as much information as possible about PBN to their operations departments and crews, develop training curriculum and scenarios, and review standard crew procedures.

Operators should fully understand the capabilities of each airplane and match present and future capabilities to what they hope to achieve with PBN operations. For example, one

RNP-CERTIFIED BOEING AIRPLANES
Figure 6

Boeing has been steadily increasing the RNAV and RNP capabilities of its commercial airplane fleet. Every Boeing commercial airplane currently produced, including the 787, incorporates RNP capability. This figure illustrates when RNP capability was introduced in the fleet.



airline took advantage of the improved access afforded by RNP to avoid more than 980 diversions at one airport in 2006. Another airline replaced a non-precision approach into a valley surrounded by mountainous terrain with an RNP "Special Aircraft and Aircrew Authorization Required" (SAAAR) approach. The new approach enhanced safety with a guided, stabilized three-dimensional path to the runway, lowering the landing minima by 1,600 feet and two miles visibility (see fig. 7).

Boeing provides service letters, airplane flight manuals, and other documentation to assist operators in implementing PBN operations. Boeing also offers support information for PBN operations to assist operators seeking approvals by regulators or air navigation service providers, as well as implementation guidance (see sidebar). Also, Boeing subsidiary Jeppesen has begun to expand its RNP services to include FAA AC90-101 Readiness and Application Consulting Services, RNP NavData and Charting, RNP Training, and RNP Monitoring Tools in addition to its current offering of RNP Procedure Development.

Operators should be aware that the operational approvals can range from requiring relatively little effort (i.e., RNAV) to demanding a great deal of time and extremely complex information (i.e., RNP SAAAR).

As PBN continues to evolve, operators have the opportunity to provide input and raise issues and concerns to ICAO and other governing bodies.

LOOKING AHEAD

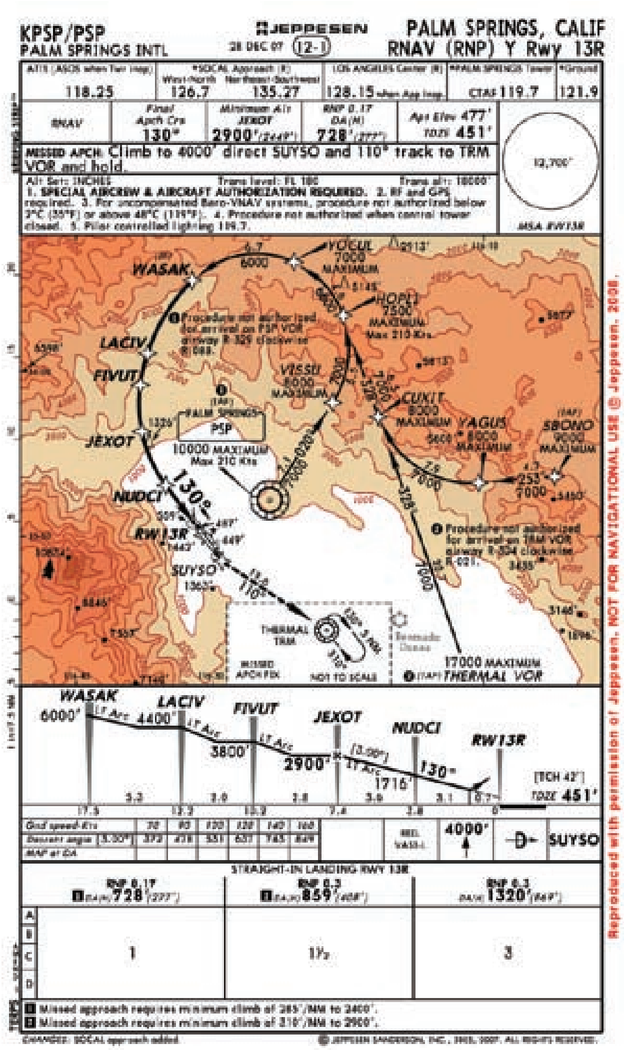
Airspace designers envision airplanes flying on defined RNP paths from takeoff to touchdown and using RNP path options in combination with time-of-arrival management and speed control for sequencing, separation, and weather rerouting. Improved air traffic control planning tools are being developed to optimize controller performance in such an "RNP path" world. It is also expected that RNP may eventually make a transition to an integration with global navigation satellite landing systems, which ensure reliable, predictable takeoff and touchdown in all visibility conditions.

Glossary of terms

RNAV
Area navigation (RNAV) enables airplanes to fly on any desired flight path within the coverage of ground-based navigation aids, within the limits of the capability of the self-contained systems, or a combination of both capabilities. As such, RNAV airplanes have better access and flexibility for point-to-point operations. When values are specified, they indicate the required performance level for the operation.

RNP
Required navigation performance (RNP) is RNAV with the addition of a number of functional enhancements, including onboard performance monitoring and alerting capability. A defining characteristic of RNP operations is the ability of the airplane navigation system to provide improved performance information, monitor the navigation performance it achieves and inform the crew if the requirement is not met during an operation. This onboard monitoring and alerting capability enhances the pilot's situational awareness and can enable reduced obstacle clearance or closer route spacing without intervention by air traffic control. When values are specified, they indicate the required performance level for the operation.

PBN
Performance-based navigation (PBN) is a framework for defining navigation performance requirements that can be applied to an air traffic route, instrument procedure, or defined airspace. PBN includes both RNAV and RNP specifications. PBN provides a basis for the design and implementation of automated flight paths as well as for airspace design and obstacle clearance. Once the required performance level is established, the airplane's own capability determines whether it can safely achieve the specified performance and qualify for the operation.



APPROACH PLATE USING RNP SAAAR

Figure 7

This approach plate shows an RNP SAAAR approach for Palm Springs International Airport in Palm Springs, California.

Using PBN also could help prepare operators for advanced navigation concepts, such as trajectory-based operations (TBO). TBO creates lateral and vertical flight profiles for airplanes that are very specific while being highly flexible and adaptable to operational needs. These profiles can be visualized as tunnels in space. The profiles would change depending on the navigation accuracy required, the climb and descent points, and time of arrival to satisfy traffic flow requirements. TBO encompasses what many call "three- and four-dimensional operations." The relationship to PBN is that the core airplane capability from takeoff to landing is to navigate accurately along a defined flight path both laterally and vertically, and to be at the correct points along that path at precise times.

SUMMARY

PBN represents an evolution of aviation navigation away from ground-based navaids. This offers a number of tangible benefits to operators, from greater safety and more reliable airport access to more efficient operations. Some operators are already realizing these benefits. Others are taking advantage of the opportunity to develop a PBN-compatible fleet in anticipation of continued adoption of PBN-based approaches and departures at airports around the world. Boeing provides implementation services to operators considering a move to PBN systems.

For more information, please contact David Nakamura at dave.nakamura@boeing.com.

Implementation Guidance

Boeing has identified three main processes that are part of the successful implementation of a PBN operation. These processes require the combined efforts of regulators, air navigation service providers (such as the Federal Aviation Administration, National Air Traffic Services, and NAV CANADA), and users to be effective. Contact Boeing at jeff.s.roberts@boeing.com for details about these implementation processes, or for assistance in implementing PBN.

1

Determine Requirements

Formulate airspace concept.

Assess fleet capability and navaid infrastructure.

Identify performance and functional requirements.

2

Identify ICAO Navigation Specification(s) for Implementation

Review ICAO *Navigation Specifications* (Volume II), or appropriate airworthiness circulars and procedure design guidance material.

Identify the appropriate ICAO navigation specification to apply in the specific communication navigation surveillance/air traffic management environment.

Identify tradeoffs with airspace concept and/or functional requirements.

Select ICAO navigation specification(s), or appropriate airworthiness circulars and procedure design guidance material.

3

Plan and Implement

1. Formulate safety plan.
2. Validate airspace concept for safety.
3. Design procedure.
4. Perform procedure ground validation.
5. Make implementation decision.
6. Conduct flight inspection and validation.
7. Account for air traffic control (ATC) system considerations.
8. Provide awareness and training for ATC and flight crews.
9. Establish operational implementation date.
10. Conduct a post-implementation review.