Introduction to Performance Based Navigation

Sofema Aviation Services (SAS) Takes a deep dive into the world of Performance Based Navigation from the perspective of Maintenance & CAMO Staff.

Introduction

The transition from traditional ground-based navigation to Performance-Based Navigation (PBN) marks a significant evolution in the management of instrument flight rules (IFR) route structures. Historically, IFR routes—including Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs)—were designed to follow predefined paths linked to ground-based navigation aids such as VORs and NDBs. While effective in earlier phases of aviation development, this method constrained route flexibility, introduced inefficiencies in airspace use, and limited opportunities for optimization in terms of fuel usage, noise abatement, and air traffic flow.

PBN enables point-to-point navigation that is no longer restricted by the geographic placement of ground stations. Instead, it leverages satellite-based navigation (primarily GNSS/GPS), inertial reference systems, and flight management systems to allow aircraft to follow precisely defined flight paths. By applying navigation specifications such as RNAV and RNP to SIDs, STARs, and approach procedures, airspace planners can design flexible, tailored routes that enhance both vertical and lateral navigation. These procedures can be optimized to avoid terrain and obstacles, reduce separation minima in congested airspace, and support seamless transitions between en-route, terminal, and approach phases.

A central element of PBN is the use of defined performance standards—specifically, RNAV and RNP specifications, each with a numeric value representing the required lateral accuracy (e.g., RNAV 1 or RNP 1, meaning 1 nautical mile accuracy 95% of the time). While both types support area navigation, the key distinction is that RNP includes onboard performance monitoring and alerting, whereas RNAV does not. This monitoring capability enables the navigation system to detect when performance is outside acceptable limits and alert the flight crew accordingly, offering a significantly higher level of operational integrity.

This fundamental difference justifies the increased adoption of RNP in complex or safety-critical environments, particularly in terminal airspace and approach procedures where precise lateral and vertical guidance is essential. RNP Authorization Required (RNP AR) approaches, for instance, allow for curved paths and tighter containment areas, making them ideal for airports surrounded by terrain or constrained by airspace limitations. The

result is a safer, more predictable, and more efficient operational environment, aligned with the growing global emphasis on performance-based, scalable navigation solutions.

Performance-Based Navigation (PBN) represents a significant shift from traditional sensor-based navigation toward performance-driven criteria.

Maintenance and Continuing Airworthiness Management staff requires a thorough comprehension of the performance parameters associated with RNP and RNAV systems, and how these parameters affect the aircraft's operational capabilities.

- To ensure the proper calibration, configuration, and functioning of onboard avionics and navigation systems
- To continuously meet the designated performance criteria, Continuing Airworthiness Staff should integrate these requirements into maintenance programs, ensuring ongoing compliance with regulatory standards, and facilitating the necessary documentation and monitoring processes.

Legacy Navigation Systems

Historically, navigation specifications relied heavily on ground-based navigational aids such as navigation beacons and predefined waypoints.

- DME (Distance Measuring Equipment) provides pilots with the slant range distance between the aircraft and a ground-based transponder station. DME is typically paired with a VOR (as VOR/DME) or an Instrument Landing System (ILS) to assist in both en-route navigation and approach procedures. DME is crucial for calculating position fixes, estimating time to station, and ensuring compliance with minimum navigation performance specifications in distance-sensitive segments of flight paths.
- VOR (VHF Omnidirectional Range) emits a radio signal that allows aircraft equipped with a VOR receiver to determine their bearing *to or from* the station. By tuning into two VOR stations and plotting the radial from each, pilots could triangulate their position—an essential capability for en-route navigation and terminal procedures before the widespread use of GPS. VORs provided greater accuracy and flexibility compared to older non-directional aids and enabled the development of airways with more precision.
- ADF (Automatic Direction Finder) operates in conjunction with NDBs (Non-Directional Beacons), transmitting signals in all directions. The ADF instrument in the aircraft points toward the NDB station, allowing the pilot to fly toward or away from the beacon. Although less accurate than VOR and more susceptible to

signal distortion (especially from terrain and weather), ADF/NDB systems were widely used for basic navigation and as redundancy in instrument approach procedures.

These systems collectively defined aircraft navigation performance in terms of available infrastructure rather than aircraft capabilities. Air routes, known as airways, were constructed by linking navigation aids, and aircraft were expected to navigate from beacon to beacon following these fixed tracks.

What is PBN

The limitations of this "Legacy" sensor-specific approach—particularly in terms of flexibility, efficiency, and cost—ultimately drove the transition toward Performance-Based Navigation (PBN).

- PBN enables more precise and efficient routing based on area navigation (RNAV) and required navigation performance (RNP) capabilities, supported by satellite navigation and onboard systems rather than reliance on fixed ground stations.

Area Navigation (RNAV)

RNAV (Area Navigation) is a method of navigation that allows aircraft to fly on any desired flight path within the coverage of ground- or space-based navigation aids, or within the limits of onboard navigation capabilities, without the need to overfly specific ground-based navigation beacons (like VORs or NDBs).

This flexibility enables:

- More direct routing (reducing flight time and fuel burn),
- Optimized airspace usage (especially in congested terminal areas),
- Tailored arrivals and departures (enhancing airport efficiency),
- More environmentally friendly flight paths.

RNAV relies on various navigation sources, such as:

- GNSS (e.g., GPS),
- DME/DME (two or more DME stations used to triangulate position),
- INS (Inertial Navigation Systems),
- VOR/DME combinations.

An RNAV specification typically defines what type of navigation accuracy is required, such as RNAV 1 (accuracy within 1 NM 95% of the time) or RNAV 5 (accuracy within 5 NM).

Key Feature: RNAV is a navigation method based on system performance, but it does not include onboard performance monitoring and alerting.

Required Navigation Performance (RNP)

RNP is a type of RNAV with the added requirement of onboard performance monitoring and alerting. This means that the navigation system not only guides the aircraft but also continuously monitors its performance to ensure it stays within defined accuracy limits—and alerts the flight crew if it does not.

RNP enhances safety and efficiency, especially in environments with limited navigation infrastructure or where terrain or airspace restrictions require tighter control.
For example:

- RNP 1 requires aircraft to maintain accuracy within 1 NM, with monitoring and alerting.

- RNP AR APCH (Authorization Required Approach) allows aircraft to fly highly precise approaches into airports with challenging terrain or limited infrastructure, provided the operator has specific approval.

Key Feature: RNP supports greater assurance and safety by ensuring the navigation system knows when it's not meeting required performance—and can notify the crew.

ICAO's as a driver for Performance-Based Navigation

However, with the introduction of ICAO's Performance-Based Navigation, the focus has shifted towards defining aircraft navigation capabilities based on specific performance metrics rather than particular navigation sensors.

- ICAO defines Performance-Based Navigation by specifying Required Navigation Performance (RNP) and Area Navigation (RNAV) systems

    - These criteria are tailored specifically to the demands and operational requirements of particular airspaces, supported by the appropriate navigation infrastructure.

- This approach ensures that aircraft navigation capabilities meet the precise needs of the airspace environment, promoting enhanced safety, optimized airspace utilization, and improved operational efficiency.

Further Distinction Between RNP and RNAV:

While both RNP and RNAV are both considered as elements of Area Navigation, a key distinction lies in their functional requirements.

- RNAV enables aircraft to fly on any desired flight path within the coverage of ground- or space-based navigation aids, or within the limits of the capability of self-contained systems, or a combination of these. It facilitates efficient routing by allowing more flexible use of airspace compared to conventional sensor-based navigation.

- RNP builds upon RNAV capabilities by incorporating onboard performance monitoring and alerting.

    - This means that aircraft equipped with RNP can autonomously monitor the accuracy and integrity of their navigation performance in real time and alert the crew if the required performance level is not being met.

In summary, all RNP systems are RNAV systems, but not all RNAV systems qualify as RNP. The distinguishing feature of RNP is its requirement for onboard performance monitoring and alerting, which enhances safety and enables more demanding navigation applications.

From Fixed Tracks to Point-to-Point Navigation

Traditionally, **IFR SIDs and STARs were constructed using fixed ground-based navigation aids** (such as VORs, DMEs, and NDBs), leading to airway structures that often **zig-zagged between beacons** rather than offering the most efficient path.

Understanding IFR, SID, and STAR

IFR (Instrument Flight Rules) refers to a set of regulations under which pilots fly primarily by reference to instruments, not visual cues. IFR is essential in low visibility conditions or high-traffic airspace, where structured navigation and separation are required. Within IFR operations, two critical components are:

SID – Standard Instrument Departure

A SID is a published IFR departure route that guides aircraft from the runway to the en-route phase of flight. It provides a safe, standardized way to depart from an airport, ensuring obstacle clearance, traffic sequencing, and airspace integration.

Key features:

- SID procedures are designed around navigation aids or waypoints.
- They typically involve step-by-step lateral and vertical guidance.
- They reduce radio communication load and increase predictability.

STAR – Standard Terminal Arrival Route

A STAR is a published IFR arrival route that provides a standardized transition from the en-route structure into the terminal area of an airport. It guides aircraft toward initial approach fixes in a safe and orderly manner.

Key features:

- STARs manage high volumes of arriving traffic efficiently.
- They integrate with approach procedures (e.g., ILS, RNAV approach).
- STARs also provide clear altitude and speed restrictions for traffic flow management.

Performance-Based Navigation (PBN - point-to-point navigation) uses GPS and other systems to guide aircraft along precisely defined routes, not limited by the location of ground-based infrastructure.

GNSS/GPS: The primary navigation source for PBN,
Global Navigation Satellite Systems (GNSS) – including GPS
The primary enabler of modern PBN is GNSS, a generic term that includes:

- GPS (United States),
- Galileo (European Union),
- GLONASS (Russia),
- BeiDou (China).

SBAS: Satellite augmentation to improve GNSS precision and integrity,
Satellite-Based Augmentation Systems (SBAS)
SBAS improves the performance of basic GNSS signals by providing:

- Greater accuracy (through correction signals),
- Improved integrity (real-time monitoring and alerting of faults).

Examples include:

- WAAS (Wide Area Augmentation System – USA),
- EGNOS (European Geostationary Navigation Overlay Service – Europe),
- MSAS (Japan), and
- GAGAN (India).

SBAS enables advanced applications such as LPV (Localizer Performance with Vertical Guidance) approaches, which provide near-precision approach capability without the need for ground-based ILS.

INS/IRS: Inertial systems for redundancy and continuity,
DME/DME: Ground-based triangulation backup,
FMS: The onboard system managing all navigation inputs and executing the PBN route.

PBN Standards for Air Routes, SIDs, STARs, and Approaches

Under the ICAO PBN concept, navigation specifications apply to routes and procedures, including SIDs and STARs. These specifications are expressed using:

- RNAV (Area Navigation) specifications (e.g., RNAV 1, RNAV 5),
- RNP (Required Navigation Performance) specifications (e.g., RNP 1, RNP AR APCH).

The numeric value (e.g., "1" in RNAV 1) indicates the required navigation accuracy, in nautical miles, that must be maintained 95% of the time during the operation.

Examples:

- **RNAV 1 SID/STAR**: Aircraft must remain within 1 NM of the intended path.
- **RNP AR APCH**: Highly precise approaches with required onboard monitoring.

The Fundamental Difference Between RNAV and RNP

While both RNAV and RNP enable point-to-point navigation, **the critical difference lies in the level of integrity assurance** provided by the onboard systems:

Feature	**RNAV**	**RNP**
Area Navigation Capability	Yes	Yes
Defined Lateral Navigation Accuracy	Yes	Yes

Feature	RNAV	RNP
Onboard Performance Monitoring	**No**	**Yes**
Alerting to Performance Failures	**No**	**Yes**
Operational Assurance	Moderate	**High**

Explanation:

- **RNAV** routes require aircraft to maintain a specified level of navigation accuracy but do not require onboard monitoring and alerting of system performance.
- **RNP**, on the other hand, requires that the aircraft's navigation system continuously monitors its performance, and alerts the crew if it cannot maintain the required level of accuracy.

This onboard monitoring and alerting function is what makes RNP operations more suitable for complex or high-risk airspace—such as terrain-constrained areas, or where minimal route separation is needed.

Next Steps

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