Performance Based Navigation

In a nutshell, Performance Based Navigation (PBN) is simply saying, if you want to fly IFR en-route or perform approaches, you must be able to keep to a minimum level of navigational accuracy. The navigational accuracy required will be defined for the airspace you are flying in and for the operation you want to perform. These requirements are called specifications (either RNAV or RNP), and there are different specifications depending on what you want to do. You must also continuously tell everyone precisely where you are, using ADS-B and Mode-S transponders.

As an IFR pilot, you and your aircraft equipment will need to meet the minimum PBN requirements which apply to all phases of your flight and it will be up to you to make sure of that during your pre-flight planning.

Aircraft operating under PBN specifications are able to use flexible routings independent of ground-based aids. Since PBN also incorporates ADS-B, aircraft can operate with reduced separation minima which will help ease congestion in Australia's busiest airspace areas. This has knock-on economic benefits because routing can be more direct which results in shorter track distances and therefore reduced fuel costs. Safety is also enhanced by PBN because safer approaches can be made as more and more straight-in approaches become available at aerodromes nationwide.

Let us now take a look at the elements of PBN and its implementation in more detail.

The world's airspace is getting crowded and ICAO's Global Air Navigation Plan (GNAP) looks to address this problem and also to standardise the navigation performance standards internationally. The core components of the PBN airspace concept as described by ICAO are **communications**, **air traffic management**, **surveillance** and **navigation**.

Air Traffic Management
ATM is covered by Air Services as they restructure the Australian airspace to incorporate the new PBN classifications and update ATC procedures to work with the new airspace model. At the moment, airspace, procedures and RNAV routes are not given a PBN designation but Air Services is, at time of writing, working to transition Australian Airspace to PBN by February 2016. How the airspace designations will eventually look is still a work in progress.

Surveillance
The surveillance aspect of PBN is handled by the use of ADS-B and Mode-S transponders. ADS-B uses an extended squitter (ES) datalink operating on 1090MHz transmitted from a Mode-S transponder. A squitter transmits information at regular intervals, compared to a Mode-A or Mode-C transponder, which only transmits information when interrogated.

Here's an important tip for aircraft owners: the FAA has approved the Universal Access Transceiver (UAT) protocol for use in ADS-B-out on aircraft not operating above 18000ft. Unfortunately, units using UAT will not work in Australia and it is vital pilots buying US Mode-S transponders, ensure the equipment operates using ES.

ADS-B will be a requirement for all IFR by 4th February 2017 and some IFR operations were required to be fitted with this equipment well before then (e.g. 4th Feb 2016 for IFR aircraft in the area 500 nm North and East of Perth). ADS-B requires a TSO C145a, C146a or C196 GNSS so IFR operations with TSO C129 GNSS equipment will no longer be possible after that date.

Until then, TSO C129 GNSS units can still be used but, as discussed under alternate requirements in the IREX text, the C129 units must plan for an alternate with a conventional ground-based aid. Since many of these are being decommissioned, it is going to be harder to find suitable alternates within economic range of commercial operators.

Navigation
For PBN to work, an aircraft needs ***Absolute Navigation*** where an aircraft's latitude and longitude are precisely calculated and this position is then compared to the aircraft's desired path. This is more accurate than ***Relative Navigation*** where the system (or pilot) calculates their position based on bearings relative to one of the legacy, ground-based aids. Relative navigation is unable to provide the accuracy required for the new PBN concept.

The ICAO PBN Manual (Doc 9613) defines PBN as:

> *Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.*

These performance requirements are broadly split into RNAV and RNP categories with specifications defined for each and these describe the navigation performance required. The requirements are expressed in terms of:

- **Accuracy** which is the precision of the navigation solution of the system.
- **Integrity** e.g. how trustworthy is the navigation solution? For example, does the system tell you when it thinks there might be a problem?
- **Continuity** which is the time the system is available with the required accuracy and integrity, and,
- **Functionality** which refers to the functionality required in the equipment for the operations you intend.

The navigation standard can be met using GNSS or any other computerised on-board systems (such as INS) as long as any equipment is installed in an approved manner, as defined in CAAP 35-1 or CASA AC 21-36. Depending on the equipment though, PBN authorisations issued may be limited to RNAV.

So what's the difference between RNAV and RNP?

RNAV (or aRea NAVigation)
RNAV uses on-board systems to calculate an absolute position but there is no requirement for failure mode error detection and alerting systems to be available. For example an INS programmed with the wrong initial starting position will happily calculate your current position based on motion away from that false starting point. RNAV systems tend to use straight line navigation between waypoints based on ground based aids or fixes determined by absolute location.

RNP (or Required Navigation Performance)
RNP is similar to RNAV, but RNP systems must provide a failure mode and error detection/alerting system. Since all aviation GNSS systems implement some form of RAIM, it is fair enough to say an RNP system is GNSS based.

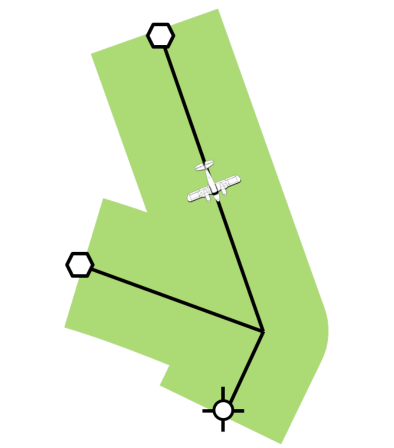
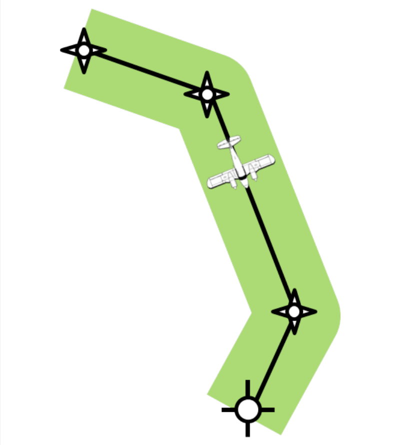
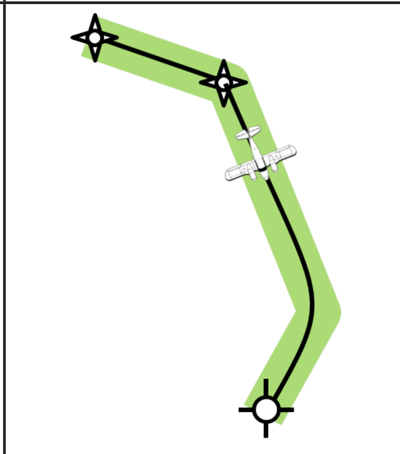
Since RNP has the added benefit of error alerting, RNP specifications allows for much narrower obstacle and traffic separation and is also more practical for the inclusion of curved segments in PBN paths.

Naming the Specifications
The numbering system indicates the required tolerance to be achieved by the system 95% of the time. For example, RNAV1 specifies an aircraft must be capable of calculating its position to within 1 nm of its actual position, 95% of the time.

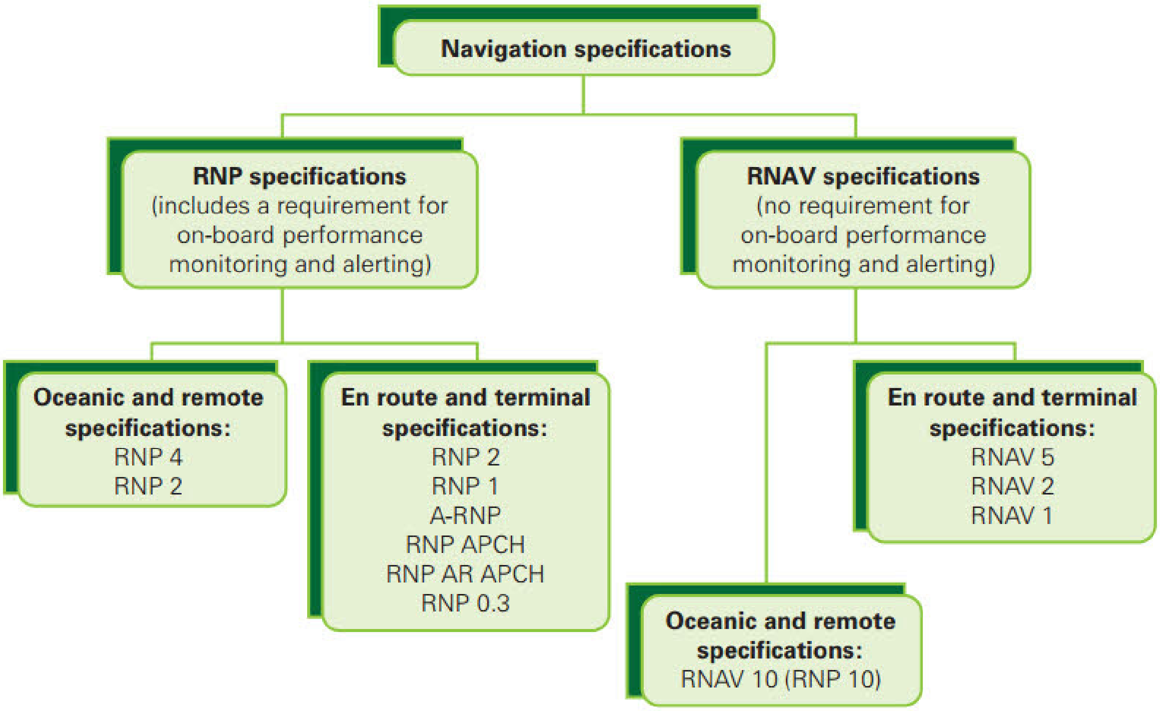
RNP1 on the other hand means the aircraft needs to remain within 1 nm tolerance 95% of the time but also within a further containment limit for 99.99% of the time. Therefore RNP1 means the aircraft's calculated position will be accurate to within 1 nm for 95% of the time but also within the +/- 2nm containment limit for 99.999% of the time.

The GNSS equipment used for RNP will issue alerts if the navigation solution calculated by the unit exceeds the tolerances set. For example, if the unit is in RNP 0.3 mode, an error exceeding 0.3 nm detected in the calculated position will trigger an alert for the pilot.

The following diagram highlights some of the differences between conventional routes, RNAV and RNP.

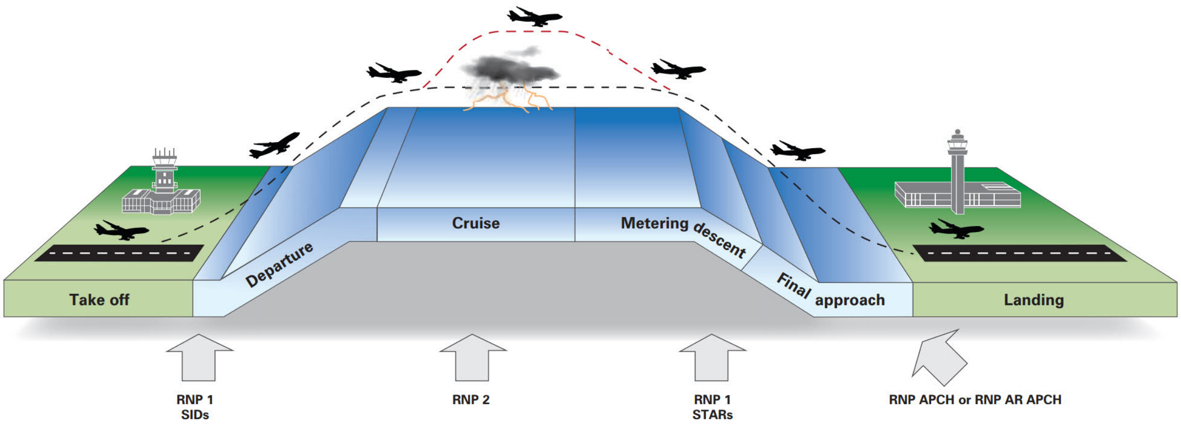
Conventional Routes	RNAV Routes	RNP Routes
		
• Based on legacy, ground-based aids. • Limited design flexibility.	• Straight paths between waypoints. • More efficient use of airspace.	• Variable paths between waypoints. • Narrow containment area means optimal use of airspace.

PBN Specifications are split into two main categories as outlined in the following diagram.



RNP requirements applicable to IFR flight

A pilot may not use the particular PBN navigation specification on an IFR flight unless the pilot satisfies all the requirements for each segment during the flight, the flight is conducted according to those PBN navigation specifications and the manual for the RNAV system is in the aircraft and easily accessible to the pilot (see CAO 20.91 8.2).



An example of the RNP Qualifications required for a typical IFR flight.

RNAV and RNP Qualifications

The RNAV and RNP qualifications issued for an aircraft's equipment depends on the manufacturer, class and model of the avionics used to satisfy the PBN requirements. The appendices in CAO 20.91 outline the equipment eligibility as well as the knowledge and training of flight crew operating under the various PBN requirements.\

Existing IFR equipment will be issued PBN authorisations under deeming provisions which are described in CASA's PBN information booklet.

Requirements for use of GNSS in RNP Approach Operations
To use GNSS in RNP operations, the operator or pilot in command needs to look at the authorisations given to the equipment. These authorisations are described in CAO 20.91 (Sections 8 – 11). The navigation database has to be valid. An aircraft may fly for up to 72 hours from the time the database expires but this can be changed to three "flight days" if the aircraft uses a minimum equipment list (MEL). See CAO 20.91 para 13.11, 13.12.

RNP Approaches
RNP APCH – LNAV
The old RNAV/GNSS approach is superseded by the new RNP APCH-LNAV approach definition. For RNP APCH-LNAV the aircraft must be equipped with an appropriately authorised TSO-C129a standalone system, a TSO-C145 GNSS sensor, or a TSO-C146 standalone GNSS system and this equipment has been installed correctly (as described in CAAP 35-1 or CASA AC 21-36).

There are two types of RNP APCH with 3D vertical guidance, and they differ in where they source their vertical guidance information.

RNP APCH – LNAV/VNAV (Baro VNAV)
In these approaches the GNSS equipment sources vertical information from a barometric air source which needs to be accurate enough for the approach. The Flight management system (FMS) calculates the descent path using this barometric information.

An important limitation of baro-VNAV is that the vertical profile specified is defined for the approaches approach angle flown in ISA conditions. The actual path flown by the aircraft is dependant on the ambient air density. A temperature higher than ISA will result in a steeper approach path and temperatures lower than ISA will result in a lower descent profile.

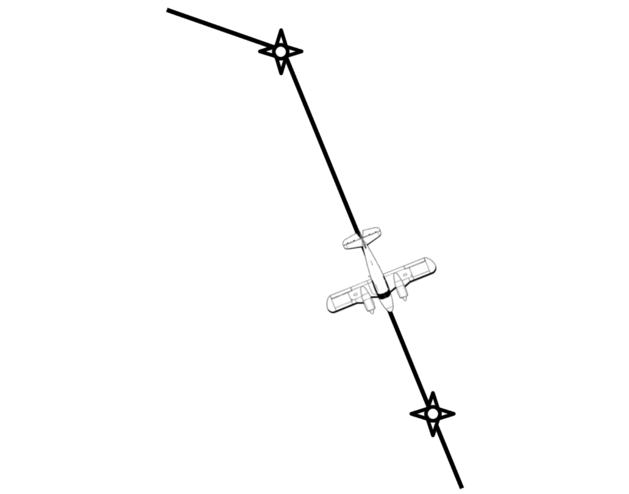
For this reason, Baro VNAV approaches may have published temperature limits and will not be available should the ambient temperature lie outside the permitted range.

RNP APCH LPV (SBAS)
The GNSS accuracy can be enhanced or "augmented" using space based augmentation systems (SBAS) or ground-based augmentation systems (GBAS). We do not have SBAS available in Australia at time of writing but GBAS is being used in a similar way to increase the accuracy of GNSS systems to the point where they can be used to provide ILS-like guidance down to decision altitudes, not below 200 ft.

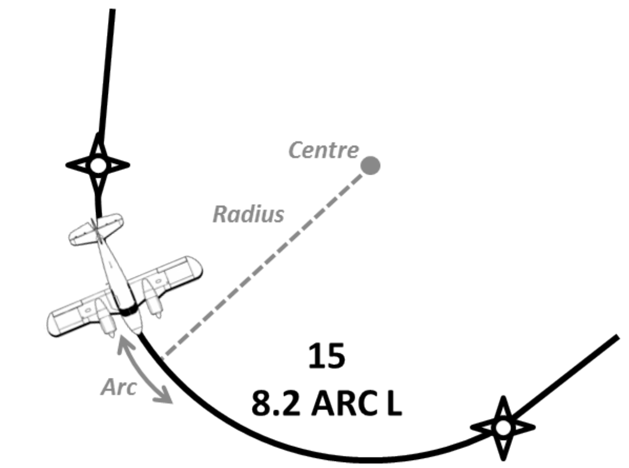
Defining PBN Routes and Paths
When creating PBN routes and paths, the designers have a toolbox of waypoint and segment types at their disposal. They can then define the waypoint positions, specify their type, and how they are linked together and this data can be easily stored in a navigation database. When a path is selected, the FMS reads this data and assembles the path for the aircraft based on the characteristics of the path elements.

Let's take a look at some of the common types of waypoint and segment the FMS is working with.

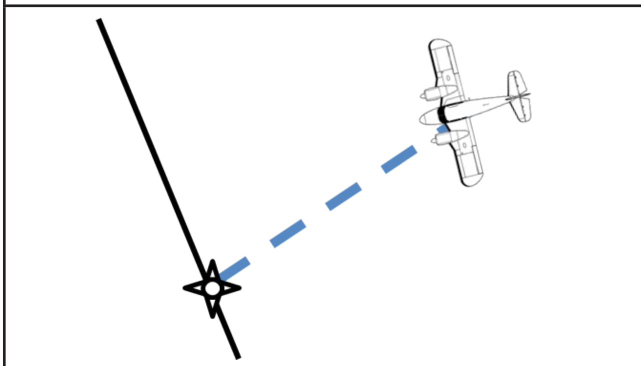
PBN Leg Types



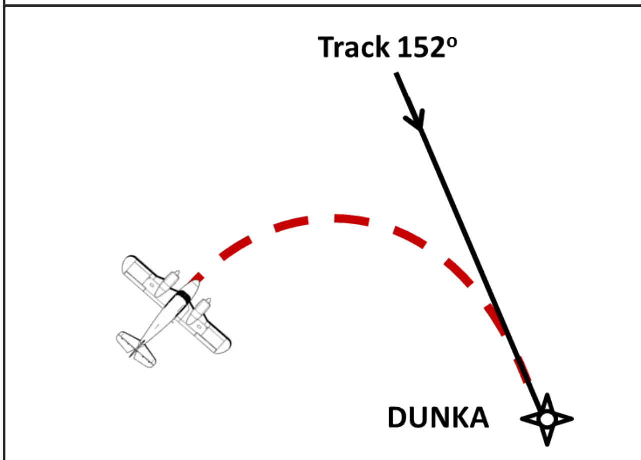
Track to a Fix (TF)
The TF leg is intercepted at some waypoint and then tracked directly to the next waypoint.



Constant Radius to a Fix (RF)
An RF leg is defined as a circular path of fixed radius around some centre point. The point need not be a fix or waypoint. An RF starts at a fix and ends at a fix and the radius of the turn can vary from segment to segment allowing for a series of fluid curving paths between waypoints.



Direct to a Fix (DF)
A DF leg is a path straight to the fix from an aircraft's current position in some area where it is safe to start the DF leg.



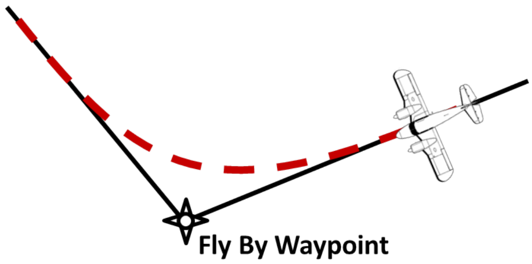
Course to a Fix (CF)
CF's used to describe a variable track to a fix where the aircraft commences a turn and intercepts the inbound track to the fix, no later than the fix itself.

For example, “CRS152 DUNKA” describes a leg where the aircraft must turn towards and intercept the track 152º to DUNKA.

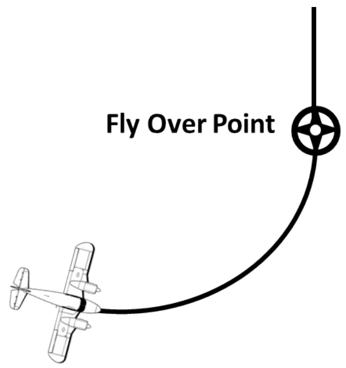
PBN Path Terminators
A path terminator marks the end of a leg
- **Initial Fix (IF)** marks the start of a series of path terminators such as the beginning of a SID.
- **Hold Fix (HF)** is a point where the aircraft is expected to hold on the fix for one circuit and then continue.
- **Hold for clearance (HM)** is a point where the aircraft is expected to hold while awaiting clearance.
- **Hold to Altitude (HA)** is a point where the aircraft is expected to hold and climb while in the holding pattern.
- **Fix to an Altitude (FA)** this leg defines a point from which the aircraft is expected to climb to altitude.

PBN Leg Transitions (or Waypoints)
Waypoints are a fixed geographical position defined in terms of latitude and longitude and as such can be completely independent of ground-based aids.

- **Fly-by waypoints** are fixes where the aircraft should begin the turn before reaching the waypoint, or in other words use turn anticipation to "cut the corner" and shorten the track distance.

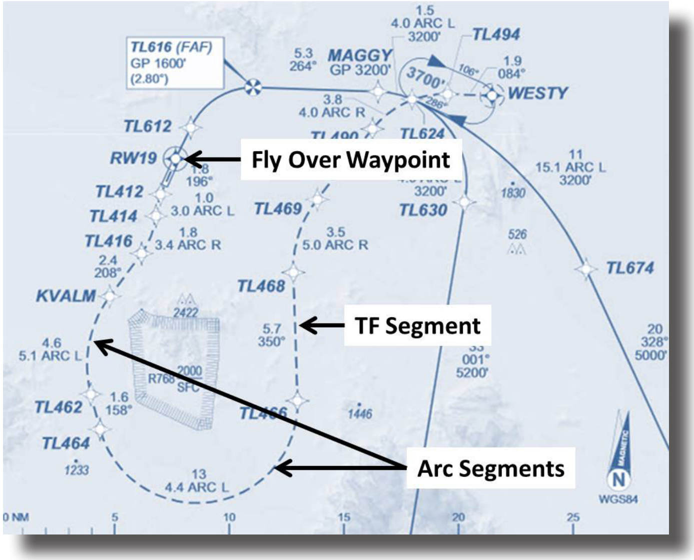


- **Fly-over waypoints** on the other hand must be flown over before the aircraft may commence the turn onto the next leg.



- **Fixed Radius Transition (FRT)** is used for en-route procedures and is used to define a turn of a standard radius in the path. These turns have a radius of either 22.5 nm for high altitude routes or 15nm for low altitude routes. Don't confuse this with the RF leg (described above). RF legs can have any radius required by the airspace designer.

The following diagram shows some of these waypoint and leg types in the RNP approach for Townsville runway 19.



RNP Navigation Errors
The three main errors defined in PBN are:

- **Flight Technical Error (FTE)** which refers to the ability of the pilot (or autopilot) to fly the required path and it includes errors in the display of the required path to the crew.
- **Path Definition Error (PDE)** refers to problems with defining a precise horizontal or vertical path and also errors in the navigation database. Precise path definition is very difficult in paths such as CF or FA as the actual flight path varies with wind and aircraft speed or power.
- **Navigation System Error / Position Estimation Error (NSE/PEE)** are errors in the calculated position and the actual position of the aircraft.
- **Total System Error (TSE)** is the sum of all these errors combined.

Further Information
The information covering PBN and RPN is covered by *CAO 20.91 (Instructions and directions for performance-based navigation) Instrument 2014.*

CAO 20.18 contains the information you need on PBN and ADS-B equipment required to be carried.

Finally, there is a convenient downloadable PBN booklet in PDF form available on the CASA website:

http://www.casa.gov.au/wcmswr/_assets/main/lib100178/pbn-booklet.pdf

