

Flying RNAV (GNSS) Approaches in Private and General Aviation Aircraft

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Part 1: Introduction to PBN and RNAV approach operations

1.1 Introduction

Global Navigation Satellite Systems (GNSS) have changed the face of navigation dramatically in recent years, in that they can give an accurate and instant readout of position almost anywhere in the world. At the time of writing, the most familiar GNSS system is the US Department of Defense Global Positioning System (GPS), and this document is based on the use of GPS aviation receivers.

GPS has already brought the opportunity for accurate Area Navigation (RNAV) within the budget of most aircraft operators. The development of GNSS based instrument approaches has now also brought the requisite technology for RNAV approach operations to light and private aircraft.

RNAV brings with it many new techniques. As with any new technology, there is a natural transition from the experience and knowledge of the old, to the techniques of the new. During this time, the opportunities for error and misunderstanding are great and, for a time at least, the new technology is likely to represent an increased risk of error before the benefits of the system's greater accuracy can be realised.

This document contains information on training and operational use of GPS for the flying of RNAV (GNSS) Approaches.. Whilst, for the purposes of background, some information is given on the concept of Performance-Based Navigation (PBN) and RNAV, this document focuses mainly on the application, training and operational use of RNAV approach operations. This document is intended as a guide to pilots and instructors of privately operated, non-complex general aviation aircraft but much of the information may also be of use to other operators in the preparation of their own PBN training and operations programmes.

Further guidance on the wider use of GPS for VFR navigation in light aircraft is available from the CAA in Safety Sense Leaflet 25 which may be printed or downloaded free of charge from the CAA website at www.caa.co.uk/safetysenseleaflet25

1.2 Background

IFR operations depend upon a variety of navigation aids and techniques. A combination of these effectively provides the monitor and crosscheck necessary to capture both technical and human error. Where a single technical facility becomes the primary steering reference (primary reference), in instrument meteorological conditions (IMC), situational awareness and some form of crosscheck become critical to flight safety.

1.3 Basic GPS

For the basic GPS signal in space, whilst there are monitors of the signal available to the aircraft, it is still possible for the satellites to give erroneous information and for receivers to display it. Once an anomaly has been detected, without access to or reception of the correcting (differential) signals, it can take up to several hours for the error to be removed or corrected by the GPS system itself. The GNSS receiver manufacturers have, therefore, developed systems, internal to some of their aircraft receivers, known as aircraft-based augmentation systems (ABAS), most of which now include some sort of integrity monitor such as Receiver Autonomous Integrity Monitor (RAIM) - see paragraph 3.2.2 below.

The GPS constellation and the ground stations are controlled from Colorado, in the United States. The system has demonstrated exceptional reliability, but like all systems, it has suffered technical and human failure. The satellite clocks are critical to the integrity of the system and are subject to regular intervention. Furthermore, the designs for receivers vary; particularly in the software that manages the satellite data for navigation. It is for these reasons that GPS must be used with knowledge and caution when used as the primary steering reference, for flight critical applications, such as instrument approach.

1.4 More recent developments

Satellite Based Augmentation System (SBAS)

SBAS augments the core satellite constellation by providing ranging, integrity and correction information via geostationary satellites. This system comprises a network of ground reference stations that observe the satellites' signals, and master stations that process this observed data and generate SBAS messages for uplink to the geostationary satellites which, in turn, broadcast the SBAS message to the users.

Within Europe the SBAS is provided by the European Geostationary Navigation Overlay Service (EGNOS). Many receivers are now available with a Vertical Navigation (VNAV) function using SBAS services.

Other SBAS services provided or under development in other regions of the world include:

- Wide Area Augmentation System (WAAS)* in the USA.
- Multi-functional Satellite Augmentation System (MSAS) in Japan
- GPS Aided Geo Augmented Navigation (GAGAN) in India

- System for Differential Corrections and Monitoring (SDCM) in Russia

*The term 'WAAS' also tends to be used in a wider generic reference to SBAS services elsewhere in the world.

These services are expected to be 'interoperable', meaning the receivers should interpret whichever signal(s) they 'see' providing an apparently seamless operation from one area of coverage to another.

Further information on the status and performance of GPS may be obtained from <http://www.navcen.uscg.gov>.

1.5 References

- ICAO PBN Manual (Doc 9613)
- EASA AMC 20-27A
- EASA AMC 20-28
- EASA Opinion Number 01/2005 on "The acceptance of navigation database suppliers dated 14th January 2005
- TSO / ETSO C129A, C145A() and C146A()
- FAA AC 20-138()
- EASA AMC 20-5
- EASA Part FCL
- CAA CAP 804
- FAA AC 20-153
- CAA Safety Sense Leaflet 25

Note: Appendix 5 is an extract from Australian Civil Aviation Safety Authority (CASA) Civil Aviation Advisory Publication CAAP 179A-(1) and is reproduced with the kind permission of CASA

1.6 Acronym Glossary

2D	Two Dimensional (Lateral Only)
3D	Three Dimensional (Lateral and Vertical)
ABAS	Aircraft Based Augmentation System
AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ADF	Airborne Direction Finder
AFM	Aircraft Flight Manual
AIP	Aeronautical Information Publication
AIRAC	Aeronautical Information Regulation And Control
AMC	Acceptable Means of Compliance
ANO	Air Navigation Order
ANP	Actual Navigation Performance
ANSP	Air Navigation Service Provider
APCH	Approach
APV	Approach with Vertical Guidance
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic services
Baro VNAV	Barometric data derived Vertical Navigation
B-RNAV	Basic Area Navigation
C/S	(aircraft) radio Call Sign
CA	Course Acquisition (code)
CAA	Civil Aviation Authority
CAAP	Civil Aviation Advisory Publication (Aus)
CAP	Civil Air Publication (UK)
CASA	Civil Aviation Safety Authority
CCO	Continuous Climb Operations
CDFA	Constant Descent Final Approach
CDI	Course Deviation Indicator
CDO	Continuous Descent Operations
CDU	Control Display Unit (in FMS)
DA/H	Decision Altitude / Height
DIS	Distance

DME	Distance Measuring Equipment
DOP	Dilution of Precision
DR	Dead Reckoning (navigation)
DTK	Desired Track
EASA	European Aviation Safety Agency
EFIS	Electronic Flight Instrument System
EGNOS	European Geostationary Navigation Overlay Service
EPE	Estimated Position Error
EPU	Estimated Position Uncertainty
ESSP	European Satellite Services Provider
ETA	Estimated Time of Arrival
ETSO	European Technical Standard Order
FAA	Federal Aviation Authority (USA)
FAF	Final Approach Fix
FAS	Final Approach Segment (of approach)
FAT	Final Approach Track
FD	Fault Detection
FDE	Fault Detection and Exclusion
FMC	Flight Management Computer
FMS	Flight Management System
FNPT	Flight Navigation Procedures Trainer
FSTD	Flight Simulation Training Device
GAGAN	GPS-Aided Geo-Augmented Navigation (India)
GDOP	Geometric Dilution of Precision
GLS	GNSS Landing System
GNSS	Global Navigation Satellite System
GP	Glidepath
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GS	Groundspeed
HAL	Horizontal Alarm Limit
HIS	Horizontal Situation Indicator
HUL	Horizontal Uncertainty Level
IAF	Initial Approach Fix
ICAO	International Civil Aviation Organisation

IF	Intermediate Fix
IFR	instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
INS	Inertial Navigation System
IR	Instrument Rating
IR(R)	Instrument Rating (restricted) (UK only)
JAA	Joint Aviation Authorities
LNAV	Lateral Navigation
LoA	Letter of Acceptance (navigation data base publication)
LOC	Localiser
LOI	Loss of integrity
LP	Localiser Performance
LPV	Localiser Performance with Vertical Guidance
MAP	Missed Approach Procedure
MAPt	Missed Approach Point
MDA/H	Minimum Descent Altitude / Height
MFD	Multi-function Display
MLS	Microwave Landing System
MSAS	Multi-functional Satellite Augmentation System (Japan)
NANU	Notices to Navstar Users
NATS	National Air Traffic Services (UK)
NDB	Non Directional Beacon
NOTAM	Notices to Airmen
NPA	Non-precision Approach
NTF	Nouvelle Triangulation de France (1970)
OPMA	On-board Performance and Monitoring & Alerting
Part FCL	EASA Regulation 1178/2011 Annex 1 - Flight Crew Licensing (as amended)
PBN	Performance Based Navigation
PDOP	Position Dilution of Precision
PIC	Pilot in Command
POH	Pilots' Operating Handbook

PPS	Precise Positioning Service
P-RNAV	Precision Area Navigation
RAIM	Receiver Autonomous Integrity Monitoring
RMI	Radio Magnetic Indicator
RNAV	Area Navigation
RNP	Required Navigation Performance
RTF	Radiotelephony (Phraseology)
RVR	Runway Visual Range
SA	Selective Availability
SARPS	Standards and Recommended Practices
SBAS	Satellite-based Augmentation System
SDCM	System for Differential Corrections and Monitoring (Russia)
SDF	Step-down Fix
SID	Standard Instrument Departure
SOP	Standard Operating Procedures
SPS	Standard Positioning Service
SRA	Surveillance Radar Approach
STAR	Standard Instrument Arrival
TA	Transition Altitude
TAA	Terminal Approach Altitude
TAWS	Terrain Awareness Warning System
TCAS	Traffic Collision Avoidance System
TGL	Temporary Guidance Leaflet
TSO	Technical Standard Order
US	United States
VAL	Vertical Alarm Limit
VFR	Visual Flight Rules
VGP	Vertical Glidepath
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation
VOR	VHF Omni-directional Range Beacon
WAAS	Wide Area Augmentation System
WGS 84	World Geodetic System (1984)
XTK	Cross-track Error

Part 2: Performance-Based Navigation (PBN)

2.1 What is PBN?

PBN aims to ensure global standardisation of RNAV and RNP specifications and to limit the proliferation of navigation specifications in use world-wide. It is a new concept based on the use of RNAV systems. Significantly, it is a move from a limited statement of required performance accuracy to the following:

The International Civil Aviation Organisation (ICAO) PBN Manual (Doc 9613) definition is:

Area navigation based on performance requirements for aircraft operating along an Air Traffic Services (ATS) route, on an instrument approach procedure or in a designated airspace.

Where:

Airborne performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity and functionality needed for the proposed operation in the context of a particular airspace concept. Within the airspace concept, the availability of GNSS Signal-In-Space or that of some other applicable navigation infrastructure has to be considered in order to enable the navigation application.

PBN is then described through means of RNAV and RNP applications with respective RNAV and RNP operations.

PBN is one of several enablers of an airspace concept. The others are Communications, ATS Surveillance and Air Traffic Management (ATM). The PBN Concept is comprised of three components: The Navigation Specification, the Navaid Infrastructure and the Navigation Application.

The Navigation Specification prescribes the performance requirements in terms of accuracy, integrity, continuity for proposed operations in a particular Airspace. The Navigation Specification also describes how these performance requirements are to be achieved i.e., which navigation functionalities are required to achieve the prescribed performance. Associated with the navigation specification are requirements related to pilot knowledge and training and operational approval. A Navigation Specification is either a Required Navigation Performance (RNP) specification or an RNAV specification. An RNP specification includes a requirement for On board Performance Monitoring and Alerting (OPMA) where the receiver provides an alert to the flight crew if the navigation position is in error, while an RNAV specification does not.

The Navaid Infrastructure relates to ground- or space-based navigation aids that are called up in each Navigation Specification. The availability of the navaid infrastructure has to be considered in order to enable the navigation application.

The Navigation Application refers to the application of the Navigation Specification and Navaid Infrastructure in the context of an airspace concept to ATS routes and instrument flight procedures.

The Navigation Capability Graphic shown at the end of Part 2 depicts the overall Navigation Capability and the relationship between the navigation specifications defined within the ICAO PBN Concept.

Note: Precision approach and landing systems such as the Instrument Landing System (ILS), Microwave Landing System (MLS) and GNSS Landing System (GLS) form part of the navigation suite, but are not included within the concept of PBN. Whilst GLS is based on satellite navigation, it differs from PBN applications in that it is not based on area navigation techniques

2.2 The PBN manual (ICAO doc 9613)

The PBN Manual comprises two Volumes. Volume I of the PBN Manual is made up of two parts: Part A describes the PBN Concept, The Airspace Concept and how the PBN Concept is used in practice. Part B provides Implementation Guidance for Air Navigation Service Providers (ANSP's) in the form of three processes. Volume II of the PBN Manual is also made up of three parts. Part A describes on-board performance monitoring and alerting and Safety Assessments, whilst Parts B and C contain ICAO's RNAV and RNP specifications which are to be used by States as a basis for certification and operational approval.

2.3 PBN in the UK

En-route and Terminal RNAV developments in the UK have been performance-driven since their inception. Some of the impact of ICAO's PBN Concept on UK includes:

The B-RNAV standard contained in European Aviation Safety Agency (EASA) Acceptable Means of Compliance - AMC 20-4 is identical to the RNAV 5 specification in ICAO PBN. The term B-RNAV has been replaced by RNAV 5. RNAV 5 is now required for operation on all ATS routes in UK airspace.

The P-RNAV standard is not identical to the ICAO RNAV 1 specification but may be viewed as a European Application of the RNAV 1 specification. The difference between P-RNAV and RNAV1 centres on the allowable ground navigation aids and the PBN Manual identifies additional requirements for obtaining RNAV 1 approval for an operator already having approval against Joint Aviation Authorities (JAA) Temporary Guidance Leaflet (TGL) 10. In the UK the plan is to migrate from P-RNAV terminology to RNAV 1 as procedures are introduced.

Note: For the differences between P-RNAV and ICAO's RNAV 1 specification, see PBN Manual Vol. II, Part B, Chapter 3, paragraph. 3.3.2.4.

Approach operations in the UK are already RNP Approach compliant. All future UK navigation developments will be aligned with ICAO's PBN Strategy

2.4 Terminology

Approach applications based on GNSS are classified RNP Approach (RNP APCH) in accordance with the PBN concept and include existing RNAV(GNSS) approach procedures designed with a straight segment. The flight deck displays and charting will likely retain the RNAV (GNSS) label for some time and until standardisation can be achieved, pilots should expect to use the terms RNP APCH and RNAV (GNSS) interchangeably. This document therefore uses both terms interchangeably.

2.5 Benefits from PBN

The principal benefit derived from PBN is the transition to a total RNAV environment. This will lead to flight efficiency and allow optimisation of the airspace including reduced holding containment areas. Without the constraints of navigating via fixed, ground-based aids, the airspace designer has a powerful tool in terms of positioning of routes and instrument flight procedures in relation to areas of congestion or population density.

Of concern to the industry is the potential cost from proliferation of regional and State navigation specifications. PBN brings about a more disciplined approach through a limited set of specifications which are globally applied. The aircraft and equipment manufacturers therefore have greater certainty in their market place and can anticipate a tangible return on their capital investment in the aircraft's performance capability.

From an aircraft operator perspective, certain carriers have long claimed that their fleet capability far exceeded anything the airspace could offer by way of capacity and environmental benefits. So with the modern air transport aircraft having this enhanced performance and functionality, PBN starts to harness that aircraft capability. For those with less well equipped aircraft, pressure to upgrade or be faced with exclusion from certain routes or procedures, has to be applied as an incentive rather than as a threat to their business.

2.6 What PBN can offer

- Predictable and repeatable path trajectories moving to a systemised environment with designed interactions;
- Closer spaced routes;
- Curved path transitions;
- Greater tactical flexibility through parallel offsets; and
- Higher integrity from RNP which brings greater assurance to the safety equation and reduces flight crew workload.

From an airspace and airports perspective the envisaged benefits of PBN include:

- Increase in capacity in controlled airspace;
- Greater access to airports, especially for General Aviation (GA) aircraft which have traditionally been limited to higher operating minima due to their basic equipment;
- Improvement in safety through onboard monitoring and performance alerting to the flight crew; and
- Reduction in the effects that flights have on the environment from more efficient routes, more accurate path keeping for noise abatement and, in conjunction with other airspace initiatives such as increased Transition Altitude (TA), the increased use of Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO).
- Increase in capacity in controlled airspace;

From an ATM service provider perspective the envisaged benefits of PBN include:

- Reduced service cost through reduced navigational infrastructure, increased systemisation and increased controller productivity;
- Improvement in safety through the introduction of flight path monitoring tools and alerting to controllers; and
- Improvement in the quality of the service to meet new airspace-user requirements.
- The navigation infrastructure is a key element in PBN and the transition to an RNAV environment is linked to a move towards a space-based navigation environment (GNSS) and a move away from dependence on traditional ground-based navigation infrastructure such as VOR and NDB facilities. This in turn will allow rationalisation of infrastructure leading to savings from capital investment; maintenance and spectrum utilisation with commensurate savings passed onto the operators through reduced navigation services charges and a requirement to carry less equipment.

2.7 Introduction to approach applications

Approach Applications which are classified as RNP Approach (APCH) in accordance with ICAO Doc 9613 Performance Based Navigation (PBN) Manual (and ICAO state Letter SP 65/4-10/53) give access to minima (on an instrument approach procedure) designated as:

2.7.1 LNAV (Lateral Navigation)

This is a Non-Precision or 2D Approach with Lateral only navigation guidance provided by GNSS and an Aircraft Based Augmentation System (ABAS). Receiver Autonomous Integrity Monitoring (RAIM) is a form of ABAS. Lateral guidance is linear with accuracy to within +/- 0.3 NM parallel to either side of the final approach track.

2.7.2 LP (Localiser Performance)

This is a Non-Precision or 2D Approach with Lateral only navigation guidance provided by GNSS and SBAS. The EGNOS is a form of SBAS in Europe. The lateral guidance is angular with increasing sensitivity as the aircraft continues along the final approach track; much like a localiser indication

2.7.3 LNAV/VNAV (Lateral Navigation / Vertical Navigation)

This is a 3D Approach Procedure with Vertical Guidance (APV). The lateral navigation guidance is provided by GPS and Aircraft Based Augmentation Systems (ABAS) such as RAIM in the same way as for LNAV. The vertical guidance is provided by a Barometric Altimeter. This type of approach is commonly known as APV/Baro VNAV. Lateral guidance is normally linear with accuracy to within ± 0.3 NM parallel to either side of the final approach track. Some aircraft systems may provide angular guidance, however, and pilots should be aware of the display format of their system.

Vertical guidance derived from the barometric data in the Flight Management System (FMS) is based on normal altimetry and any displacement from the indicated glidepath represents the same altitude error throughout the final approach. This is fundamentally different from the angular indications such as on an ILS glidepath.

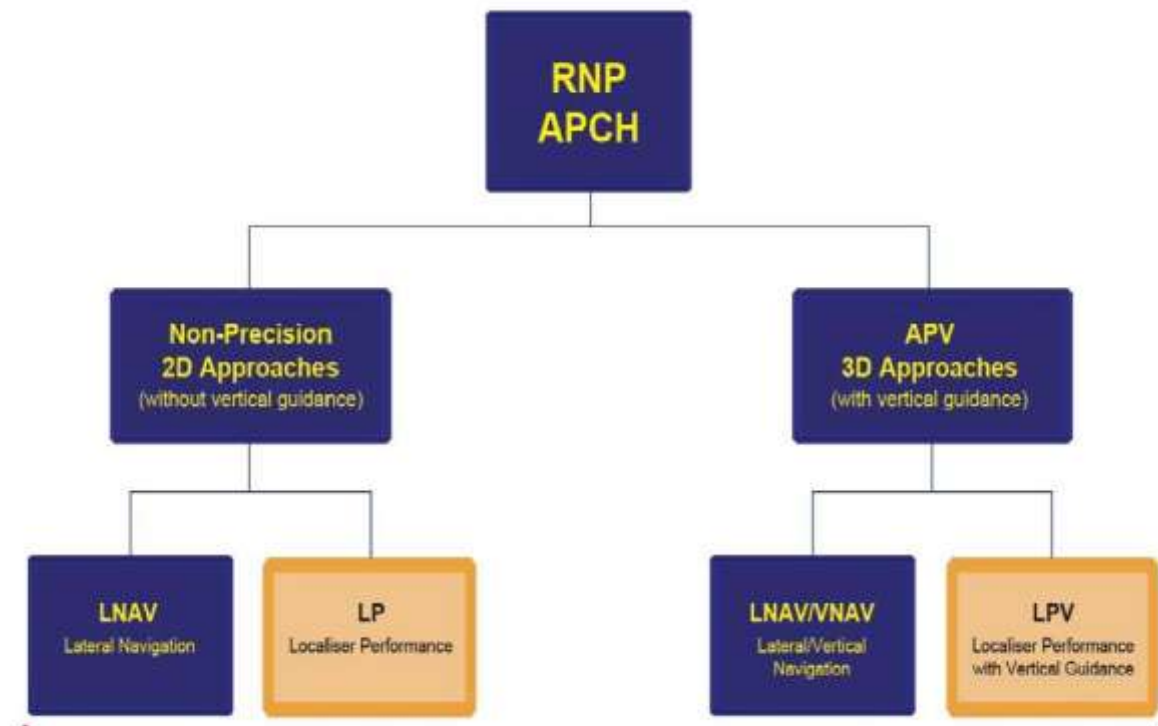
WARNING! At the time of writing this document (Autumn 2014), the use of SBAS to provide augmentation for the VNAV element of a notified LNAV/VNAV approach is not permitted in the UK. Notwithstanding any certification for RNAV VNAV approach operations using SBAS, aircraft which are not certified for the use of barometric VNAV data are currently precluded from flying approach operations to LNAV/VNAV minima. These aircraft are not authorised to continue RNAV approach operations below the published LNAV-only minima.

2.7.4 LPV (Localiser Performance with Vertical Guidance)

This is an Approach Procedure with Vertical Guidance (APV). The Lateral and Vertical guidance is provided by GPS and SBAS. Lateral and vertical guidance are angular with increasing sensitivity as the aircraft progresses down the final approach track; much like an ILS indication.

NOTE: The instrument approach procedures associated with RNP APCH are entitled RNAV (GNSS) to reflect that GNSS is the primary navigation system. With the inherent onboard performance monitoring and alerting provided by GNSS, the navigation specification qualifies as RNP, however these procedures pre-date PBN, so the chart name has remained as RNAV.

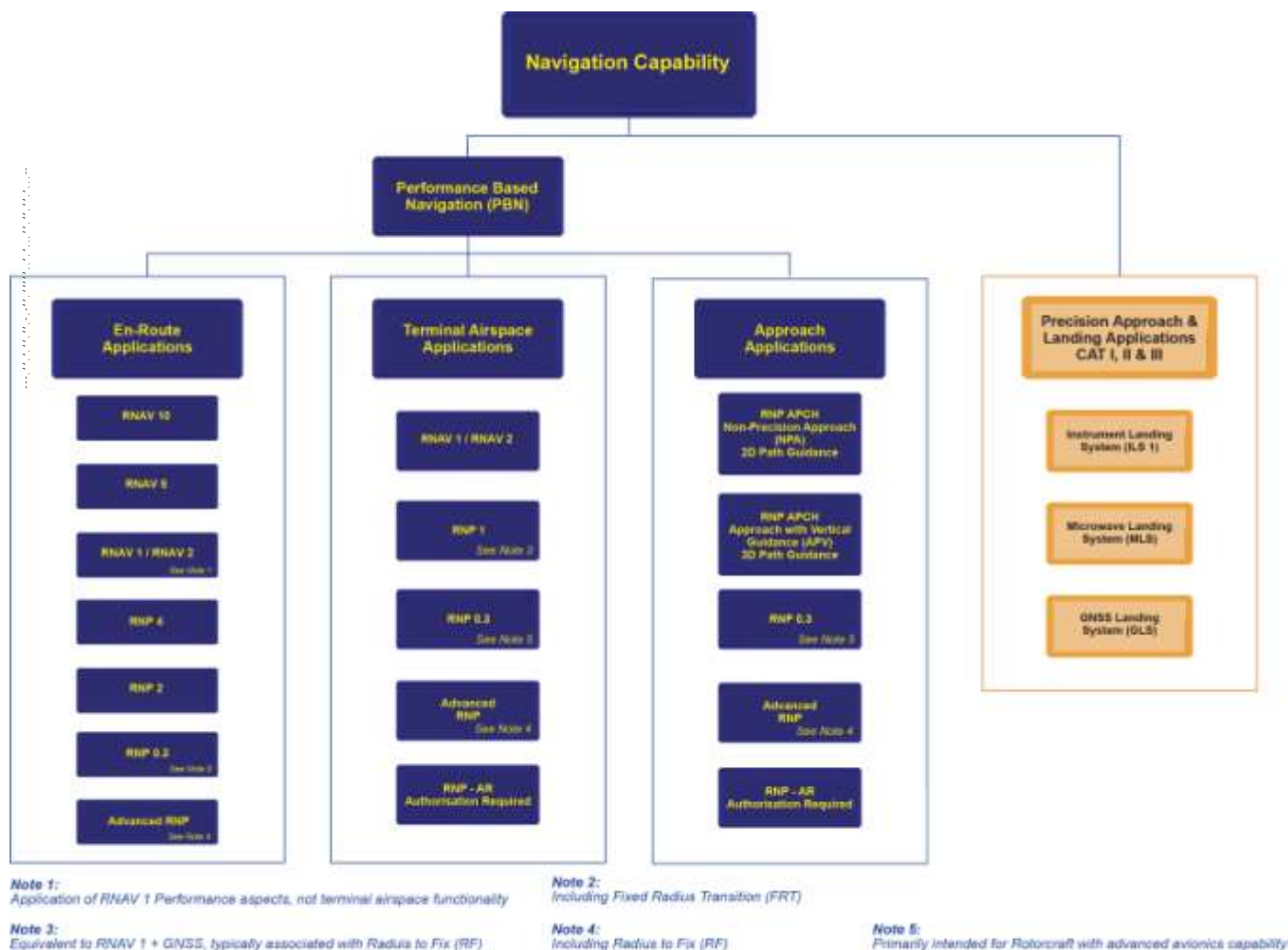
RNP Approach Model



NOTE: APV (Approach with Vertical Guidance) is defined in ICAO Doc 8168 as:

An instrument procedure which utilizes lateral and vertical guidance but does not meet the requirements established for precision approach and landing operations.

Navigation Capability Graphic



Part 3: Technical information, requirements & recommendations

3.1 Human factors

3.1.1 Data Entry and Familiarity with the System

All systems using RNAV principles must compute the aircraft's position velocity and time, in order that steering and other information towards a future position can be presented to the aircraft crew. This is accomplished either by the crew manually entering the co-ordinates of the next position, or by the automatic extraction of these co-ordinates from a database.

Experience of RNAV systems, and Flight FMS in general, has identified the pitfalls of waypoint entry error at the receiver as well as inaccuracies and errors in the database itself. Extensive research by the UK CAA, and experience by other States, has shown that human error, often the result of a lack of familiarity with the airborne equipment, represents the major hazard in operations using RNAV systems. Therefore, it is imperative that pilots understand their system thoroughly and are able to determine whether it is safe to proceed. This requires robust procedures, which check for possible errors in the computer database, monitor continued performance of the RNAV systems and enable pilots to identify and avoid not only their own mistakes but also errors in the information presented to them.

3.1.2 Automation Induced Complacency

Whilst the GPS is an excellent system, it is neither error free nor totally dependable. However, GPS has an excellent record and the continued experience of using such a highly accurate navigation system can lead to an impression of infallibility.

Monitoring of the system for gross errors becomes tedious; as the system appears to do it all for you and the temptation simply to trust the system regardless, becomes powerful. This can result in a form of complacency that leaves the pilot more vulnerable to error and to failure or inaccuracy of the system for whatever reason.

A GPS receiver with RAIM provides some integrity monitoring of position which apparently reduces the requirement for cross checking. However, it cannot alert the pilot to other flight technical or data error. The pilot(s) must continue to monitor data entry, system management, progress against intended flight-path and steering performance against a Course Deviation Indicator (CDI) or Flight Director/Autopilot.

3.1.3 Training and licensing

The advent of RNAV approach operations presents new opportunities for human error at a critical phase of flight. The programming skills required of the crew, and the errors and failure modes of approach-enabled RNAV systems (such as GPS), are different from those associated with the established network of ground-based approach aids. Pilots using any type of GNSS equipment must ensure that they are familiar with and competent in operating that type of equipment, before using it in flight. The wider aviation community generally now accepts that thorough training of pilots in the procedures required for use of these systems is paramount.

Flying an instrument approach procedure in IMC in the UK requires the pilot to hold either an Instrument Rating (IR) or an 'IMC' Rating or IR(R) (Instrument rating (Restricted)). The syllabus of training for these ratings should already include all types of Non-precision Approach (NPA), including Surveillance Radar Approach (SRA), Localiser (LOC) only, VOR and NDB, with and without DME.

When operating under Visual Flight Rules (VFR), all pilots are recommended to obtain training from an appropriately experienced or qualified instructor (see 3.1.5 below) before using any RNAV system, including GPS.

For IFR operations, public and commercial air transport operators are required by the operating regulations and, in the UK, Schedule 9 to the Air Navigation Order (ANO) 2009 to ensure that their pilots have been tested as to their proficiency in using instrument approach-to-land systems of the type in use at the aerodrome of intended landing and any alternate aerodrome.

Private operators are strongly advised to follow suit and engage in a structured training programme before attempting to fly any RNAV approach procedure, including GNSS approaches, and when operating any RNAV system.

UK Flying schools and training organisations are encouraged to develop differences training for RNAV (GNSS) approaches and include this in any IMC or Instrument Rating syllabus as soon as practical. Detailed guidance on training structure and techniques, together with suggested syllabus content is contained in the INSTRUCTORS' GUIDE in Part 5 of this document.

3.1.4 Practice instrument approaches

Pilots are reminded of the requirements of the Rules of the Air Regulations. In the case of practice approaches in Visual Meteorological Conditions (VMC), Rule 24 of the 2007 Rules requires not only that the appropriate air traffic control unit be informed beforehand, but that a competent observer must be carried. Rule 23 requires that if the pilot is flying in simulated instrument flight conditions, a safety pilot must be carried with access to dual controls and adequate vision.