PBN Manual

Including RNP, RNAV and GNSS

A complete reference to PBN and GNSS for General Aviation

non-commercial fixed wing pilots using GNSS for IFR

4th Edition Extensively Revised January 2023 Including BIR

PPL/IR EUROPE

4th Edition (rev 1) Jan 2023

PPL/IR Europe

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(including RNP, RNAV and GNSS)

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http://www.pplir.org

Introduction

- This manual covers the Performance Based Navigation (PBN) theoretical knowledge and ground training for a Europe based Instrument Rated pilot operating single-pilot general aviation aircraft under IFR in Europe
- The focus of the manual is on European single pilots using GNSS in an IFR context. Other technologies are mentioned only for completeness and with little detail.
- Some of the detailed content and reference material is beyond the scope of what is required for pilot training, but may be of interest. Appendices 2,3 and 4 contain information which will be only of interest to those seeking a deeper technical understanding, not required of the average, competent pilot.
- The learning objectives to meet EASA PBN training requirements shown in Appendix 1 refer to the applicable text which meets those objectives. Some of these learning objectives are outside the scope required by a GA fixed wing pilot, but are included, as they could appear in an exam. In those cases we have kept detail to an absolute minimum.
- However, we have not limited ourselves to EASA learning objectives. The intention is to provide a comprehensive PBN manual, practical as well as theoretical.
- For example, we have provided detailed illustrations of departures, arrivals and approaches, with cross referencing between plates and GNSS receiver displays, and these merit close attention. Understanding the relationships in advance might help avoid confusion at times of high workload close to terrain.
- The contents of this manual change regularly as regulatory and technical changes are made. We try to keep it up to date. The latest version is always available in PDF form from the PPL/IR website.

Introduction

- Due to these changes over the years, and variations in interpretation and implementation between regulatory authorities, there remain areas of ambiguity in PBN. We have focussed on ICAO standards and EASA implementation. Thus there may be differences between what is written here and other sources, particularly outside Europe.
- This manual assumes that the reader is an instrument rated pilot or familiar with normal IFR terminology i.e. ‘IAF’, ‘minima’ etc. IFR terminology is used without explanation unless PBN concepts modify non PBN usage.
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- PPL/IR Europe welcomes feedback and questions via its website forum (www.pplir.org). Any person interested in operating aircraft under IFR in Europe is encouraged to join.

Acknowledgements and notes

- Edition 1 was written by Vasa Babic. This Edition has been mostly rewritten by John Shannon and Timothy Nathan to take account of the many changes that have occurred since Edition 1. This 4th addition takes into account changes up to January 2023, and will be revised incrementally as the world moves on
- Errors and omissions are entirely John and Timothy's responsibility
- PPL/IR Europe receives no royalties for this book; the cover price reflects only the costs of printing and distribution. If you find this material valuable, you are asked to:
  - please consider joining and/or donating to PPL/IR Europe (www.pplir.org). This small voluntary organisation serves GA IFR pilots in Europe by publishing and exchanging information to help promote the safety and utility of IFR flight in single-pilot aircraft, and works with regulators in Europe to ensure they have input on the specialised needs of private IFR from a credible and qualified source
  - please also consider joining and supporting your national AOPA. Internationally, AOPA is the only GA representative organisation for private pilots accredited to ICAO, the FAA, EASA and national regulators. IFR regulations are planned and decided upon many years in advance, at a global and regional level. AOPA needs your support to make sure that private IFR operators continue to have practical and cost-effective access to airspace worldwide
- None of the AIP or Jeppesen charts or Garmin screen shots in this manual may be used for navigation purposes

RNP Approaches

Different Types of Approach, and Different Types of Avionics

On the next two pages is a summary of different types of RNP approach and how to fly them; everything that is written on these two pages is explained later in the manual, but if you read nothing else, read these two pages.

There are two kinds of IFR certified GNSS (GPS) receivers:

- TSO-C129() (non-SBAS) receivers, which use only GPS signals (eg GNS430)
- TSO-C146() (SBAS) receivers, which, in addition to the GPS signal, receive a further correction signal that makes them far more accurate. (eg GNS430W, GTN)
- In Europe there are the following RNP approaches:

Type	Annunciation	Description
LNAV	**LNAV** or **APR**	Lateral Navigation with no vertical glidepath
LNAV/VNAV	**L/VNAV**	LNAV-like Lateral Navigation with vertical guidance (less accurate than ILS) *
LPV	**LPV**	Localiser Performance with Vertical guidance (similar to ILS)
LNAV+V	**LNAV+V**	LNAV with advisory vertical guidance (ie the glidepath assists the pilot but is unofficial)

- TSO-C129() receivers can only fly LNAV approaches, and they annunciate **APR** when doing so; the horizontal sensitivity does not increase as the aircraft approaches the threshold.
- TSO-C146() receivers can fly all the approaches; sensitivity does increase as the aircraft approaches the threshold.
- LPV approaches can have minima to 200’ (the same as a Cat 1 ILS).

** See p154 for Baro-VNAV*

Here is a summary of how to fly an RNP approach.

- Brief yourself thoroughly, from either Jepp plates or the AIP, well before commencing the approach. In particular, note the positions of the IAFs, the "cake slice" TAA/MSAs for each sector serving those IAFs and the minima lines available (LPV, LNAV, LNAV/VNAV) and their minima for your approach category.
- If you have a legacy (TSO-C129) navigator, such as a GNS430, check RAIM, either online or on the receiver.
- Determine the IAF which serves your direction of arrival and load the approach from that IAF. As part of the loading process, read the page which shows the waypoint and graphic and check the visual layout of the graphic as well as every waypoint, track and distance, including missed approach and hold against the plate for the correct aircraft approach category.

- Ensure that the CDI is selected to GPS.
- When you are cleared for the approach, route directly to the IAF, either by Activating the approach or by DCT to the IAF, descending to the IAF altitude remaining above the TAA/MSA.
- Follow both the profile and the tracks carefully. If you have SBAS, keep the CDI centralised, even in the turns. If you have HSI without autoslew, turn it to the next track in anticipation.
- Only descend on the profile once the track has turned magenta and the CDI is within half scale deflection.
- Before the FAF, ensure that the expected annunciations (**APR**, **LPV**, **LNAV**, **LNAV+V** or **L/VNAV**, and **GPS**) and that no unexpected ones (**LOI**, **INTEG**) are showing.
- At the FAF ensure that the final approach track goes magenta, the To flag is showing, the Glidepath indicator (if available) and the CDI are centralised and that there are no warnings.
- During the final approach, check regularly for warnings and do not ignore them. Check any altitude restrictions.
- If the annunciator falls back to a lesser specification (eg **LPV** to **LNAV**) above 1000' AAL, reset minima as appropriate and use the distance vs altitude table. If it falls back below 1000' AAL, go around.
- In the missed approach, once past the MAP, unsuspend. Using a TSO-C129() navigator, do not turn before reaching the altitude specified in the MA Procedure.

Contents

Introduction to PBN (Performance Based Navigation)

Before describing PBN, we should start by explaining that PBN only forms part of a systematic way of determining:

- What is to be achieved in an airspace (Airspace Concept)
- How it is to be achieved

An Airspace Concept describes, amongst other things:

- The intended operations within an airspace
- The operational and technical requirements to achieve the intended operations

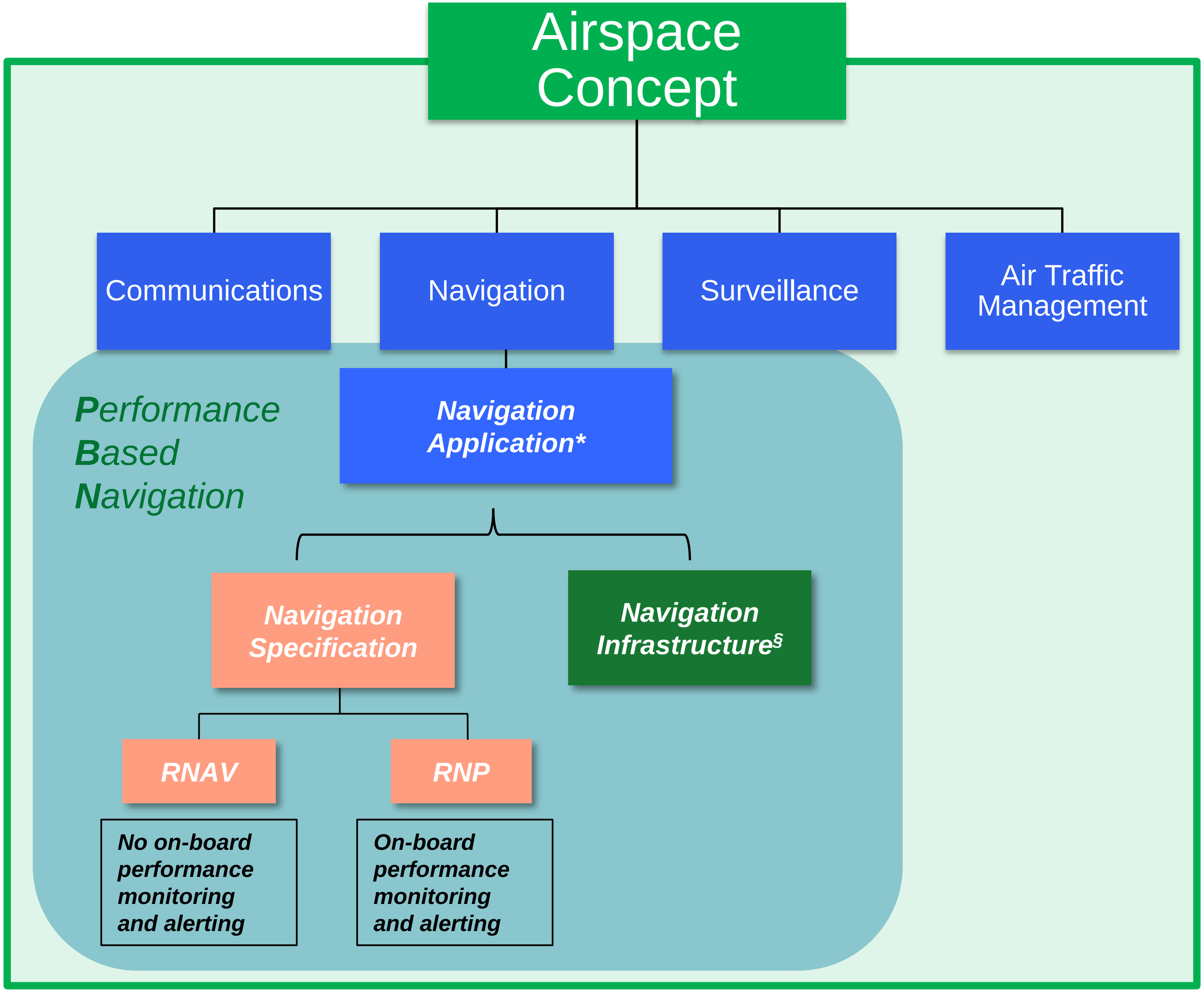
The Airspace Concept includes:

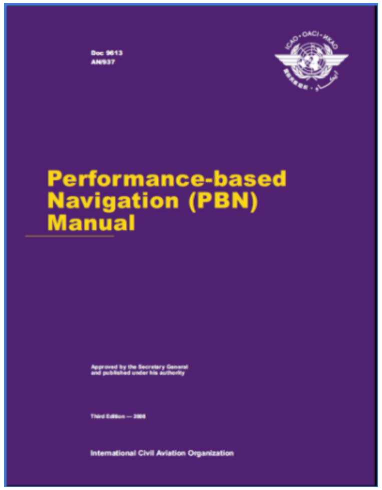
- Communication
- Navigation
- Surveillance
- Air Traffic Management

PBN is only about that part of the Airspace Concept concerned with Area Navigation (RNAV) specifications and infrastructure.

The above is described graphically on the next page.

Introduction to PBN





* Navigation Application includes pilot training and qualification.

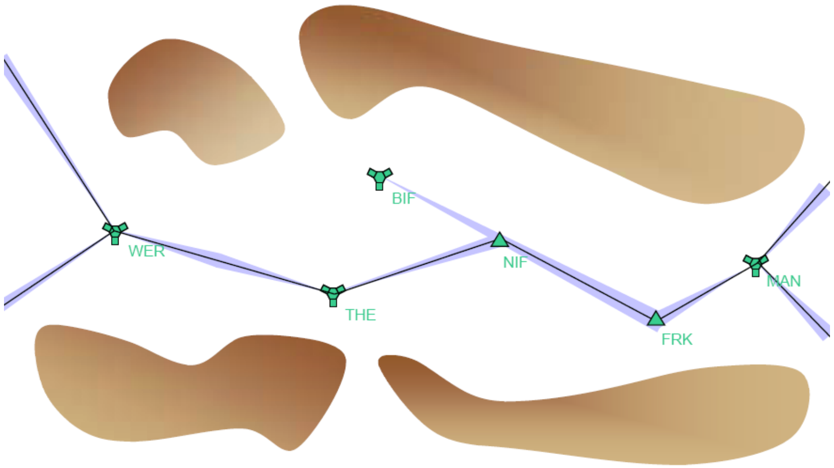
§ RNAV Systems Only

Background to the Development of PBN
1. The Basic Concept of RNAV

PBN was developed out of a requirement to bring order to the airspace structures based on existing RNAV applications.

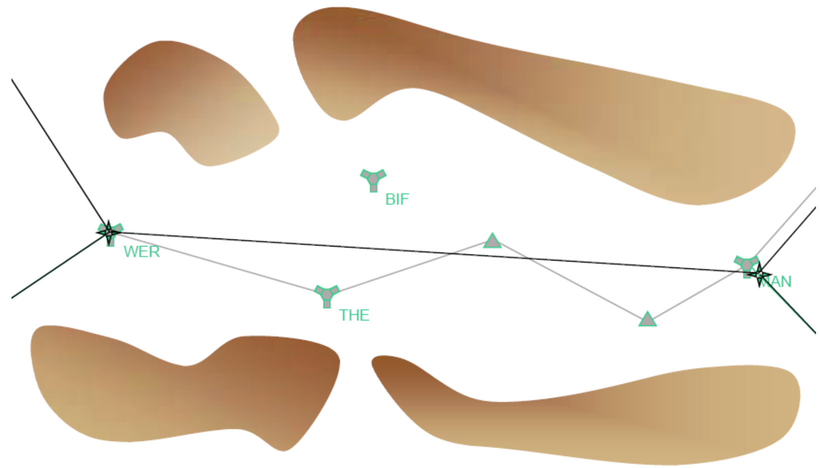
Therefore, a short background to how RNAV systems have evolved will help the reader understand why it has proved necessary to develop PBN.

"Traditional" IFR Navigation



- "Traditional" IFR Navigation relies on aircraft crossing radio beacons and tracking to and from them directly, or via intersects
- This constrains IFR routes and procedures to what is achievable from a limited and expensive infrastructure of ground-based stations

RNAV



- Area Navigation (RNAV) is a method of navigation that permits aircraft to follow IFR routes and procedures based on any desired routing, subject to the system limits of the RNAV technology
- Modern RNAV in general aviation aircraft is based on panel-mounted GNSS. Larger aircraft also use Inertial Reference and DME-DME in multi-sensor Flight Management Systems (FMS), but these technologies are outside the scope of this manual.

Background to the Development of PBN
2. How RNAV was Implemented

Traditional IFR had a single, simple “implementation” which is valid in airspace worldwide using a standard set of aircraft equipment (the VOR, DME, ADF and ILS receivers and instruments) and the standard Instrument Rating pilot qualification.

First-generation RNAV was implemented in much the same way. Aircraft equipped with one of the many kinds of RNAV “box” could fly additional RNAV routes. However, the accuracy and predictability of an aircraft’s flight path was limited by a lack of standardisation

- in navigation equipment accuracy and reliability
- in how route and procedure data was entered, coded, interpreted and displayed
- in how pilots and autopilots would fly turns, intercepts, climbs to a fix and any other “non-straight and level” legs

Modern applications have aimed to increase the usefulness of RNAV by allowing very precise procedure designs that use airspace more efficiently and create more direct routes. This also has the benefit of improving terrain and traffic separation, and providing better noise abatement and fuel-efficient descent management

However, until recently, no consistent way of providing the standards and safeguards needed for accurate and consistent RNAV had emerged, and thus there were a variety of RNAV applications in different regional and national airspace and for different phases of flight (enroute, terminal, approach)

- eg. RNAV 1, RNAV 5 in Europe; MNPS (RNAV 10 or RNP 4) in the North Atlantic.

The PBN Concept
1. The Definition of PBN

The ICAO PBN definition is:

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

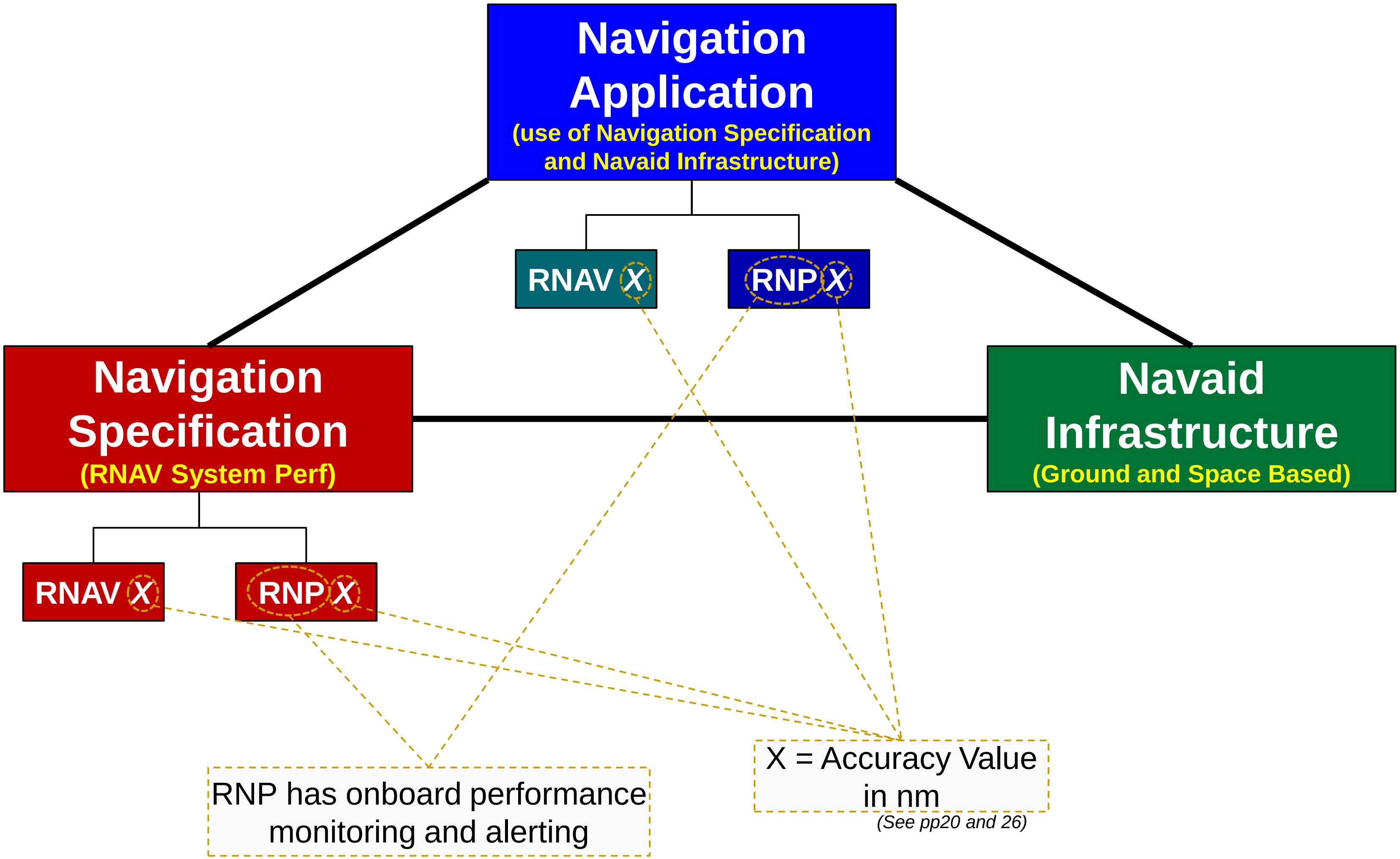
Where:

> *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 (SIS) or that of some other applicable navigation infrastructure has to be considered in order to enable the navigation application.*

Performance Based Navigation has been developed to provide a consistent way of specifying navigational applications on a global basis. Instead of aircraft navigation applications being directly specified in terms of sensors (navigation beacons, navigational receivers and/or waypoints), under PBN, generic navigation requirements and applications are first defined based on the operational performance requirements. As long as the performance requirements are satisfied, it does not matter what sensors are used.

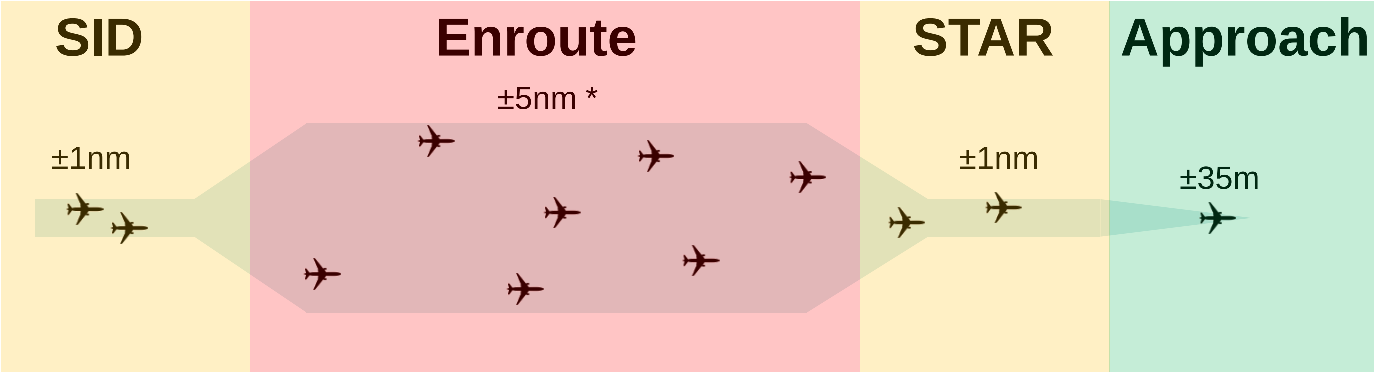
Please note that in ICAO terms, “Navigation Application” includes **pilot training and qualification**. That means that PBN is not just a structure of navigation, but embraces the whole system that results in the aircraft getting from A to B on the desired route.

The PBN Concept
2. Application, Specification and Infrastructure



The PBN Concept
3. Performance and Functionality Requirements

- ‘Performance based navigation is area navigation based on performance requirements for aircraft operating along an ATS route or on an instrument approach procedure or in a designated airspace.’ (ICAO PBN Manual Doc 9613).
- PBN is based on detailed navigation specifications, which contain performance and functionality requirements.

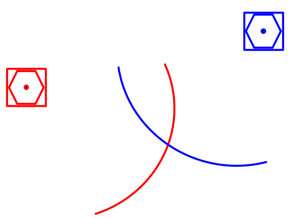


** In Europe. 2nm Elsewhere*

The PBN Concept
4. Technology Independence

- PBN is a shift from sensor based (ie VOR, DME, NDB/ADF, GNSS) to performance based navigation. Generic navigation requirements are defined based on operational requirements and include the contributions of crew, ATC and navigational systems; operators then chose the best mix of available technology and navigation services to satisfy those requirements.
- The underlying technologies and navigation services can change over time without the navigational requirements needing to be revisited, as long as the requisite performance is maintained. That is to say a procedure, such as a SID, STAR or Approach, can be flown using yesterday's, today's or tomorrow's equipment, as long as the required performance is achieved.

DME/DME



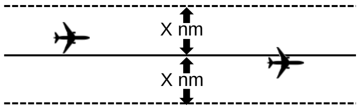
INS

GNSS

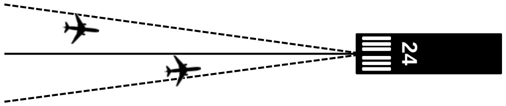
???

- In oceanic/remote, enroute and terminal phases of flight, PBN is limited to operations with linear lateral performance requirements and time constraints. In the approach phases of flight, PBN accommodates both linear and angular laterally guided operations (LNAV) and, for certain approaches, vertical guidance (VNAV).

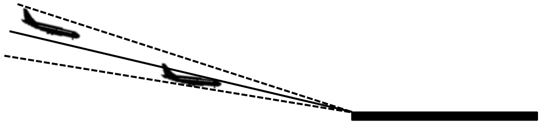
Linear



Angular Lateral

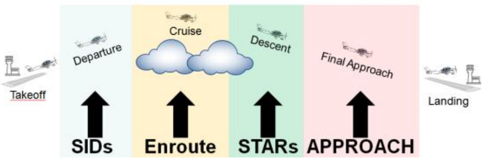


Angular Vertical



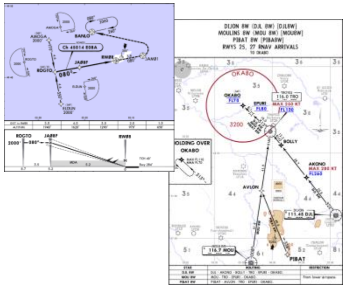
The PBN Concept
5. Specification, Infrastructure and Application

- The **Navigation Specification** prescribes the performance requirements in terms of accuracy, integrity, continuity and functionality 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 an RNP specification or an RNAV specification. An RNP specification includes a requirement for on-board self-contained performance monitoring and alerting 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.

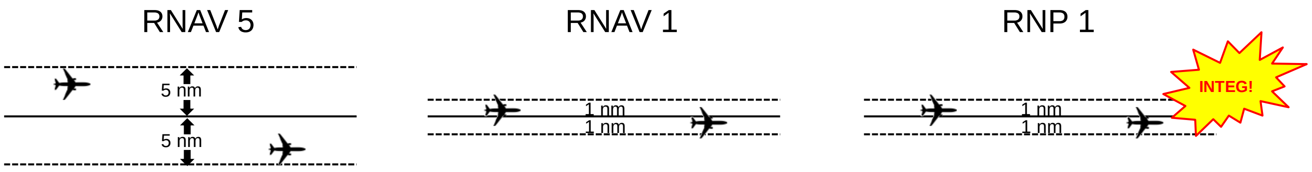


6. An example of a PBN Specification

The components of a PBN Specification in terms of a navaid infrastructure, navigation specification and a navigation application can be difficult to grasp. It is perhaps easiest to explain by way of example:-

- RNAV 1 and 2
  - **Navaid infrastructure**: Radar environment with radio communications, and with GNSS, DME/DME and DME/INS availability.
  - **Navigation specification**: RNAV 1 and RNAV 2 operations are based upon the use of RNAV equipment that automatically determines the aircraft position in the horizontal plane using input from the following types of position sensors – GNSS, DME/DME RNAV or DME/DME/IRU RNAV approved to the RNAV 1 and 2 accuracy requirements.
  - **Navigation application**: The RNAV 1 and 2 specification is applicable to all ATS routes, including enroute, standard instrument departures (SIDs), and standard arrival routes (STARs). It also applies to instrument approach procedures up to the final approach fix.

- Under PBN there are two general classes of specification,
  - **RNAV**, which does not require on-board Performance Monitoring and Alerting
  - **RNP** (Required Navigation Performance), which does.
- RNAV and RNP, as *performance specifications,* are measures of the lateral accuracy in nautical miles, relative to a desired flight path, that an aircraft can be expected to maintain 95% of the total time
  - Referred to as "RNAV X" or "RNP X" where the "X" indicates the lateral accuracy. For example, RNAV 1 means an RNAV specification (no on-board Performance and Alerting required) which has a required accuracy of 1 nautical mile either side of the desired flight path (see also page 26).



  - However, it is important to note that aircraft approved to more stringent accuracy requirements may not necessarily meet some of the functional requirements of the navigation specification having a less stringent accuracy requirement. So being approved for RNAV 1, for example, does not by any means imply an approval for RNAV 10, even though, on the face of it, RNAV 10 is less stringent than RNAV 1.
- Flight crew and air traffic controllers must be aware of the on-board RNAV or RNP system capabilities in order to determine whether the performance of the RNAV or RNP system is appropriate for the specific airspace requirements.

PPL/IR EUROPE

Traditional Procedures	PBN procedures

Traditional Procedures

- Execution is demanding
  - selecting, identing and displaying navaids
  - following track, distance and timing from raw data
  - repeated for each leg
- Management is easy
  - select the right chart and then follow the execution steps

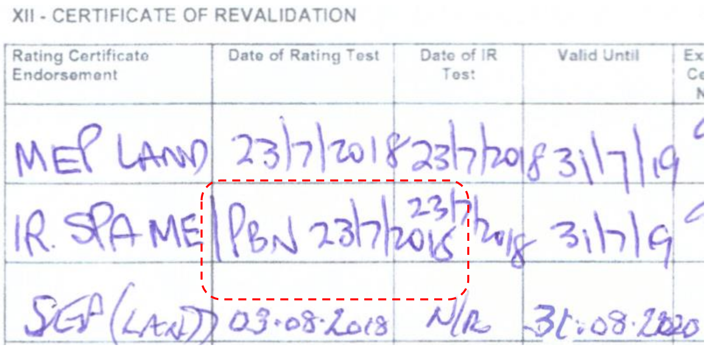
PBN procedures

- Execution is easy
  - following the GNSS guidance from waypoint to waypoint
- Management is more complex
  - valid database, correct procedure loaded and verified
  - RAIM availability checked (if SBAS* not available); GNSS, CDI and Autopilot mode selection
  - avoidance of gross errors and “WIDN?” (what’s it doing now?) confusion with GNSS receivers

The focus of most of PBN training is on the proficient and safe *management* of RNAV flight, as opposed to skills training.

** For SBAS see page 56*

Under the EASA Aircrew Regulation, pilots are required to be qualified to fly PBN procedures. These may be gained as part of the instrument rating training or, for existing instrument rated pilots, the revalidation or renewal process.



XII - CERTIFICATE OF REVALIDATION

Rating Certificate Endorsement	Date of Rating Test	Date of IR Test	Valid Until
MEP LAND	23/7/2018	23/7/2018	31/7/19
IR. SPA ME	PBN 23/7/2018	23/7/2018	31/7/19
SEP (LAND)	03.08.2018	N/R	31.08.2020

This process consists of a theoretical and practical element. The precise mechanism to gain the privileges varies between States, but generally the theoretical element may be completed by passing an exam or, in some States, verbally by an examiner during a instrument proficiency check. The practical element is performed as part of the instrument rating test or proficiency check, which must include one approach based on a PBN specification. This would normally be an RNP approach, which can be either a 2D or 3D Operation (ie without or with vertical guidance (Glidepath)). The UK CAA has said that it is not intending to require a PBN endorsement for IR(R) holders.

Provided this process is completed, there are no operational approval requirements for normal GA PBN operations.

PBN Navigation Specification by Flight Phase
1. Introduction

On page 24, we lay out firstly the navigation specifications that you, as a European GA Pilot using GNSS, are likely to encounter, and followed by, on pp 25-26, a graphic depiction and a table of all the ICAO approved capabilities.

You should understand the former for practical purposes, the latter is for completeness and *could* be asked about in a PBN examination.

Note from the table on page 24 that legacy technologies do not form part of PBN, but are still used as approved navigational aids.

PBN Navigation Specification by Flight Phase

2. Specs Normally Applicable to GA in Europe

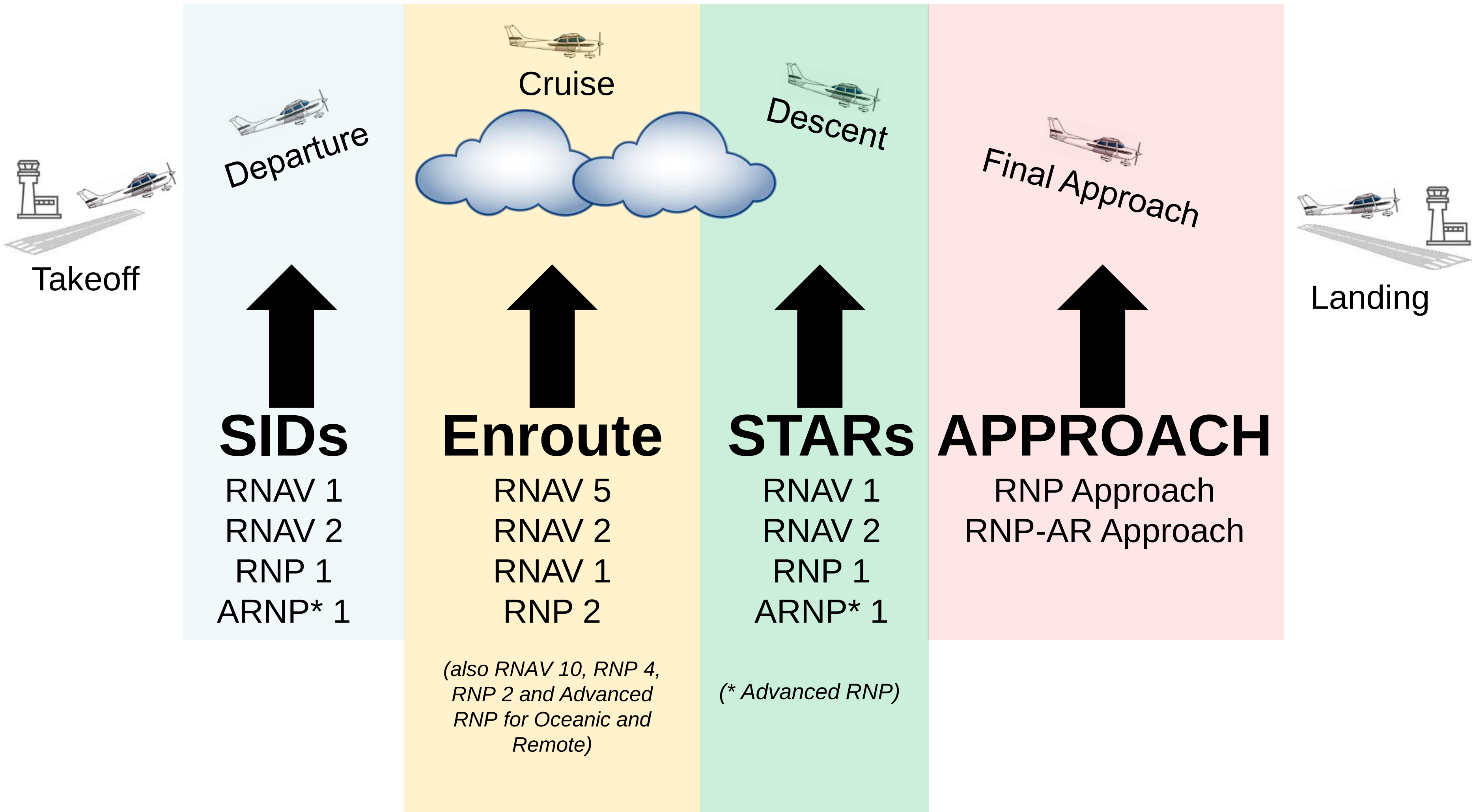
RNAV

RNP

	Enroute Airspace	Terminal Airspace	Approach
Legacy Navigation	VOR/NDB/DME Radar	VOR/NDB/DME Radar	VOR/NDB/DME ILS/DME/MLS Radar
***P**erformance **B**ased **N**avigation*	RNAV 5 RNAV 2	RNAV 5 RNAV 1 RNP 1	RNP APCH

PBN Navigation Specification by Flight Phase

3. Complete List Graphic



PBN Navigation Specification by Flight Phase

4. Complete List

- Below is a complete list of PBN navigation specifications, flight phases and RNP accuracy limits in nm.
- The GA pilot will normally only encounter those specifications on page 24, but they are all included below for completeness (see Learning Objectives in Appendix 1).

Navigation Specification	Flight Phase							
	Enroute Oceanic Remote	Enroute Continental	ARR	Approach				DEP
				Initial	Intermediate	Final	Missed	
RNAV10 (RNP10)	10							
RNAV 5		5	5					
RNAV 2		2	2					2
RNAV 1		1	1	1	1		1	1
RNP 4	4							
RNP 2	2	2						
RNP1			1	1	1		1	1
Advanced RNP	2	2 or 1	1	1	1	0.3	1	1
RNP APCH				1	1	0.3 – 0.1§	1	
RNP AR APCH				1 - 0.1	1 - 0.1	0.3 – 0.1§	1 - 0.1	
RNP 0.3*		0.3	0.3	0.3	0.3		0.3	0.3

** RNP 0.3 is a helicopter specification*

§ Different angular performance requirements are applicable to LPV

PBN Navigation Specification by Flight Phase
5. Additional Functionalities

PPL/IR EUROPE

The table below lists additional PBN functionalities. Most of these are unlikely to affect European GA pilots. However, RF is being introduced to procedures we fly. Usually there is an alternative available, but the alternative may lead to ATC delays. Some current GNSS receivers are capable of providing approved RF guidance. For example, the GTN supports RF legs, but only in an approved installation, requiring, for example, an EHSI.

Navigation Specification	Additional Functionalities (Required or Optional)			
	RF	FRT	TOAC	Baro VNAV
RNAV10 (RNP10)				
RNAV 5				
RNAV 2				
RNAV 1				O
RNP 4		O		
RNP 2		O		
RNP1	O			O
Advanced RNP	R	O	O	O
RNP APCH	O			O
RNP AR APCH	*Specific Requirements for RF & VNAV*			
RNP 0.3	O			O

- **RF** Radius to Fix: Constant Radius Arc Leg defines a constant radius turn between two database fixes, lines tangent to the arc and a centre fix
- **FRT** The fixed radius transition is intended to be used in enroute procedures. These turns have two possible radii, 22.5 nm for high altitude routes (above FL195) and 15 nm for low altitude routes. Using such path elements in an RNAV route enables improvement in airspace usage through closely spaced parallel routes.
- **TOAC** Time Of Arrival Control enables an aircraft to reach a waypoint within X number of seconds of a specific time.
- **Baro-VNAV** computes vertical navigation based on barometric pressure, rather than on GPS-based SBAS altitude. (See Appendix 1 page 154)
- (RNP AR APCH See Appendix 1, Page 159)

R	Required
O	Optional

Further notes on PBN Specifications
1. Enroute Remote and Oceanic Navigation Applications

PPL/IR EUROPE

- Apart from RNAV 5 and RNAV 10, all waypoints, procedures or approaches must be accessed from the receiver database.
- Not all the specifications below are found in EU continental airspace.
- **Enroute Remote and Oceanic navigation applications**
  - **RNAV 10 (RNP 10)**
    - RNAV 10 requires that aircraft operating in oceanic and remote areas be equipped with at least two independent and serviceable Long Range Navigation Systems comprising an INS, an IRS FMS or a GNSS, with an integrity such that the navigation system does not provide an unacceptable probability of misleading information. Dual INS based systems are subject to a time limit (usually about 6 hours) between being updated from either a ground based signal (VOR/DME) or GNSS. Dual GNSS receivers are not subject to a time limit as long as it is not predicted that they will lose Fault Detection and Exclusion for more than 36 minutes.
  - **RNP 4**
    - For RNP 4 operations in oceanic or remote airspace, at least two fully serviceable independent long-range navigation systems (LRNSs), with integrity such that the navigation system does not provide misleading information, must be fitted to the aircraft and form part of the basis upon which RNP 4 operational approval is granted. GNSS must be used and can be used as either a stand-alone navigation system or as one of the sensors in a multi-sensor system (i.e. with an Inertial Navigation System). Fault Detection and Exclusion is required for the GNSS receiver.
  - **RNP 2**
    - RNP 2 is primarily intended for a diverse set of enroute applications; particularly in geographic areas with little or no ground NAVAID infrastructure, limited or no ATS surveillance, and low to medium density traffic. Use of RNP 2 in continental applications requires a lower continuity requirement than use in oceanic/remote applications. In the latter application, the traffic is primarily transport category aircraft operating at high altitude; whereas, continental applications may include a significant percentage of lower altitude general aviation aircraft.
    - The RNP 2 specification is based upon GNSS and should not be used in areas of known GNSS signal interference. GNSS Fault Detection is required.

Further Notes on PBN Specifications
2. Enroute and Terminal Navigation Applications

- **RNAV 5**
  - While primarily addressing requirements of RNAV operation in an ATS surveillance environment, RNAV 5 implementation has occasionally occurred in areas where there is no ATS surveillance. This has required an increase in route spacing to meet the target level of safety.
  - RNAV 5 can be based on VOR/DME RNAV equipment or GNSS receivers.
  - The RNAV 5 specification does not require an alert to the pilot in the event of excessive navigation errors. Since the specification does not require the carriage of dual RNAV systems, the potential for loss of RNAV capability requires an alternative navigation source.
  - User defined Waypoints can be input manually. Due to the limitations of the specification, RNAV 5 is not suitable for IFR navigation below enroute or terminal safety altitudes.
- **RNAV 1 and RNAV 2**
  - The RNAV 1 and 2 specification is applicable to all ATS routes, including enroute, standard instrument departures (SIDs), and standard arrival routes (STARS). It also applies to instrument approach procedures up to the final approach fix.
  - The RNAV 1 and 2 specification is primarily developed for RNAV operations in a radar environment (for SIDs, radar coverage is expected prior to the first RNAV track change). RNAV 1 and RNAV 2 may be used in a non-radar environment but not normally below MEA or MSA, as applicable. If RNAV 1 and 2 are used in a radar environment below minimum vectoring altitude (MVA) or below MEA or MSA in a non-radar environment, the implementing State must ensure appropriate system safety and take account of the lack of on-board performance monitoring and alerting.
  - RNAV 1 and 2 for general aviation is usually based on the availability of one GNSS receiver, although DME/DME RNAV systems and INS are acceptable as long as they can achieve the required accuracy.

Further Notes on PBN Specifications
3. RNP 1 and Vertical Navigation

- **RNP 1**
  - The RNP 1 specification is intended for connecting routes between the enroute structure and terminal airspace (TMA) with no or limited ATS surveillance, and with low to medium density traffic.
  - At present, the RNP 1 specification can only be met by GNSS; only one GNSS receiver is required. RNP 1 shall not be used in areas of known navigation signal (GNSS) interference
  - In the event of a predicted, continuous loss of appropriate level of fault detection of more than five minutes for any part of the RNP 1 operation, the flight planning should be revised (e.g. delaying the departure or planning a different departure procedure).
  - RNP 1 can be used, when authorised, in a non-radar environment below MEAs or MSAs up to the final approach fix.

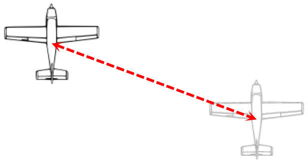
- **Vertical Navigation**
  - Unlike Lateral Navigation, there is no concept of RNP in Vertical Navigation (VNAV). At the moment, vertical navigation is dependent on Barometric system performance and the sensitivities that apply, including the effects of pressure changes and Density Altitude. There is no vertical equivalent to the lateral Onboard Performance Monitoring and Alerting (OBPMA) described in ICAO Doc 9613, PBN Manual.
  - ICAO distinguishes between ‘Approved VNAV’ as opposed to the application of VNAV to procedures where VNAV is not required, referred to as ‘Advisory VNAV’. The former is required in support of instrument approach procedures (LPV) for use in the Final Approach Segment, whereas advisory vertical guidance is provided by the aircraft’s avionics and its use is left to the discretion of the flight crew.

Further Notes on PBN Specifications
4. Fix Substitution and Overlay Approaches

- **Fix Substitution**
  - GNSS can be used to substitute for VOR, NDB, DME/TACAN (including for DME arcs), except for the final approach.
  - The ground based aid need not be operative and airborne equipment need not be installed, or, if installed, need not be operative.
  - If the overlay procedure (SID, STAR, IAP, MAP) can be loaded from the database, it may be used in place of conventional navigational equipment, except on final approach where only DME substitution is permitted.
  - Sometimes the AIP or charts may indicate that fix substitution is not authorised
  - Particular attention should be paid to:
    - when a DME offset is used (eg zero range to a threshold)
    - CDI scaling (full scale deflection and sensitivity may not be the same under fix substitution)
    - Ensuring that the correct aid is selected as multiple radio aids often share the same identifier

RNP Performance Requirements
1. The Main Navigation Performance Criteria

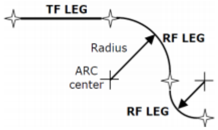
- There are four main navigation performance criteria:



1. **Accuracy** is the conformance of the true position and the required position.
2. **Integrity** is a measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid alerts to the user.

INTEG

3. **Continuity** is the capability of the system to perform its function without unscheduled interruptions during the intended operation



4. **Functionality** - The detailed capability of the navigation system (such as the execution of leg transitions, parallel offset capabilities, holding patterns, navigation databases) required to meet the airspace concept

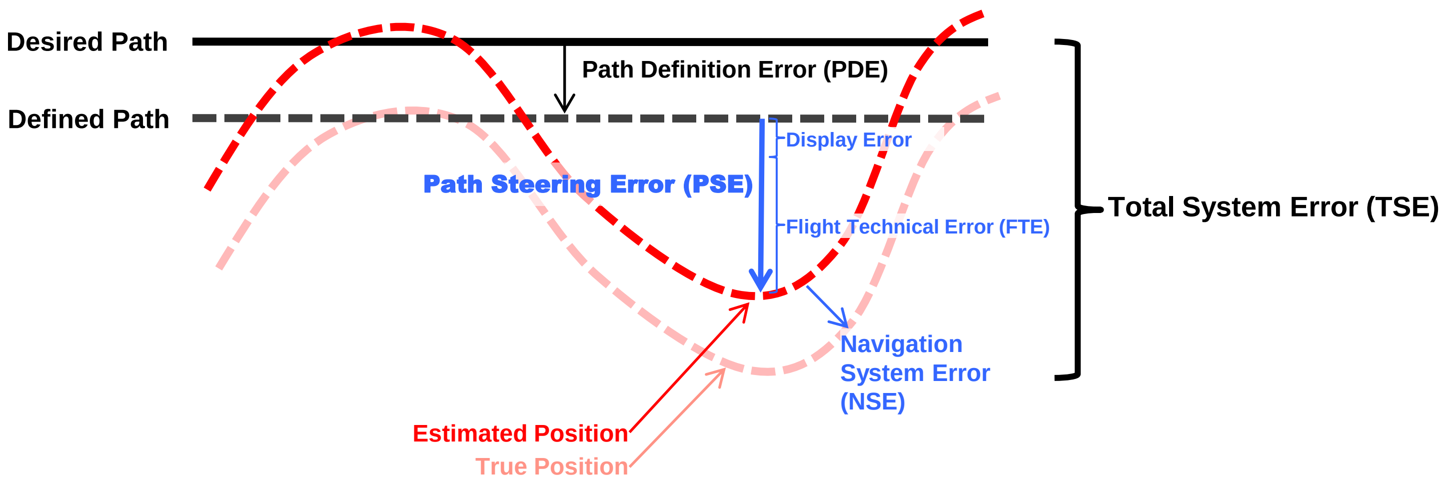
- The key requirement of RNP X is an <u>accuracy</u> specification expressed as a Total System Error (TSE) of X nm or less for more than 95% of the total flight time

Total System Error (TSE) is the sum of

- **Path Definition Error (PDE) -** the difference between the path intended by the procedure designer and the path the aircraft is guided along as a result of **database coding and navigator processing**
- **Path Steering Error (PSE)** - the sum of **display error** in Nav systems and **Flight Technical Error (FTE);** ie. the **errors in manual flight by pilots or autopilot performance** in following a desired path. FTE includes reaction times and wind/turbulence induced errors, it does not include human "conceptual" errors eg. selecting the wrong procedure, waypoint or autopilot mode, or simply turning in the wrong direction
- **Navigation System Error (NSE)** - the combination of **navigation system/sensor (GNSS) error** and **computation error** (GNSS software). NSE is expressed as a 95% confidence radius, called the Estimate of Position Uncertainty (EPU) or Actual Navigation Performance (ANP). NSE is sometimes also called Estimated Position Error (EPE)

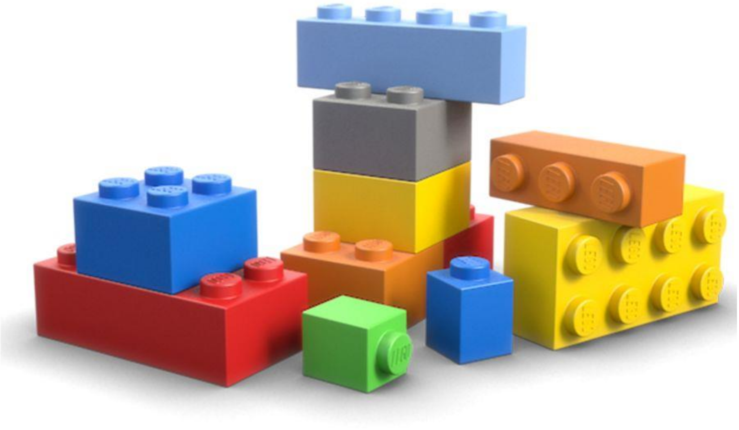
The navigation system compares *Actual* Navigation Performance with the *Required* Navigation Performance (RNP) for the phase of flight and annunciates if the RNP is not met.

In practice, the Path Definition and Navigation System Errors are negligible, **the key concerns for the GA pilot are FTE and the human factor errors in selecting RNAV procedures**, using GNSS units, interpreting guidance and in manual flying or operating the autopilot



Path-Terminators
1. Introduction

- IFR routes and procedures are designed using standardised specifications and criteria (ICAO PANS-OPS in Europe.)
- Instrument procedures have always been published in chart and text form. Since the 1970s, the ARINC 424 standard has also been used to codify IFR procedures, so they can be stored and managed as records in electronic databases.
- A key concept in ARINC 424 is that of the "Path-Terminator" – the definition of which is a specific way of defining a leg or segment of an IFR procedure, based on a set of standard components that define the flight *path* along the leg, and the *terminator* or end-point of the leg
  - It might be helpful to think of the Path Terminators as Lego-like building blocks, from which the designers must create procedures. There are simply no other tools in the box. So if the procedure cannot be built out of the PTs, it cannot be coded into the database. This is one reason why some legacy procedures are not in the database.

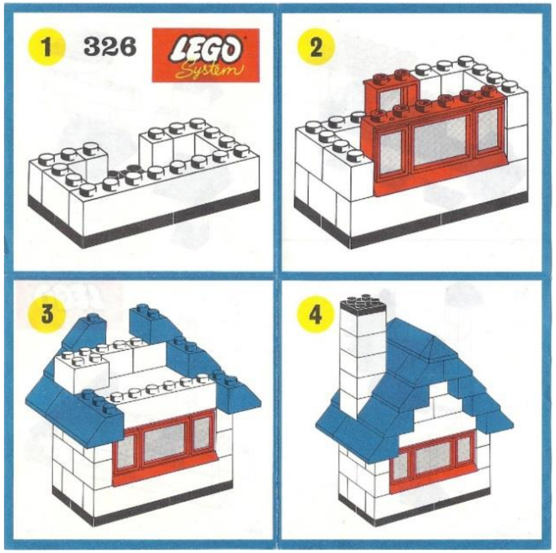


Path-Terminators
2. Building Blocks

- Different combinations of Path types (eg. a Heading or a Track) and Terminator types (eg. a radio beacon, RNAV waypoint or DME arc) are used to define 23 different “Path-Terminator” leg types
  - these 23 Path-Terminator types are, in effect, the “periodic table” of IFR procedure design and codification

- When a Departure, Arrival or Approach procedure is loaded, the flight plan will include each of the path-terminators that make up the procedure.

- Some receivers do not support all the leg types used at the start and end of RNAV procedures. For example, in some earlier receivers (eg Garmin GNS530/430), an enroute flight plan consists only of one leg type: the basic “Track (from Fix) to Fix” (TF) between each of the waypoints entered.
  - As a result, in such receivers, in a legacy procedure, the outbound and inbound tracks are shown, but the base turn joining the two cannot be coded and therefore is not displayed.



Path-Terminators

3. ARINC 424 Path-Terminator leg types

IF leg type

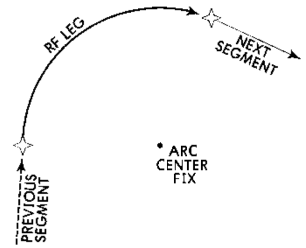
- The Initial Fix Leg defines a database fix as a point in space
- It is only required to define the beginning of a route or procedure

TF leg type

- Track to a Fix defines a great circle track over ground between two known databases fixes
- Preferred type for straight legs

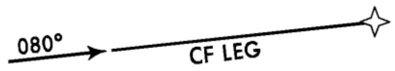
RF leg type

- Constant Radius Arc Leg defines a constant radius turn between two database fixes, lines tangent to the arc and a centre fix
- **Optional in Basic RNP, requires AFM approval (GTN + EHSI only)**



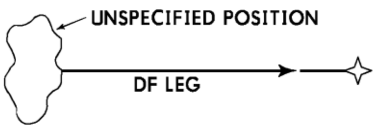
CF leg type

- Course to a Fix Leg defines a specified course to a specific database fix
- TF legs preferred over CF to avoid magnetic variation issues



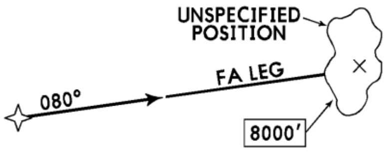
DF leg type

- Direct to a Fix Leg defines an unspecified track starting from an undefined position to a specified fix



FA leg type

- Fix to an Altitude Leg defines a specified track over ground from a database fix to a specified altitude at an unspecified position

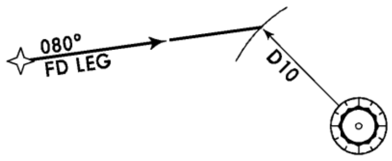


FC leg type

- Track from a Fix to a Distance Leg defines a specified track over ground from a database fix for a specific distance

FD leg type

- Track from a Fix to a DME Distance Leg defines a specific track from a database fix to a specific DME Distance from a DME Navaid

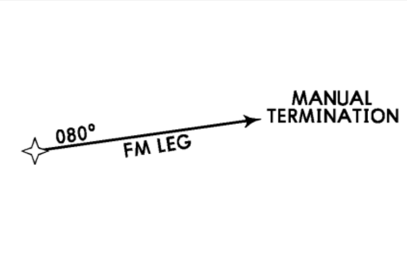


Path-Terminators

4. ARINC 424 Path-Terminator leg types

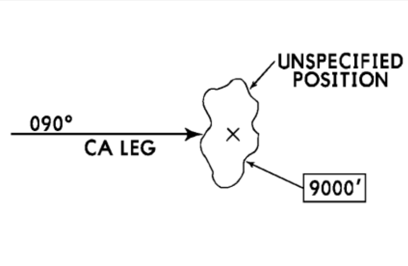
FM leg type

- From a Fix to a Manual termination Leg defines a specified track over ground from a database fix until Manual termination of the leg



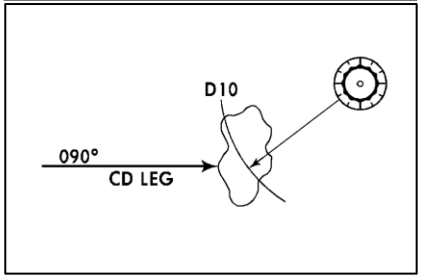
CA leg type

- Course to an Altitude Leg defines a specified course to a specific altitude at an unspecified position



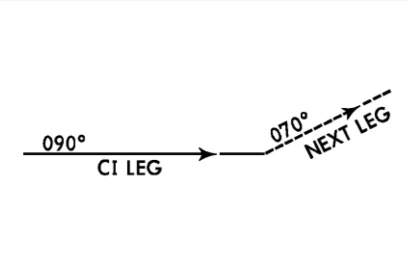
CD leg type

- Course to a DME Distance Leg defines a specified course to a specific DME Distance which is from a specific database DME Navaid



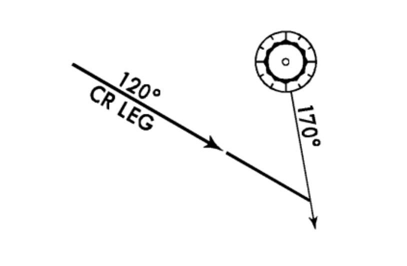
CI leg type

- Course to an Intercept Leg defines a specified course to intercept a subsequent leg



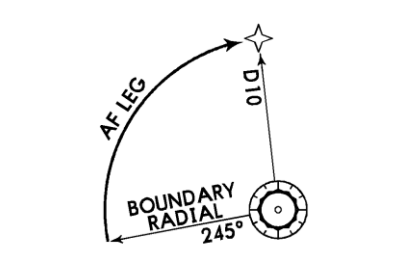
CR leg type

- Course to a Radial termination Leg defines a course to a specified Radial from a specific database VOR Navaid



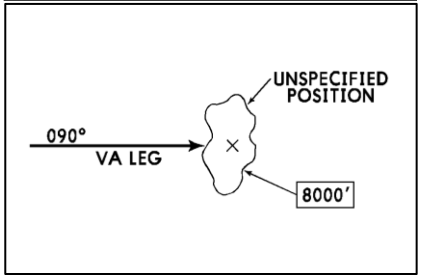
AF leg type

- Arc to a Fix Leg defines a track over ground at specified constant distance from a database DME Navaid



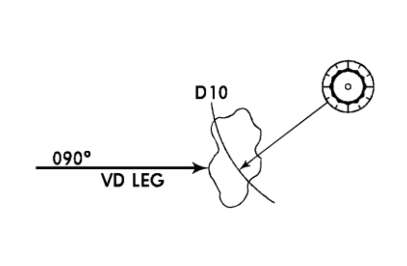
VA leg type

- Heading to an Altitude termination Leg defines a specified heading to a specific Altitude termination at an unspecified position



VD leg type

- Heading to a DME Distance termination Leg defines a specified heading terminating at a specified DME Distance from a specific database DME Navaid

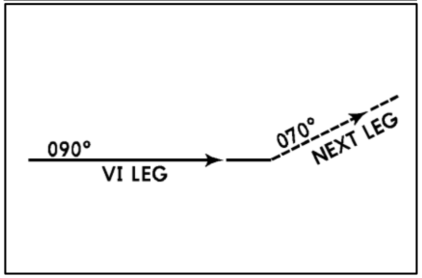


Path-Terminators

5. ARINC 424 Path-Terminator leg types

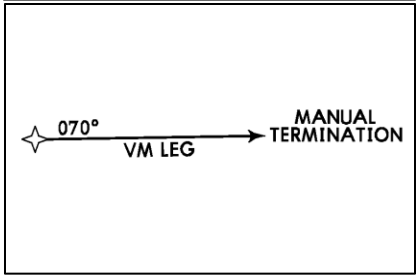
VI leg type

- Heading to an Intercept Leg defines a specified heading to intercept the subsequent leg at an unspecified position



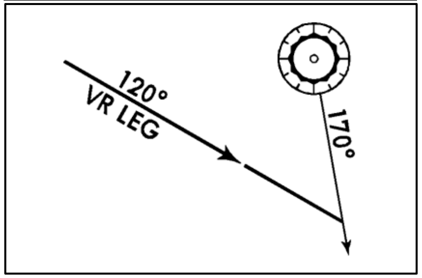
VM leg type

- Heading to a Manual termination Leg defines a specified heading until a Manual termination



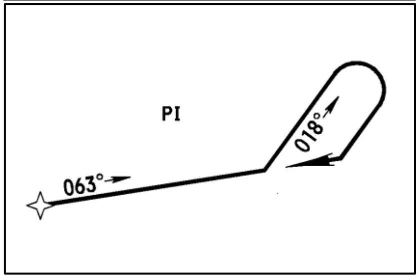
VR leg type

- Heading to a Radial termination Leg defines a specified heading to a specified radial from a specific database VOR Navaid



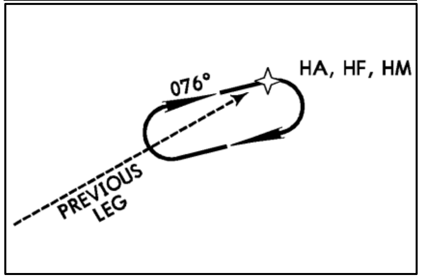
PI leg type

- Procedure Turn leg defines a course reversal starting at a specific fix, includes Outbound Leg followed by 180 degree turn to intercept the next leg



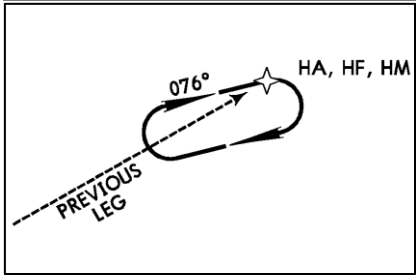
HA leg type

- HA leg defines racetrack pattern or course reversals at a specified database fix terminating at an altitude



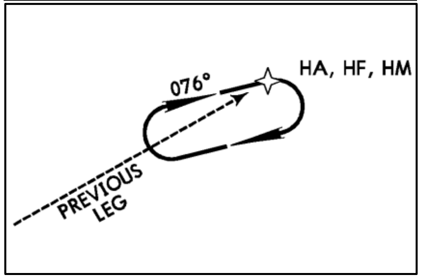
HF leg type

- HF leg defines racetrack pattern or course reversals at a specified database fix terminating at the fix after a single pattern



HM leg type

- HM leg defines racetrack pattern or course reversals at a specified database fix with a manual termination



Path-Terminators
6. The ARINC 424 “periodic table” of Path-Terminator Legs

Paths

Terminators

	Fix to	Track from fix to	Course to	Heading to	Direct to	Racetrack	DME Arc to	Radius to fix
Fix	**IF**	**TF**	**CF**		**DF**	**HF**	**AF**	**RF**
Altitude *		**FA**	**CA**	**VA**		**HA**		
Manual Termination §		**FM**		**VM**		**HM**		
Distance		**FC**						
DME Distance		**FD**	**CD**	**VD**				
Intercept			**CI**	**VI**				
Radial			**CR**	**VR**				
Procedure Turn	**PI**							

Each leg type has a two letter name based on the path and terminator combination

* Path terminators ending at an altitude do not terminate at a specific geographical point and that can result in disorientation. This particularly applies to missed approaches, where the first terminator ends at an altitude. This is represented on the GNSS map as a point, because the designers have no other choice, but in reality the leg need not be flown to that point once the altitude is achieved.

§ Manual termination means that the pilot is required to intervene at the terminator. For example changing to radar vectors.

Path-Terminators
7. Altitude Restriction Coding

- ARINC 424 provides for the encoding of altitude restrictions published in IFR procedure charts and this feature is implemented in modern Flight Management Systems
- Altitude restrictions are part of path-terminator records, or the waypoint associated with a path-terminator.
- This data is generally not implemented in panel-mount GNSS units, or the integrated ‘glass cockpits’ currently fitted to GA aircraft, except for the altitude terminator of the CA, VA or FA leg types (course, heading and track to altitude respectively). For SBAS approved receivers FA leg types are used for defining the altitude at which a turn can be commenced to the missed approach holding point. For non-SBAS receivers it is important not to unsuspend waypoint progression after a missed approach until you have reached the initial turning altitude required
- A brief description of the coding is provided below; however, any further detail is beyond the scope of this book.

Altitude Restrictions

- Altitude restrictions are usually applied at waypoints, although ARINC 424 provides a number of different ways they can be coded.
- The altitude field will designate whether a waypoint should be crossed “at”, “at or above” or “at or below” or “between” specified altitudes or flight levels.
- **If a published departure requires a turn greater than 15° from the runway heading after take-off, without an altitude specified before the turn, the GNSS database will generally include a CA, VA, or FA on the runway heading to an altitude of 400 feet (or as specified by source) as the first leg of the departure**
- Conditional altitudes (eg. turn at 2000’ or 4DME whichever is later) are treated in different way by different FMS types.
- Altitude restrictions that only apply during specific times are not coded

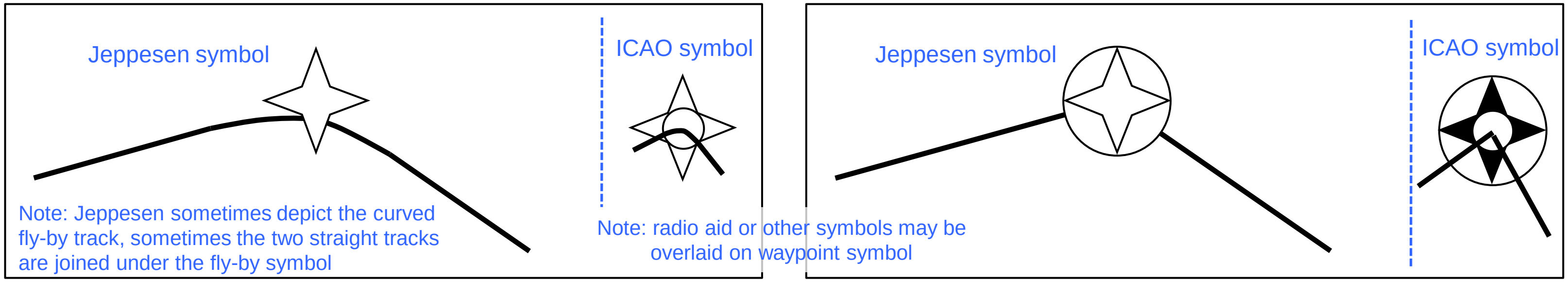
Speed Restrictions

- In departures, a speed limit is applied <u>backwards</u> from the terminator of the leg on which the limit is encoded to the start of the procedure, or to the first prior speed limit
- In arrivals, a speed limit is applied <u>forwards</u> from the speed limit point to the end of arrival, unless a subsequent speed limit is encoded
- Speed restrictions that only apply during specific times are not coded

Fly-By and Fly-Over RNAV waypoints
1. Definition

- The “fix” in Path-Terminator legs is either based on radio aids or it is an RNAV waypoint. ICAO define a waypoint as “*a specified geographical location used to define an RNAV route or the flight path of an aircraft employing RNAV*”
- There are 2 kinds of RNAV waypoint: Fly-By and Fly Over

Fly-By waypoint	Fly-Over waypoint



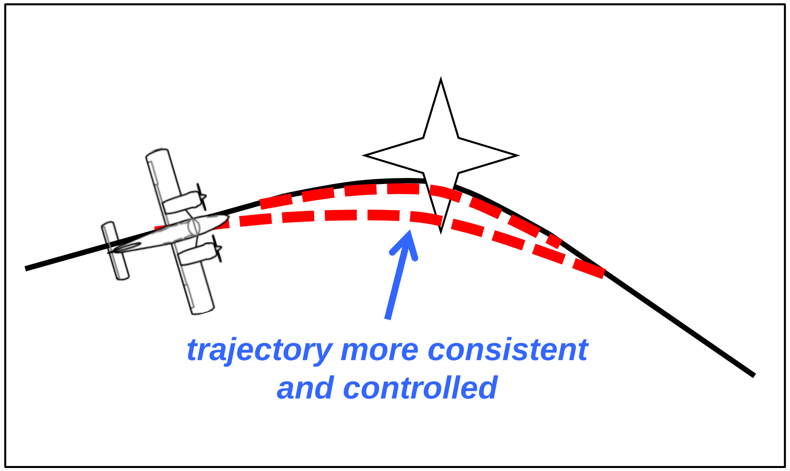
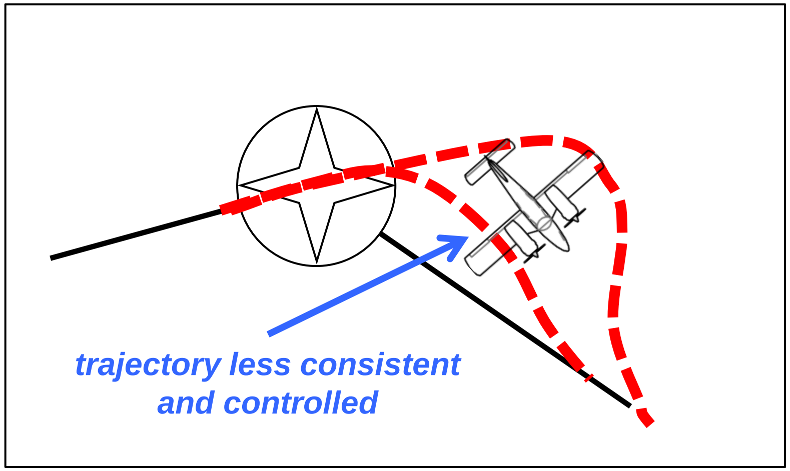
Fly-By waypoint

- A waypoint which requires turn anticipation (start of turn before the waypoint) to allow tangential interception of the next segment of a route or procedure
- The aircraft navigation system calculates the start of the turn onto the next route leg before the waypoint
- This is the preferred type of waypoint for all Area Navigation (RNAV) Standard Instrument Departures/Standard Instrument Arrivals (SIDs/STARs)

Fly-Over waypoint

- A waypoint at which a turn is initiated
- The aircraft starts to turn onto the next route leg as it passes over the waypoint
- Fly-Over waypoints are most often used as the first fix in the missed approach procedure and in depicting traditional procedures designed around overflying radio aid fixes
- RNAV Procedure designers are increasingly avoiding the use of Fly-Over waypoints

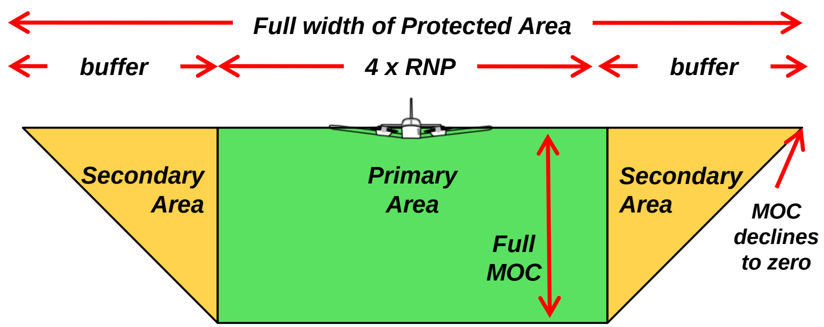
Fly-By and Fly-Over RNAV waypoints
2. Aircraft Trajectory

Fly-By	Fly-Over
	
• Turn is a Rate 1 curved path tangential to both the inbound and outbound track	• Turn consists of roll-in, Rate 1 turn, roll-out and intercept elements

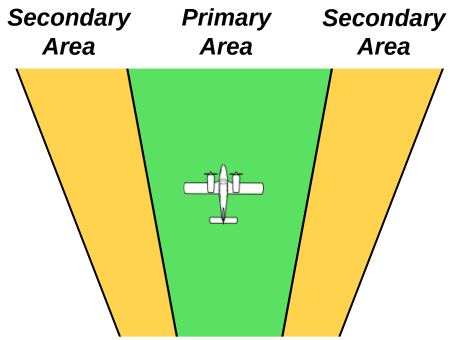
- Both types of trajectory are subject to variations in wind, aircraft speed and bank angle, navigation system logic and Pilot or Autopilot performance. However, flight paths resulting from Fly-By turns are, in practice, much more consistent and predictable, and thus preferred in RNAV procedure design (eg. they require a smaller protected area)
- Although the Fly-By turn is a simple concept, it is important for the pilot to understand exactly how turns are annunciated and displayed on the receiver and how lateral guidance is provided to the autopilot in Nav or Roll-Steer (GPSS) modes, in order to consistently and accurately achieve the tangential path the procedure requires
- Fly over waypoints are most commonly encountered at Missed Approach Points

- The key design criteria is to provide safe obstacle and terrain clearance whilst an aircraft is flown in accordance with the published procedure
  - *horizontally*, within a Protected Area,
  - *vertically*, with a specified Minimum Obstacle Clearance (MOC)
- Both are divided into Primary and Secondary areas
- Full MOC is only provided in the Primary area and reduces rapidly to zero in the secondary area

Profile of Protected Area



Plan View of Protected Area



- The width of the buffer varies depending upon the leg and, on final approach, the type of approach.
- The low minima that can be achieved using RNP approaches is based on the very accurate navigation that RNP provides.
- It is therefore necessary for the procedure to be flown precisely to maintain the MOC provided by the Primary Area.
- This applies equally to the Missed Approach.

2. Aircraft Approach Categories

- Aircraft speed is the key criteria for the design of any manoeuvring elements of an instrument procedure (turns, procedure turns, holds, missed approaches, landing and circling minima)

- Procedures are designed around 5 aircraft categories, based on a notional approach speed of 1.3x the stalling speed in the landing configuration at maximum landing mass (V_{at})

Aircraft Category	V_{at}	Initial Approach speeds	Final Approach speeds	Max Circling speed
A	<91	90-150	70-100	100
B	91-120	120-180	85-130	135
C	121-140	160-240	115-160	180
D	141-165	185-250	130-185	205
E	166-210	185-250	155-230	240

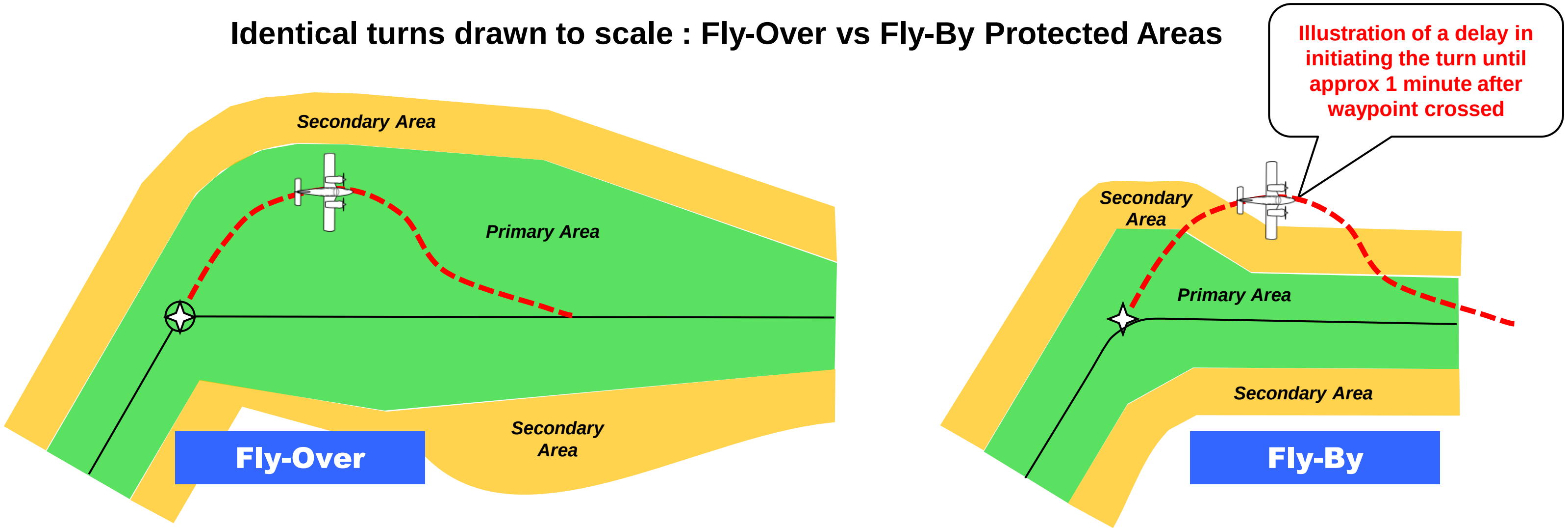
All speeds are KT IAS

- Most general aviation aircraft are Categories A or B. However, in busy Terminal airspace, ATC will often request a higher than normal speed from light aircraft. If appropriate, the pilot should also elect to follow a higher-Category procedure and observe the corresponding minima. Note that the V_{at} is as certified but the approach speeds are as flown.
  – Note that databases sometimes only include the Category C&D procedures, including altitudes
  – In Garmin equipment where there are procedures for different speed categories normally they are ordered with **faster categories on the list above the slower categories** (eg C&D before A&B)

- The Fly-By turn design assumes
  - a fix tolerance of RNAV X or RNP X (eg. 1nm in RNAV 1)
  - aircraft turn at Rate 1 (3°/sec), up to a maximum bank angle of 25°, whichever is lower
  - a 5 seconds allowance, from the time the aircraft's navigation system computes that a turn should start, for either the pilot or autopilot to react and to establish the appropriate bank angle

- The Fly-By turn design thus uses the same bank angles, fix tolerances, wind effects and pilot/autopilot reaction times as the Fly-Over design. However, the diagrams below illustrate how much *inherently smaller* the Fly-By protected area is with those same safety margins built-in

Identical turns drawn to scale : Fly-Over vs Fly-By Protected Areas

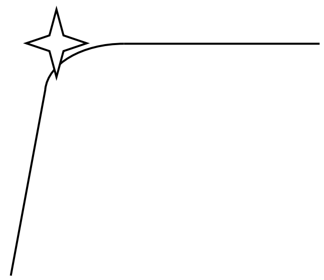
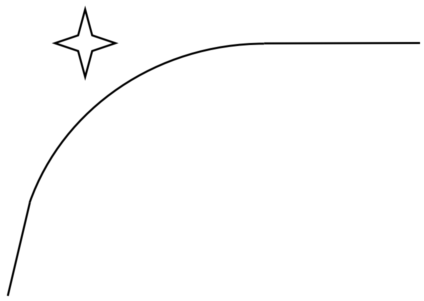


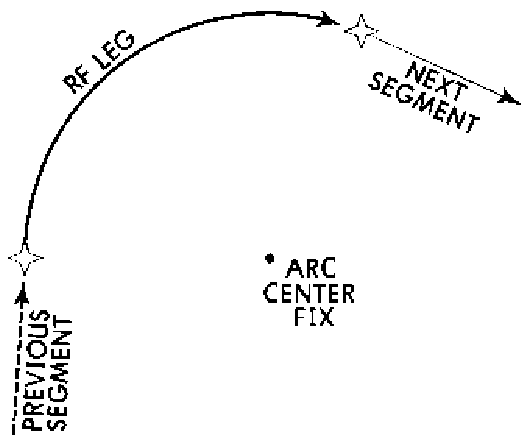
- This demonstrates why it is important to conform to a Fly-By requirement; it is not a choice.

Instrument Procedure Design

4. Radius to Fix

A fly by waypoint does not ensure that aircraft flying at different speeds will follow a path within the 1nm requirement of RNP 1. In the diagram below, the greater radius of the faster aircraft places it further from the waypoint.

120kts	420kts
	



- A Radius to Fix Leg defines a constant radius turn between two database fixes, lines tangent to the arc and a centre fix
- Optional in RNP 1
- The RF leg is designed to be used for terminal procedures
- The certification requirements for RF legs require software and equipment which has been approved in the AFM. At present, approval limited to Garmin GTN installations with autoslew EHSI.
- RF legs are used in circumstances where navigational precision is vital (eg due to terrain) so it is important to follow navigational guidance and the speed constraints associated with the procedure.

The Global Navigation Satellite System (GNSS)

1. Global Navigation Satellite And Ground Station Infrastructure

Although we have got used to thinking of GPS as the only satellite navigation system, there are others, in varying stages of development and usability:

GNSS

Note: there are other national GNSS programmes and proposals , eg. India, France

GPS

- The USA's "Navstar" Global Positioning System
- A military system that became fully operational for worldwide civilian use in 1995
- Designed around a network of 24 medium-earth orbit satellites
- "Selective Availability" (SA) degradation of civilian signal accuracy ended in 2000

GLONASS

- Russian "Global Navigation Satellite System"
- Introduced during the Soviet era for military applications
- 24 satellites providing global coverage

BeiDou

- Chinese Navigation Satellite System (BDS)
- 24 satellites providing global coverage
- Aviation use is gradually coming in, with Chinese airliners using it and wider uptake expected soon.

Galileo

- The European Union's GNSS project
- After some controversy, formally approved in Nov 2007
- USA/EU agreement that Galileo and GPS will be "interoperable"
- Uses a 30 satellite constellation (24 + 6 spares); some service and accuracy improvements over current GPS

The concept is that receivers should be able to operate with multiple systems, creating in GNSS a single 'virtual' system capable of providing a high degree of resilience when used as a sole source of navigation data for aircraft

In this manual the term GPS refers to the USA GPS system and GNSS includes all the above systems.

The Global Navigation Satellite System (GNSS)

2. Overview of the GPS System's Three "Segments"

Space Segment (SS)

- The system is designed for a minimum of 24 satellites (abbreviated as "SV", Satellite Vehicle): 4 in each of 6 orbital planes, at a height of ~20,000km and completing one orbit every 12hrs
- Currently there are 31 satellites, the 7 additional ones improve accuracy and resilience. The constellation is arranged so that at least 6 satellites are always line-of-sight visible from almost any point on the Earth

- *The Master Control Station feeds back a navigational update to each satellite, synchronising its internal clock and adjusting the ephemeris model of its orbit*
- *Occasional maneuvers are commanded which maintain a satellite in its proper orbit*

- *The location of the Ground Stations is very accurately established and used to calibrate the satellites' position and clock data based on the navigation messages they send*

- *Each satellite broadcasts a "**ranging code**", used to establish distance from the GNSS receiver, and its own "**Navigation Message**" containing*
  - *Clock data at the time of transmission*
  - *Data on the satellite's orbital position ("ephemeris")*
  - *"Almanac" data on the status of the entire satellite network*

(detailed in following pages)

Control Segment (CS)

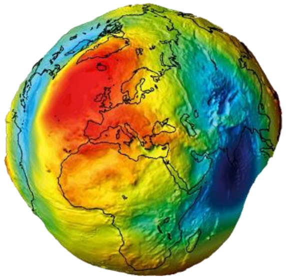
- A Master Control Station in Colorado and 4 Monitor stations across the globe
- They establish the exact orbital position of each satellite, and maintain the reference atomic clocks for the system

User Segment (US)

- Navigation devices which typically include an antenna, an accurate clock, receiver, processor and control/display components
- Modern 'multi-channel' receivers can simultaneously monitor 12-20 satellites

The receipt of ranging codes and navigation messages from multiple satellites allows GNSS Receivers to compute accurate 3D position, speed and time

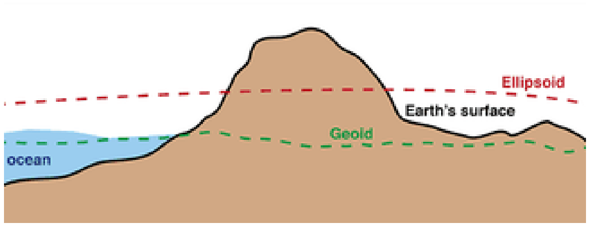
For a detailed description of how GPS works, please see Appendix 2



The Earth is not a precise globe nor oblate spheroid, it is somewhat irregular in shape.

This makes it difficult to model Mean Sea Level when we are trying to achieve accurate elevations, heights and altitudes.

There have been a number of models built to closely represent the shape of the earth accurately.



In order to standardise GNSS vertical navigation across the world, one standard, WGS-84 has been adopted.

Because of the potential differences between WGS-84 model and the Earth, for enroute and terminal navigation barometric altitudes are used.

However on the final approach of RNP approaches with vertical guidance, GNSS altitude is used, but only because it is enhanced to high accuracy by satellite based augmentation systems (SBAS, see page 55)

For a fuller description of WGS-84 see page 168

The Global Navigation Satellite System (GNSS)

4. A Model of GNSS Performance Measures and Factors Affecting Them

	Accuracy	Integrity	Continuity	Functionality
Definition	The difference between true and indicated position	The ability to provide timely failure warnings	The ability to perform at the initiation of use and without interruption	Functionality as required for the proposed operations in the context of an airspace
GNSS System and Satellite Signal	• Ephemeris error • SV clock error • Ionospheric error • Tropospheric error • Multipath error • Dilution of Precision • Signal noise	• Ground monitoring of the Space segment and provision of RAIM data in the Almanac • Spoofing potential *Civilian GNSS is vulnerable to 'fake' transmissions from 'spoofing' equipment*	• Satellite coverage • Satellite reliability • Terrain masking *(situation where terrain creates a mask angle greater than the 7.5° the GNSS constellation model is designed to provide coverage for)* • System is unaffected by number of users	
GNSS Receiver	• Receiver noise • Receiver processing error • Receiver display error	• Receiver RAIM prediction and monitoring *(see p54 on RAIM and FDE)* • Other receiver alarms and alerts • Installation vulnerability to RF interference	• Reliability of receiver hardware, software and antenna • Quality of installation and power supply • Receiver FDE • Dynamic masking*	• RF and FRT Legs • Fly-by turns • Holding patterns • Offset flightpath
GNSS Database	• Coding error	• Quality assurance by database supplier	• Completeness of database • Delivery method for updates	• Coverage
Pilot input and interpretation	• Flight Technical Error • User "conceptual" error	• Use of RAIM tools	• Database updating • Inadvertent mis-operation	• Maps • Depiction • Auto slew HSI

** Masking or attenuation of a satellite signal through aircraft motion (eg. wing blocks the signal path in a bank)*

The Global Navigation Satellite System (GNSS)

5. Sources of Accuracy Error in GNSS

PPL/IR EUROPE

	Accuracy	Nature of error	Size of error
GNSS System and Satellite Signal	• Ephemeris error	• Satellite orbits, although precisely positioned, can deviate from the ephemeris model data transmitted in the Navigation Message	2.5m
	• SV clock error	• Satellite clock errors are monitored by the Ground Segment and corrections are included in the Navigation message. These aren't "real-time" and a small residual error can develop	2m
	• Ionospheric propagation delay	• Inconsistencies in how the ionosphere disperses radio signals can only be partially compensated for by the model data in the Almanac – this is the largest single source of error in civilian GNSS	5m
	• Tropospheric error	• Different concentrations of water vapour in the atmosphere cause an inconsistency in how radio waves are refracted. This error is small, but can not be easily corrected by modelling or calculation	0.5m
	• Multipath error	• In ground-based applications, a satellite signal may arrive at a receiver via a reflection from a building or terrain. This type of error is inherently less present in most phases of flight, although it is an issue for future precision approach systems	-
	• Dilution of Precision	• Like any position line fix, GNSS accuracy is reduced if satellites are close together or very far apart. The total effect is called "Geometric Dilution of Precision" (GDOP). It is also expressed as Horizontal, Vertical, 'Position' (horizontal and vertical) and Time dilution: HDOP, VDOP, PDOP and TDOP • Dilution of Precision multiplies errors from the other sources	-
	• Signal noise	• The result of signal noise compromising the accuracy of the PRN code received	1m
GNSS Receiver	• Receiver noise	• The result of noise in the receiver further compromising the accuracy of the decoded PRN	1m
	• Receiver processing error and display error	• Not operationally significant, unless there is a failure or software bug. Unlike an Inertial system, whose estimated position drifts away from true position over time, GNSS is continuously updated and does not suffer from systematic "map shift" error	-

Civilian GPS without SBAS* is better than 35m horizontally and 75m vertically 95% of the time. In practice, the accuracy is significantly better almost all of the time. With SBAS it is typically 2-3m horizontally and 1.5m vertically.

** See p57*

6. GNSS Performance Model: a Practical Risk Assessment from a Pilot's Perspective

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GNSS System and Satellite Signal	Very low risk of system or accuracy failures that are not identified by a Receiver RAIM or Loss of Integrity alert	At the system level, very low risk of a loss of service not predicted by RAIM tools. Availability is the percentage of time (annually) during which the system is available for use. At the local level, terrain and satellite geometry surveying is part of the PBN procedure design process and thus a very low risk of local availability or continuity problems
GNSS Receiver	Very low risk of design problems with TSO/ETSO certified hardware and software	Approved installations have proven highly reliable in millions of hours of service. Of course, like all radio aids, they depend on aircraft power
GNSS Database	Generally highly reliable. However, in the light of rapid deployment of RNAV (both new procedures and approaches and new designs of procedure and approach) some extra caution is warranted in checking GNSS nav data against paper charts. Use of unapproved or expired databases presents a distinct risk	
Pilot input and interpretation	The major risk is pilot error in operating and interpreting GNSS navigation equipment	

Note: these "green" risks are not zero, and regulations thus require alternative procedures and facilities to be available for many GNSS applications

(applies only to IFR-approved aircraft installations)

- **Just as in conventional IFR, the human factor risks in using GNSS equipment can be safely managed through pilot training, currency and adherence to Standard Operating Procedures**

7. Jamming

Although the GNSS systems themselves are very reliable, there are increasing reports in Europe and the USA of deliberate jamming of the signals.

This jamming is sometimes created by (usually commercial) drivers who do not wish their position to be monitored. Such jamming is unpredictable and cannot be forecast.

The military also deliberately jam signals, but this is normally accompanied by a NOTAM, though the area in which jamming may be experienced is not always clear and predictable. Obviously jamming in war zones is not NOTAMed.

A receiver subject to jamming will normally show an error message to say that no position can be provided together with an INTEG or LOI flag.

However, there are occasional reports of position spoofing, whereby the receiver shows an incorrect position without warning.

When a pilot receives a GNSS warning, he should revert to alternative navigational methods, which may of course include radar vectors.

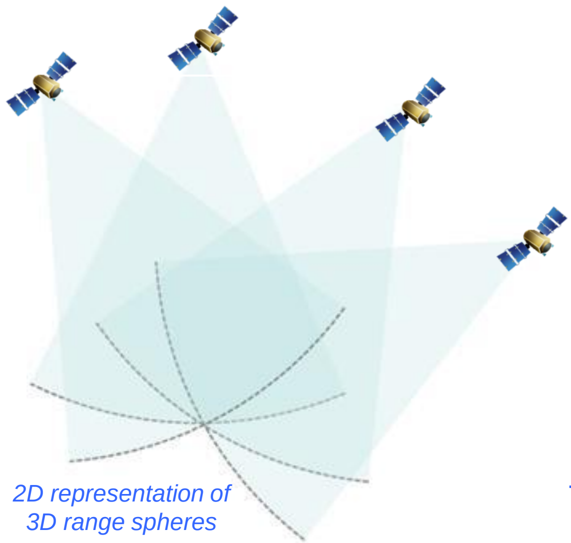
When a serious loss of navigational capability (including GNSS) is encountered, it should be reported via the European Aviation Reporting Portal (http://www.aviationreporting.eu/AviationReporting/)

GNSS Augmentation

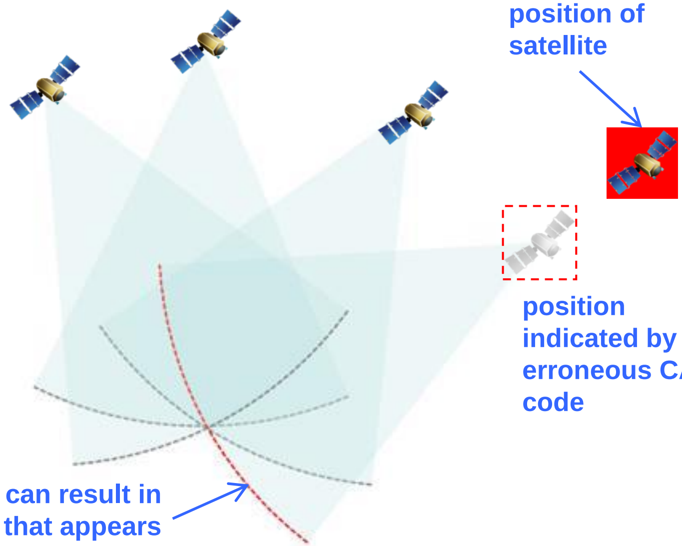
1. ABAS: RAIM (Receiver Autonomous Integrity Monitoring)

GNSS receivers require a minimum of 4 satellites to establish a 3D position fix (see Appendix 2)

However, if a satellite develops a fault and broadcasts an inaccurate signal, this could result in an incorrect position solution



2D representation of 3D range spheres



The GNSS Control Segment ground stations monitor satellites and detect faults

However, the system may take <u>up to 2 hrs</u> to detect a fault and then update the Navigation Message to declare that a particular satellite signal is erroneous

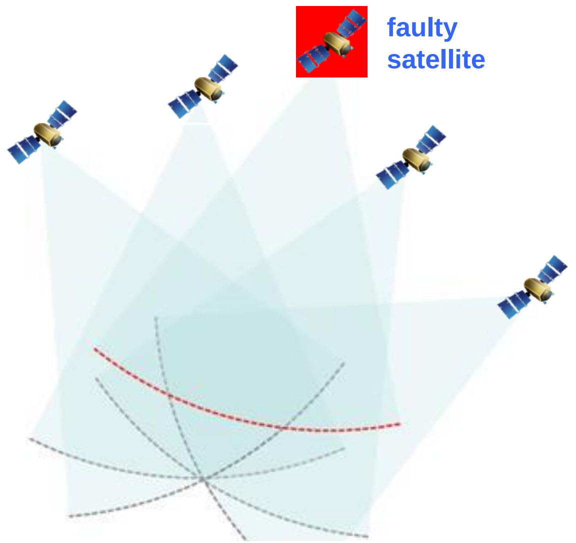
This potential delay means that IFR GNSS receivers need an "autonomous" way of assuring the integrity of the navigation solution

This is referred to as Aircraft-Based Augmentation System (ABAS)

Aircraft Autonomous Integrity Monitoring (AAIM) uses other sensors, such as barometry or Inertial Reference Systems, but this is not usually available in GA light aircraft.

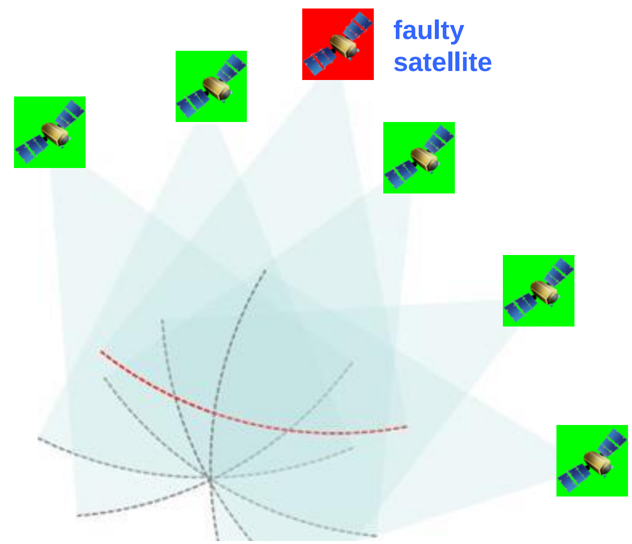
GNSS Augmentation
2. ABAS: RAIM Fault Detection (FD) and Fault Exclusion (FDE)

A 5th satellite provides a GNSS receiver with the capability for Fault Detection (FD)



- The receiver can recognise that a satellite is faulty, because the 5 range spheres don't all intersect at a consistent point; but, because any combination of 4 satellites might provide a valid solution, it can not always identify which satellite is faulty
- RAIM (Receiver Autonomous Integrity Monitoring) is synonymous with Fault Detection (FD) and is a feature of all approved IFR GNSS receivers

A 6th satellite provides a GNSS receiver with the capability for Fault Detection and Exclusion (FDE)



- The receiver can identify and isolate the faulty satellite, by finding which combination of 5 satellites will provide a self-consistent and valid navigation solution, and excluding the 6th
- Many TSO C129() receivers (eg. Garmin 430/530) and all TSO C146() receivers (eg. Garmin 430W/530W and GTN) also feature RAIM with Fault Detection and Exclusion (FDE), which requires 6 visible satellites

In the absence of SBAS*, if RAIM is available, the GNSS receiver can assure the integrity of its calculated position within the limits required for a specific segment of flight: 4 nm for oceanic, 2 nm for enroute, 1 nm for terminal and 0.3 nm for LNAV approaches.

For further explanation of RAIM, and the approved European RAIM prediction tool, Augur see page 61

* See p56

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- Basic GNSS systems, whilst highly accurate, are subject to 'technical' errors that are meaningful when the level of accuracy needed is measured in metres, eg:
  - Satellite clock synchronisation errors
  - Signal distortions induced by satellite payload
  - Satellite position errors
- Additionally, between the signal broadcast by GNSS satellites and the actual position calculated by the user device there are a number of additional sources of error, eg:
  - Ionospheric effects on signal propagation
  - Tropospheric effects on signal propagation
  - Reflections from terrain or objects ('Multipath' errors)
  - Thermal noise, Interference and receiver design
- The principle of Satellite Based Augmentation Systems (SBAS) is that a large number of ground stations monitor the position derived from GPS at their accurately surveyed, fixed locations. **They calculate error correction "feedback" information unavailable to the stand-alone GNSS system**. This information is processed and broadcast via communications satellites and is used by SBAS GNSS devices to apply corrections which mitigate satellite clock error, satellite payload induced signal distortions, satellite position uncertainties and ionospheric effects
- Tropospheric effects, multipath and user receiver errors are **local** effects that cannot be corrected by a global or regional augmentation system

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Satellite-based Augmentation Systems (SBAS)

The system is implemented by

- a network of Reference Stations providing regional/continental coverage
- a Master Station which collates their data, calculates a differential correction for each satellite in the GPS constellation being tracked and prepares a SBAS broadcast
- a Ground Earth Station that uplinks the broadcast to a geostationary satellite
- the geostationary satellite broadcast of SV corrections as an additional C/A code on the L1 frequency (see Appendix 2)
- An SBAS-enabled GPS receiver which decodes the data and applies the corrections

There are a number of regional SBAS systems shown below. All these systems are compatible, so that any current SBAS-enabled GPS receiver can work in USA, Europe, Japan, India and Nigeria.

WAAS (USA/Canada)

- Footprint of Continental United States, Southern Canada and Alaska
- Operational since 2003
- Approved as a primary (sole) navigation aid for Enroute and Oceanic navigation, and LPV approaches to 200 feet

EGNOS (Europe)

- Footprint of Europe, Africa and parts of the Indian Ocean
- Operational since 2011
- Approved as a primary (sole) navigation aid for Enroute and 3D (LPV) Approaches down to 200' DH

MSAS (Japan)

- Footprint of Japan and nearby region
- Certified operational 2007
- Enroute, Terminal and Non-Precision approaches

GAGAN (India)

- Footprint of India, Pakistan, Bangladesh
- Certified Operational Dec 2013

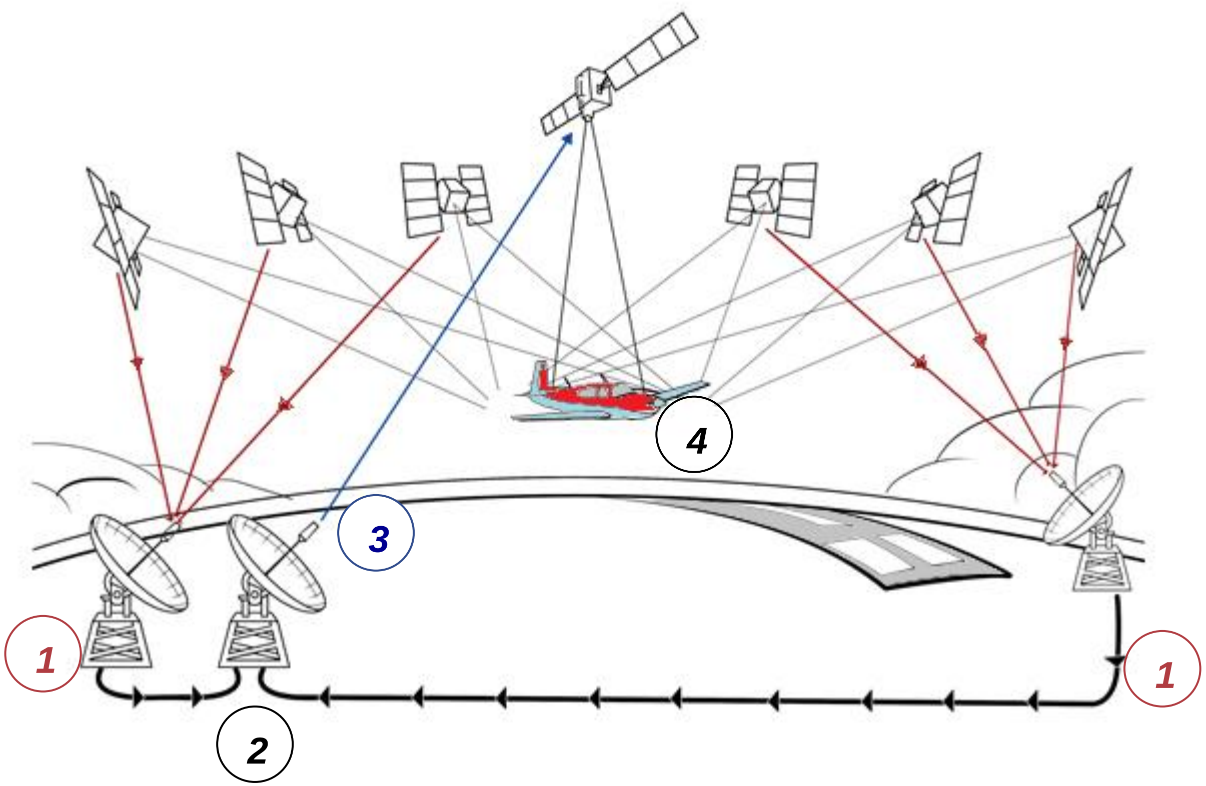
SDCM (Russia)

- Available throughout Russia, but still experimental for aviation.

As a GA Pilot, you will not directly encounter Ground Based Augmentation Systems (**GBAS)**, but you are required to know a little about them for the PBN syllabus.

- It is similar to SBAS, but instead of a Regional ground station operating through a satellite, a reference GBAS ground station, whose position is very accurately surveyed, can calculate a correction for such errors which can be broadcast to nearby GPS receivers. It broadcasts the Final Approach Segment Datablock. It uses a data link in the VHF band of ILS–VOR systems (108–118 MHz).
- The resulting correction can improve the User Equivalent Range Error by a factor of 20x: from 35m horizontal and 75m vertical to 1m horizontal and 2m vertical designed to provide precision approach capabilities to CAT III Autoland levels of accuracy and integrity. It's coverage is about 20nm.

GNSS Augmentation
5. SBAS Architecture (EGNOS)



How SBAS (EGNOS) Works

1. GNSS signals are received at 34 RIMS (Ranging and Integrity Monitoring Stations - approximately one per country)

2. Differential correction signals are calculated centrally, to cater for the entire region

3. Correction signals are sent via geo-stationary satellites which broadcast using different channels

4. Onboard SBAS receiver combines the corrections to achieve very high accuracy of typically 1m horizontally and 2m vertically

GNSS Augmentation

6. Onboard Performance Monitoring and Alerting - Overview

- **Required for RNP**
- **Managed by systems or crew procedures (i.e. is it working?)**
- **Gross reasonableness checks by crew (i.e. does it make sense?) - used to recognise Path Definition Error (see also p33).**

SBAS Available

- The pilot is not required to check RAIM.
- SBAS provides a more accurate method of error checking.
- Integrity and safety are improved by alerting SBAS users within 6 seconds if a GPS malfunction occurs.

SBAS Not Available

- RAIM checks required in-flight
- As a minimum requirement for RNP, Fault Detection (FD) is required.
- However, most navigators, including most older units, now have software that has been updated to include Fault Detection and Exclusion (ie faulty satellites do not prevent position resolution; they are excluded from calculations.)

At the time of writing (January 2023), the UK is in a transition regarding SBAS. The UK no longer has a contract with ESA for the use of Safety of Life services, meaning that it cannot be used for LPV approaches. However, it can still be used for SBAS augmented LNAV/VNAV approaches and may be used in place of RAIM checks. A UK SBAS system is in process of being developed.

GNSS Augmentation
7. Onboard Performance Monitoring and Alerting - Availability

Predicted RAIM/SBAS availability

- Although, in practice, the GPS satellite constellation provides 6 or more visible satellites in almost all circumstances, this is not guaranteed
- On a particular route at a particular time, it may be that the "geometry" of the satellite constellation, or a known satellite failure, means that the minimum of 5 satellites needed for RAIM will not be available
- Such a lack of RAIM availability may be predicted, either by the GNSS receiver software using almanac data and the time and route of flight, or by an internet-based RAIM prediction tool
- SBAS non-availability is notified by NOTAM

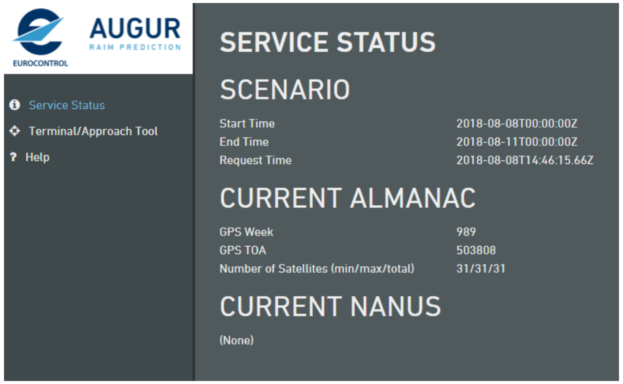
Actual RAIM/SBAS availability

- RAIM availability can be lost at any point in a flight if the number of visible, serviceable satellites falls below 5
- This may happen when RAIM was predicted to be available, if an unexpected satellite failure takes place
- All IFR GNSS receivers will provide the pilot with a prominent alert if RAIM is lost at any point in flight – this does not mean the GNSS position is wrong (eg. if 4 accurate satellite signals remain available) but it does mean that the integrity of the position is not assured (ie. one of the 4 signals could be erroneous)
- Where the receiver determines that it cannot provide integrity within limits, such as due to lack of SBAS, then the guidance mode will fallback. For example, LPV would revert to LNAV.

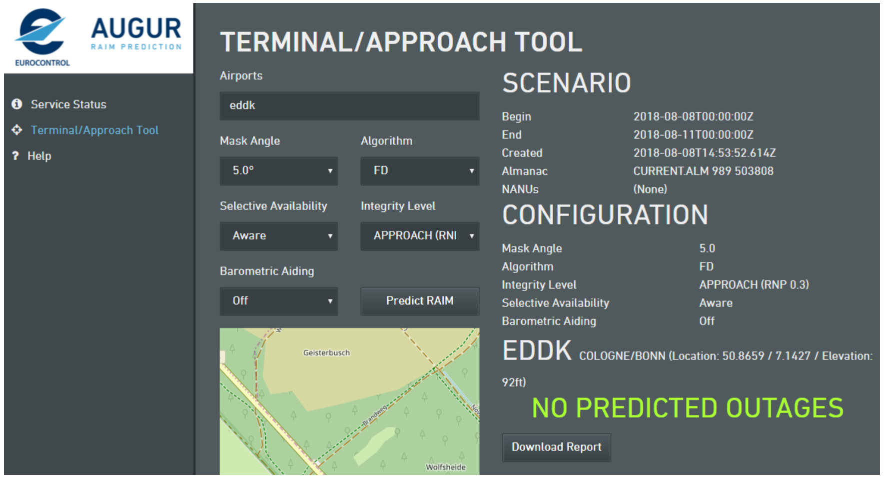
	Pre-flight Prediction	In-flight Integrity
Non-SBAS	Not required, but recommended for RNAV 5. RAIM prediction must be conducted before a RNAV 1/ flight, or SIDs/STARs and approaches. If there is a predicted lack of availability, the flight must either use alternative procedures or reschedule for a time when RAIM will be available.	For RNAV 5 GNSS navigation can be continued without RAIM as long there is no loss of GNSS position but the pilot must cross-check position using conventional radio aids. For RNAV 1 flight, or SIDs/STARs and approaches cannot be continued without RAIM.
SBAS	NOTAMs must be checked for SBAS availability. RAIM need not be separately checked.	If SBAS is unavailable the receiver will revert to RAIM. SBAS status is indicated in the Status page of the receiver. In Garmin receivers, a 'D' in a Satellite signal strength bar indicates that 'Differential' corrections (SBAS) are being used for that Satellite. If there is no D, no SBAS is available on that satellite. RNP Approaches with vertical guidance are not available and only LNAV or conventional approaches can be used. (Baro-VNAV remains available if the aircraft is so equipped.)

Predicted RAIM availability

- Eurocontrol provides a free online RAIM prediction tool called Augur http://augur.eurocontrol.int/ec/status
- The first page gives the Service Status of the GPS system, including any NANUs (Notice Advisory to Navstar Users (ie NOTAMs)) for the next three days



- The second page allows the user to enter a specific airport to get a RAIM prediction over the next three days

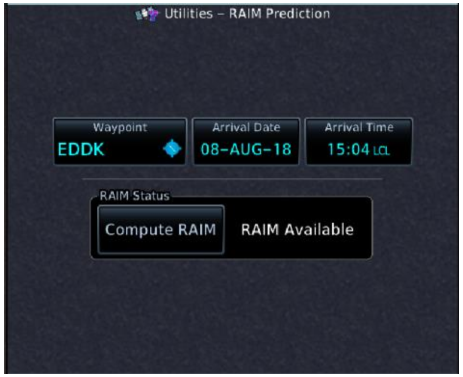


GNSS Augmentation
9. Navigator RAIM Prediction Tool

Predicted RAIM availability

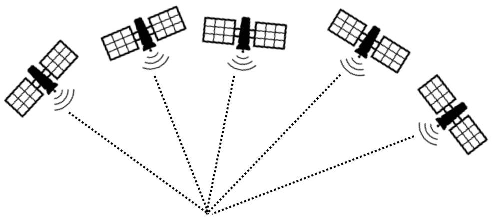
- It is also possible to get a RAIM prediction from the GNSS Navigator. For example, on the GNS, it is on the second AUX page:

- On the GTN it is under Utilities:

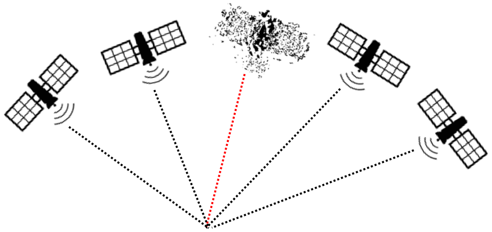


GNSS Augmentation
10. Methods of RAIM prediction

- RAIM Fault Detection consists of two algorithms
  - a geometric screening, to calculate whether the available satellite geometry can provide a position fix of sufficient accuracy for the intended phase of flight



  - an error detection algorithm, to check whether any signals (in an otherwise adequate satellite geometry) are faulty



- RAIM prediction performed by a GNSS receiver relies on the Almanac broadcast by satellites. This may not have the most up to date information on the status of the satellite constellation
- The definitive source for this data is the FAA SAPT website: https://sapt.faa.gov/default.php
- For the GPS equivalent of NOTAMs ("NANU", Notice Advisory to Navstar Users) use https://www.navcen.uscg.gov/?pageName=gpsAlmanacs
- An IFR GPS receiver's built-in RAIM prediction may not comply with the requirements of some RNAV applications and approvals (particularly RNAV 1), and the AUGUR prediction tools must be used instead. Where SBAS is available (check NOTAMs), it is not necessary to check RAIM availability on an SBAS GNSS receiver.
- RAIM prediction refers to the Fault Detection function (FD). RNAV applications requiring a predicted availability of Fault Detection and Exclusion (FDE), eg. GNSS as a primary means of navigation on Oceanic routes, need the use of approved FDE prediction tools (eg. Garmin's FDE software for the G430/530/1000 series)
- RAIM prediction is specific to the RNP requirement of a particular phase of flight – if RAIM is available for RNP 1 Procedures along a given route and time, this does not necessarily mean that it is available for RNP approaches (RNP 0.3): for example, a particular satellite geometry may have a dilution of precision that is acceptable for RNP 1 but not for RNP 0.3

11. Garmin Information on SBAS RAIM Prediction Requirements

1.2 DETERMINING WHEN A WFDE PREDICTION IS REQUIRED

The WFDE Prediction Program determines whether the GPS constellation is robust enough to provide a navigation solution for the specified route of flight. As required (dependent upon type of flight plan, GPS Software (SW) version, and GPS antenna), prior to departure the operator must use the WFDE Prediction Program supplied with the applicable trainer or route planning software to demonstrate that there are no outages in the capability to navigate on the specified route of flight (Table 1).

NOTE: *If the route of flight requires an alternate airport, multiple predictions may be required (one for the primary and one for the alternate) to verify RAIM and/or WAAS satellite availability at the primary and the alternate approach.*

A WFDE Prediction is required for the following instances (see also Table 1)**:**

- For all Garmin WAAS enabled units (regardless of the GPS software version or antenna model): an FDE prediction is required for operations where the route requires Class II Navigation (e.g. Oceanic/Remote operation) and GPS is to be the primary source of navigation per FAA AC 20-138A Appendix 1. The Oceanic/Remote flight phase occurs when the flight plan will place the aircraft more than 200 nautical miles from the nearest airport. All operators using a Garmin WAAS-certified unit as primary means of navigation in oceanic/remote areas under FAR parts 91, 121, 125, and 135 must utilize the WFDE Prediction Program prior to conducting a flight in these areas.
- For all Garmin WAAS enabled units (regardless of the GPS software version or antenna model): a RAIM prediction is required for operations in areas where SBAS coverage is not available.
- For Garmin WAAS enabled units using an unapproved* GPS antenna (regardless of the GPS software version): a RAIM prediction is required for all flight operations in accordance with the National Aviation Authority guidelines for TSO-C129a equipment. Examples of such operations include navigation of U.S. Area Navigation (RNAV) routes, Standard Instrument Departures (SIDs), or Standard Terminal Arrival Routes (STARs) per FAA AC 90-100A "U.S. Terminal and En Route Area Navigation (RNAV) Operations".
- For Garmin WAAS enabled units using an unapproved* GPS antenna (regardless of the GPS software version): an operational limitation in the form of a WAAS satellite visibility prediction is required for all LNAV/VNAV, LP, or LPV approaches.
- For Garmin WAAS enabled units with GPS Software v2.XX or earlier (regardless of GPS antenna model): an operational limitation in the form of a WAAS satellite visibility prediction is required for all LNAV/VNAV, LP, or LPV approaches.

A WFDE Prediction is not required for the following instances (see also Table 1)**:**

- For Garmin WAAS enabled units with GPS Software v3.XX or later and using an approved* GPS antenna: a RAIM prediction is not required when operating in areas where SBAS coverage is available.
- For Garmin WAAS enabled units with GPS Software v3.XX or later and using an approved* GPS antenna: a WAAS satellite visibility prediction is not required for LNAV/VNAV, LP, or LPV approaches.

GNSS Warnings
1. The Loss of Integrity (LOI/INTEG) Alert

- Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation as a result of errors or failures in the system (Hazardously Misleading Information). This is provided by RAIM, but SBAS improves upon the integrity of the basic GNSS signal and detects much smaller errors more quickly.
- Whilst RAIM is available, the GNSS receiver assures the integrity and accuracy of its calculated position within a protection limit specified for a particular phase of flight: 4 nm for oceanic, 2 nm for enroute, 1 nm for terminal and 0.3 nm for RNP approaches
- Example, from the Garmin 530 Pilot's Guide:
  - The CDI scale in IFR GNSS receivers automatically adjusts to the active phase of flight, or it may be set manually.
  - CDI auto-scaling must be enabled for RNAV operations. Activating terminal and approach procedures from the GNSS database ensures that the appropriate CDI scale and RAIM protection limits are applied
  - In some GNSS, units manually selecting a 1nm or 0.3nm CDI scale may not change the RAIM protection limit to the corresponding RNP value (although it does in the Garmin 430/530 series)

CDI Scale/Flight Phase:	RAIM Protection:
Auto (oceanic)	4.0 nm
±5.0 nm or Auto (enroute)	2.0 nm
±1.0 nm or Auto (terminal)	1.0 nm
±0.3 nm or Auto (approach)	0.3 nm

- The "Loss of Integrity" (LOI or INTEG) alert provided by a GNSS receiver is very important. It is triggered by
  - a loss of RAIM availability, or
  - the detection of a fault in satellite signals which compromises position accuracy, or
  - an unfavourable satellite geometry and dilution of precision, such that position accuracy does not meet the protection limit required
- **The integrity alert indicates that the GNSS may not be used as a source of primary guidance**
  - **during a RNP 1 Procedure, the pilot must advise ATC of the RAIM failure and request radar vectors or a conventional alternative procedure**
  - **during an RNP approach, the pilot must initiate the missed approach and advise ATC**
- In practice, most instances of loss of integrity are very brief. However, if an en-route integrity alert persists for more than 60 seconds, it should be treated seriously and an appropriate contingency procedure initiated

Note: the protection provided by the RAIM function covers all of the integrity and accuracy requirements for RNAV; therefore the pilot need not be concerned with other measures of navigation accuracy the GNSS unit may provide in the Status or Aux pages (eg. Estimated Position Error, Dilution of Precision and Horizontal Uncertainty Level)

GNSS Warnings
2. LOI and INTEG

- IFR GNSS receivers always display the LOI or INTEG alert prominently. In the Garmin GNS 430/530 series, it is a black on yellow "INTEG" annunciator on the bottom left of the screen. In the GTN the annunciator is either INTEG (for loss of RAIM) or LOI (for loss of GPS integrity.)

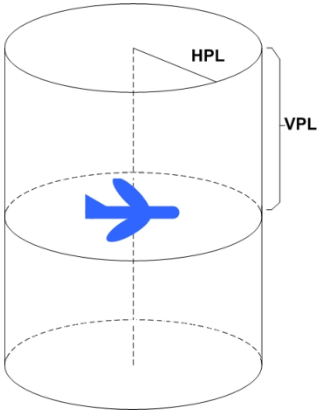
- In addition to the prominent alert, the GNSS receiver will display one or more supplementary messages, either as pop-up overlays on the active screen, or within the Message screen (accompanied by a "MSG" annunciation).
- The user must be familiar with the meaning of all the alert and advisory messages in their GNSS receiver, and how they are annunciated and accessed
- Alert messages are receiver specific. Some relevant examples below are from the GTN.

Message	Description	Action
ABORT APPROACH - GPS approach no longer available.	This message is triggered outside the MAP if the GTN system can no longer provide approach level of service. Vertical guidance will be removed from the external CDI/HSI display.	Initiate a climb to the MSA or other published safe altitude, abort the approach, and execute a non-GPS based approach.
APPROACH DOWNGRADE - Approach downgraded. Use LNAV minima.	Approach has been downgraded from LPV or LNAV/VNAV, to an LNAV approach. Vertical guidance will be removed from the external CDI/HSI display.	Continue to fly the approach using published LNAV minimums.
APPROACH NOT ACTIVE - Do not continue GPS approach.	GPS approach could not transition to active (e.g., the GTN is on an approach and did not have the required HPL/VPL to get into at least LNAV, so is still in TERM).	Abort the approach, and execute a non-GPS based approach.

Message	Description	Action
GPS NAVIGATION LOST - Erroneous position. Use other navigation source.	GPS position has been lost due to erroneous position.	Use a different GPS receiver or a non-GPS based source of navigation. Contact dealer for service.
LOSS OF INTEGRITY (LOI)- Verify GPS position with other navigation equipment.	The GPS module has reported a loss of integrity.	Use a different GPS receiver or a non-GPS based source of navigation. Contact dealer for service if this message persists.
GPS NAVIGATION LOST - Insufficient satellites. Use other navigation source.	GPS position has been lost due to lack of satellites.	Use a different GPS receiver or a non-GPS based source of navigation. Contact dealer for service.

GNSS Warnings
3. Alert Limits

- Alarms are triggered if GNSS/SBAS signal is below certain Protection Levels.
- Protection Levels are divided into Vertical (VPL) and Horizontal (HPL) components
- These Protection Levels on an SBAS receiver represent a 99.99999% probability that the aircraft position is contained within the limits (it is less on non-SBAS unit.)
- On RNP approaches, the Horizontal and Vertical Alert limits (HAL and VAL) are the highest values of HPL and VPL which are permitted for a given approach. The alert limits are stored in the navigation database for each approach to be flown (FAS data Block).



Approach	HAL(m)	VAL(m)	Horizontal 95% Accuracy (m)	Vertical 95% Accuracy (m)
Non-SBAS LNAV	556	-	220	-
LNAV/VNAV (SBAS)	556	50	220	20
LPV (DH >= 250’)	40	50	16	20
LPV (DH 200’- 250’)	40	35	16	4

- Based on these limits the SBAS GNSS navigator will offer an LPV approach, or downgrade to an LNAV, or not allow an RNP approach.
- A non-SBAS navigator will use the limits to determine whether to offer an LNAV approach.
- The maximum observed position error is substantially below the calculated protection limits. Actual performance measurements of the US SBAS system have shown it typically provides accuracy of better than 1.0 metre laterally and 1.5 metres vertically in North America. The largest vertical errors in the 17 years since the US SBAS system has been in use have all been less than 10 metres.
- EGNOS normally achieves horizontal and vertical accuracy within 3 metres.
- However, flight safety is evaluated based upon the presumption that the flight user could be exposed to an error of the maximum protection level – the alert limit. Unfortunately, although this is accepted as a very conservative assumption based on observed error, the SBAS system is not able to assure a protection level closer to the actual error with the requisite integrity.
- For comparison, non SBAS GPS typically achieves a navigational accuracy within 10 metres.
- For a fuller explanation see https://gssc.esa.int/navipedia/index.php/SBAS_Fundamentals

PBN Requirements and Approvals
1. Non-SBAS and SBAS Receivers

Receivers can be divided into Non-SBAS and SBAS capable.

TSO-C129() (Non-SBAS)	TSO-C146() (SBAS)
The certification standard for the "first generation" of panel-mount IFR GNSS units, dates back to 1996	**The more recent certification standard for SBAS-capable panel mount IFR GNSS units, published in 2002**
Examples: • Garmin GNS430, GNS530, early G1000 •All older GPS units from other makes (eg.Bendix/King, Trimble, Northstar)	Examples: • Garmin GNS430W, GNS530W, G1000W, GTN650, GTN750 • Avidyne IFD440/540

Typical features

• Most units also support database overlay and non-precision RNP IAPs • Typically a slow moving map refresh rate (1 per sec) • Require RAIM prediction • Do not provide guidance or roll-steer commands for holds, procedure turns etc	• Support database overlay, LNAV and APV approaches • Fast moving map refresh rate (5 per sec) • RAIM not required in SBAS coverage area • Provide guidance or roll-steer commands for holds, procedure turns etc

Functional requirements of RNAV and RNP specifications include continuous indication of lateral deviation, distance/bearing to active waypoint, groundspeed or time to active waypoint, navigation data storage and failure indication.

A GNSS Receiver can only be used for RNP approaches (and other PBN operations) in accordance with the approvals in the AFM.

PPL/IR EUROPE

To use a receiver for PBN

- Usually, the certification of the receiver must be stated in the Aircraft Flight Manual (AFM) or Pilot Operating Handbook (POH).
  - Where such a reference cannot be found in the AFM or POH, other information provided by the aircraft manufacturer as Type Certificate (TC) holder, the Supplemental Type Certificate (STC) holder or the design organisation having a privilege to approve minor changes may be considered.
  - This may be e.g. in the AFM, POH, Flight Crew Operating Manual (FCOM), Service Bulletin or Service Letter, Minor Change Approval or a document issued by the competent authority.
- Equipment capability, in itself, is not sufficient to define the PBN capabilities of the aircraft, since the latter depend on installation and integration.
- Deducing PBN capability is not always straightforward
  - As some PBN procedures have been developed prior to publication of the ICAO PBN manual, it is not always possible to find a clear statement of aircraft capability towards PBN in the AFM or POH.
  - Sometimes however, aircraft eligibility for certain PBN navigation specifications can rely on the aircraft performance certified for PBN procedures prior to publication of the ICAO PBN manual.
  - EASA has developed guidance material (GM1 NCO.IDE.A.195) that lists the various references (e.g. to FAA Advisory Circulars and EASA Acceptable Means of Compliance) which may be used to consider the aircraft's eligibility for a specific PBN navigation specification.
  - Flying RF Legs is subject to specific approval in the AFM, currently restricted to GTN + EHSI.

PBN Requirements and Approvals
2. Pilot Requirements for PBN

	Pilot knowledge/training
Europe	• A current Instrument Rating or BIR (Basic Instrument Rating) has PBN privileges • All EASA Part-FCL IR and BIR skill tests and proficiency checks must include at least one RNP APCH • The UK IR(R)/IMC Rating does not require PBN endorsement
FAA	• A current FAA Instrument Rating qualifies a pilot to fly PBN procedures without a requirement for further formal ground or flight training • The FAA recommends that pilots should be familiar with at least the 12 areas of GNSS operation listed in AIM section 1-1-19-P, either through training or by practicing in VMC conditions • Note that private pilots who are resident in EASA member states and operating N-registered aircraft in Europe need to hold an EASA Part-FCL licence, including an EASA IR for IFR and PBN. • For the time being UK legislation reflects EASA rules, so a UK resident requires a UK licence and IR/PBN qualification.

FPL Equipment Codes

- To fly PBN procedures, where a flight plan is required, the capabilities of the aircraft equipment must be specified in the FPL
- To enter codes in FPL, the right approvals must be in AFM
- The codes are as follows:

Equipment (Item 10)

S Standard
B LPV (APV w/SBAS)
D DME
F ADF
G GNSS
H HF RTF
L ILS
O VOR
R PBN
Y 8.33 kHz VHF

Transponder (Item 10)

A Mode A
C Mode A and C
S Mode S, ACID and Altitude
P Mode S, Altitude, no ACID
I Mode S, ACID, no Altitude
X Mode S, no ACID, no Altitude
E Mode S, ACID, Altitude, extended squitter
H Mode S, ACID, Altitude, Enhanced Surveillance
L Mode S, ACID, Altitude, Enhanced Surveillance, extended squitter

ADS-B
B1 1090 MHz out capability, or
B2 1090 MHz out and in capability

PBN/ capabilities (Item 18)

B2 GNSS RNAV 5
D2 GNSS RNAV 1
O2 GNSS RNP 1
S1 RNP APCH

- Thus, for example, a typical GA aircraft may file SBDFGRY/B1 in item 10 with PBN/B2D2S1 in item 18
- Aircraft which do not file S1 may not be permitted to do an RNP approach
- Commercial software can help get this right
  - SkyDemon, AeroPlus, RocketRoute, Autorouter etc

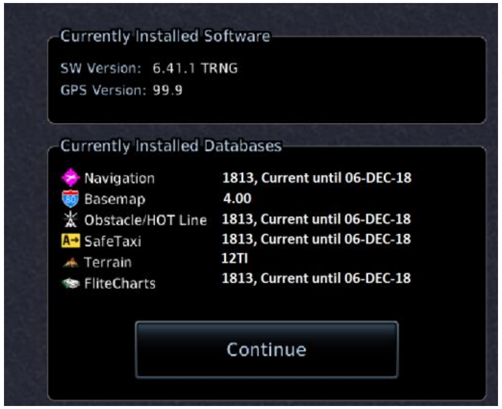
The AIRAC Cycle

Introduction to AIRAC

- Nav Data only changes on a monthly cycle.
- In order to manage and organise changes, and to keep databases and published charts up to date, there is a cycle for notifying changes called the AIRAC cycle.
- AIRAC provides a standardised batch updating process organised around 13 cycles of data per year, each becoming valid on an Effective Date and remaining valid for 28 days until the next Effective Date.
- States may publish charts on a different cycle from AIRAC, eg. 7 or 14 days for terminal charts, 28 or 56 days for enroute charts.
- Jeppesen breaks down the distribution of paper and electronic charts into 2 batches per AIRAC cycle, delivered at 14 day intervals. GNSS databases, however, are updated 13 times per year in accordance with the AIRAC cycle
- Because the input to an AIRAC cycle is “frozen” up to 42 days before it becomes effective, more urgent changes are promulgated by NOTAM

AIRAC Cycle: Updating

- As discussed under the PBN concept, it is an important requirement for the GNSS database to be current.
- This can be achieved in a number of ways - by downloading onto a card from the internet, transferring directly into the unit etc.
- It is the responsibility of the pilot to check that the navigation database is current before every IFR flight.
- All GNSS receivers display their database status on first start.

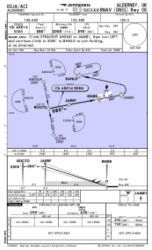


- Under EASA, it is permissible to fly IFR with a database which is out of date by no more than 28 days, but only if the procedures and routes to be used are checked against a current approved source, such as the AIP.
- A database out of date by more than 28 days may not be used for PBN.

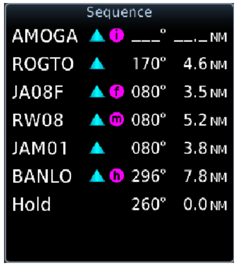
RNAV databases
1. Important Notes

PPL/IR EUROPE

- **A current, approved chart is the definitive source of navigation data; and, in operations where this is approved, a suitable, current database may be used if it agrees with the charted information. In the event of a discrepancy, the charted procedure takes precedence.**

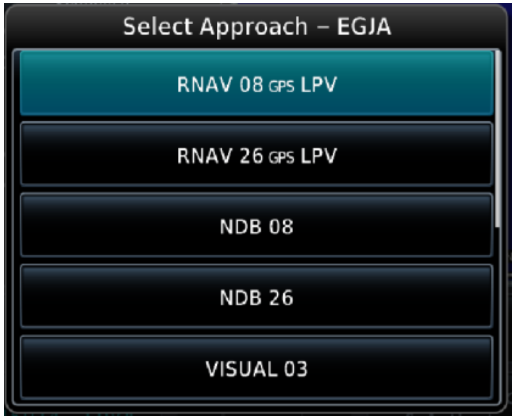


- In cases where a database is required (ie RNAV Terminal Procedures and approaches), a discrepancy between the database and chart means that the procedure <u>may not be flown</u>, and an alternative must be used.



RNAV databases
2. Important Notes

- In the event of any discrepancy between this manual's description of IFR navigation practice and methods and that of any approved chart, database or product manual, clearly, the published, approved sources must take precedence
- The manual entry, or creation of new waypoints by manual entry, of latitude and longitude or place/bearing/distance values is not permitted to be entered into most PBN procedures. The insertion in the flight plan of waypoints loaded from the database is permitted. Route modifications are allowed in the terminal area, with waypoints from the receiver database, up to the Intermediate Fix (IF).
- **Pilots must not fly an RNP APCH unless it is retrievable by procedure name** from the on-board navigation database and conforms to the charted procedure.



RNAV databases

3. The Tasks a GA Pilot Must Perform

Coverage	Currency	Cross-Check
Ensure that the GNSS database and other charts required have the coverage needed for the intended flight - geographic region, specific airports and types of procedure	**Ensure that the GNSS database and other charts required are valid for the current Effective Period of the AIRAC cycle** **Check NOTAMs and database supplier alerts**	**Cross-check the GNSS database routes and procedures that will be used against published charts**

Coverage

- **Ensure that the GNSS database and other charts required have the coverage needed for the intended flight - geographic region, specific airports and types of procedure**

- Coverage is not always self-evident for a user subscribing to European Region data; the countries included in a given subscription vary by product
- If you have GNSS database coverage for a particular country, it may not be included in the paper chart coverage (or PC readable electronic version), and vice-versa

Currency

- **Ensure that the GNSS database and other charts required are valid for the current Effective Period of the AIRAC cycle**
- **Check NOTAMs and database supplier alerts**

- Currency is particularly important, because of the rate at which new procedures are introduced as many European countries implement PBN Routes, operations and RNP approaches
- It is not permissible to enter RNP approaches or terminal procedures as user waypoints. An approved, current database is essential. RNAV 5 waypoints may be added manually.
- Note that published charts and software products may distributed up to 2 weeks before they become effective

Cross-Check

- **Cross-check the GNSS database routes and procedures that will be used against published charts**

- The quality of approved navigation data is very high and gross errors are relatively rare
- However, as new procedures are introduced, discrepancies can arise between AIP charts, commercial service provider charts and GNSS databases
- In addition, navigation databases are an inherently different format from published charts and some waypoints will not be identical in both
- Flying an PBN procedure is not the right time to be puzzling over such discrepancies

The requirements for approved database coverage, currency and cross-checks are not regulatory "gold plating"; they are a practical, as well as a legal, necessity for PBN operations

RNAV databases
4. Cross checking Procedures

- When loading a terminal (SID or STAR) or approach procedure, it is easy to choose the wrong procedure
- Also, there may be a database or charting discrepancy, and you want to know about that before you are executing it
- Accordingly, it is important to check the waypoints, layout and (if applicable) altitudes, with the procedure chart to ensure that they agree

- This should be done in plenty of time, either before take-off or on the enroute phase.
- In Commercial Air Transport operations, both pilots are required to check independently, which demonstrates how important it is for the single pilot to verify the GNSS setup.

RNAV databases
5. Computer Navigation Fix (CNF) Overview

- A Computer Navigation Fix (CNF) is a point defined by a latitude/longitude co-ordinate and is required to support RNAV system operations where a suitable waypoint is not available.

- Where a procedure does not include all the waypoints needed for RNAV guidance, the state can define CNFs or the database supplier will create CNFs and assign them database identifiers.

- The GNSS receiver uses CNFs in conjunction with waypoints to navigate from point to point. However, CNFs are not recognised by Air Traffic Control (ATC). ATC does not maintain CNFs in their database and they do not use CNFs for any air traffic control purpose.

- CNFs are usually charted on Jeppesen aeronautical navigation products, are listed in the chart legends, and are for advisory purposes only. Pilots are not to use CNFs for point to point navigation (proceed direct), filing a flight plan, or in aircraft/ATC communications. CNFs that do appear on aeronautical charts allow pilots increased situational awareness by identifying points in the aircraft database route of flight with points on the aeronautical chart.

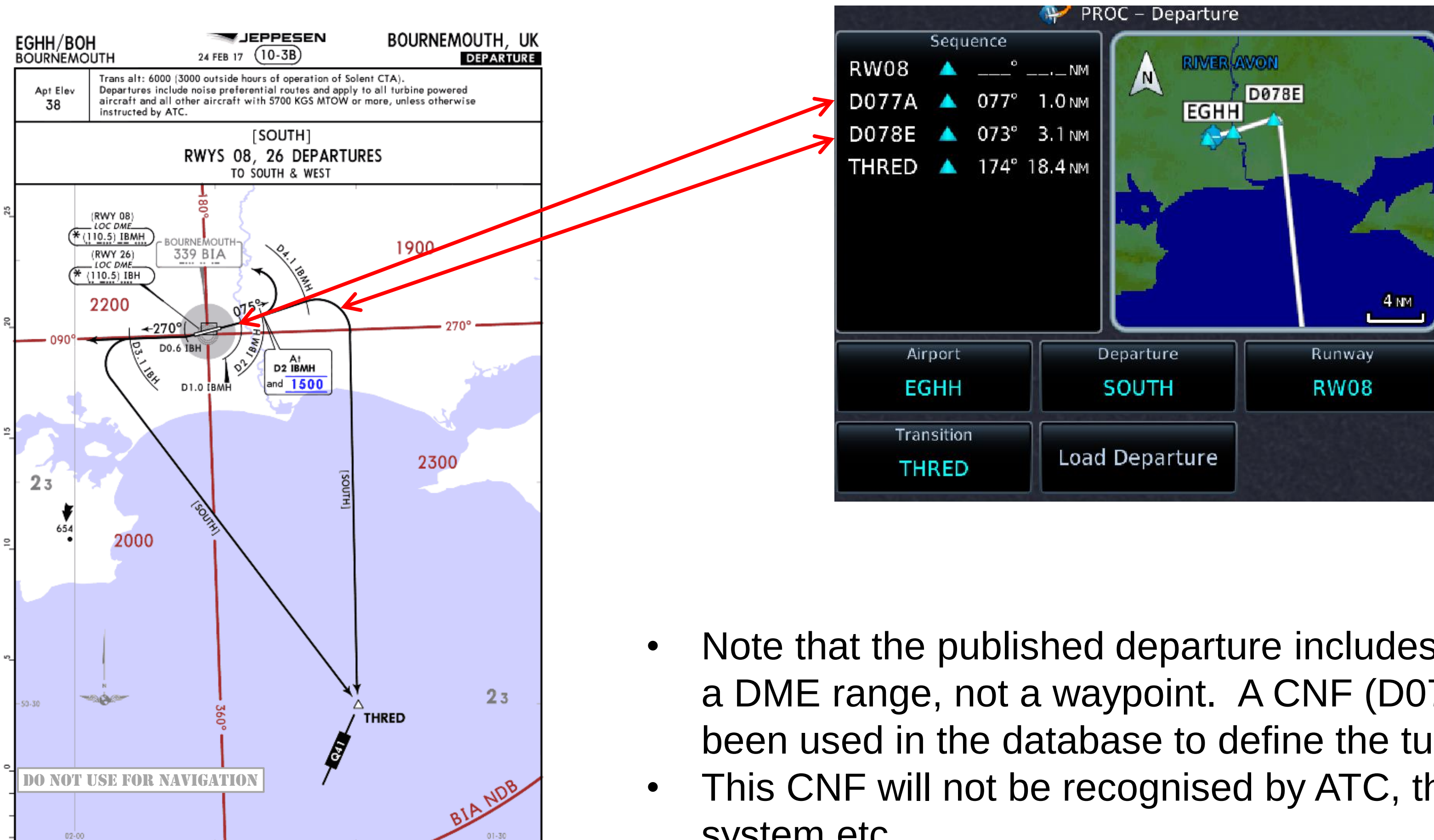
RNAV databases
6. Computer Navigation Fix (CNF) Naming

- CNFs are random five letter identifiers, and, unlike waypoints, are not pronounceable, and placed in parenthesis. Eventually, all CNFs will begin with the letters “CF” followed by three consonants (for example, CFWBG). This five letter identifier will be found next to an “x” on enroute charts and possibly on an approach chart.

- On instrument approach procedures(charts) in the terminal procedures publication, CNFs may represent unnamed DME fixes, beginning and ending points of DME arcs, and sensor (ground based signal i.e., VOR, NDB ILS) final approach fixes on RNAV overlay approaches.

- These CNFs provide the GNSS with points on the procedure that allow the overlay approach to mirror the ground based sensor approach. These points should only be used by the GNSS system for navigation and should not be used by pilots for any other purpose on the approach.

RNAV databases
7. Computer Navigation Fix (CNF) Application Example



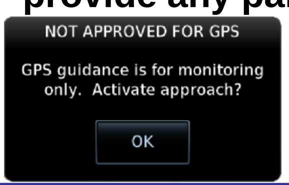
- Note that the published departure includes a turn at a DME range, not a waypoint. A CNF (D078E) has been used in the database to define the turn.
- This CNF will not be recognised by ATC, the FPL system etc

RNAV databases
8. Encoding of Both RNP and Overlays Of "Conventional" Procedures

- In paper chart form, procedures are 'conventional' (in the sense of requiring radio navigation) by default, unless specifically designated as RNAV or RNP procedures in the chart title, procedure name or chart notes.
- Generally, all published procedures are coded in GNSS databases (omnidirectional and radar procedures and some arrivals and departures are not)
- From the point of view of "coding style" and how GNSS procedure guidance may be used, this results in two kinds of database-coded procedure:

	1. "Database Overlays"	**2. RNAV Procedures**
	Traditional, non-RNAV procedures coded in the database using all the ARINC 424 path-terminators and CNFs as required	**Procedures designed and published for use only with RNAV equipment (ie for GA this means GNSS).**
Terminal Procedures	• In Europe, often terminal procedures are still conventional • These are coded as database overlays	• Generally RNAV 1 procedures • Coding uses RNAV waypoints and mainly the CF and TF path-terminators, with few, if any, CNFs needed
Approaches	• Many approaches in Europe are based on conventional navaids • These are coded in GNSS databases, providing advisory track guidance throughout the approach and missed approach procedures	• These are called RNP approaches, however if GNSS is required, the title must include either GNSS or GPS (see pp 104-105)
Use of GNSS for primary navigation guidance?	**For approaches, no. GNSS guidance is supplemental to radio aids. For SIDs and STARs above the MSA, named and coded in the database, yes.** 	**GNSS <u>required</u>; radio aids only used for gross error check. Appropriate approval requirements must be met** 

- **Note that the database display of procedure names, waypoints and path-terminators does not provide any particular distinction between RNP and overlay procedure**



- **GNSS units will generally provide a message alert when "monitoring only" guidance is activated for a database overlay procedure**

RNAV databases

9. Cross-checking Approved and Current Database with Published Charts

According to Jeppesen:

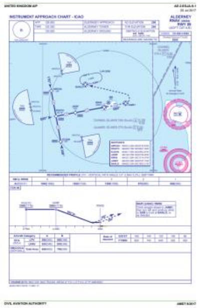
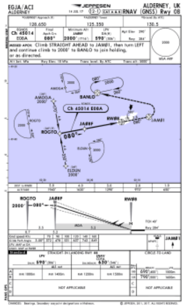
- Databases may not contain every SID, STAR and approach procedure.
- Database may not contain every leg or segment of the procedure being flown.
- Not everything needed is in the database.
- The location of each waypoint or navaid retrieved from the database should be confirmed.
- GNSS and electronic map displays with associated databases are not a substitute for current published charts.

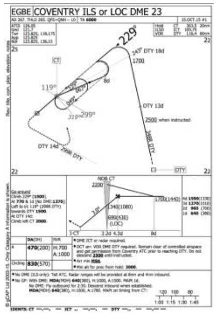
In addition:

- Many of the GNSS navigators used by GA aircraft do not display altitude restrictions, so they must be referenced from published charts (SIDs, STARs and Approaches, including stepdown fixes)
- Some databases for arrivals and departures only show altitude limitations for category C&D aircraft. Always check the database altitude limits against the published charts.
- Databases do not show minima
- Terminal Arrival Altitudes are not shown
- etc
- Appendix 3 explains the approval process for aeronautical data publishers

Published Charts
1. Overview

- ICAO Annex 15 states that ‘Contracting States shall ensure that the integrity of aeronautical data is maintained throughout the data process from survey/origination to the next intended user’
- There are numerous sources of authorised published charts, each with their pros and cons.
- We can divide the possibilities by:
    - Publisher
        - National AIPs
        - Jeppesen
        - Others
    - Cockpit Presentation
        - Printed
        - Home printed
        - Tablet - Standalone
        - Tablet - Embedded
        - Panel
- Any of these sources and methods are acceptable to the authorities, provided the pilot has the information available.




- National AIPs
  - Every state is obliged to publish charts and plates which meet a minimum set of ICAO standards
  - The standards allow considerable variation between states, meaning that the presentation, though consistent within a country, is variable between countries.
  - For example some states publish calculated approach minima, others only publish OCA/OCH and leave the operator to calculate their own minima according to the regulations.

Aircraft Category		A	B	C
OCA (OCH)	**Procedure**	**248**(193)	**255**(200)	**263**(208)
VM(C)OCA (OCH AAL)	**Total Area**	**600**(545)	**700**(645)	**900**(845)

System minima not accounted for

No RVR minima

  - AIPs are generally free to download in Europe and USA.
- Jeppesen
  - Republish aviation data in a standard format, which is the same worldwide.
  - This allows pilots to brief quickly and accurately, including minima, wherever they are.

Standard	STRAIGHT-IN LANDING RWY 05				CIRCLE-TO-LAND		
	ILS DA(H) AB: 255′(200′) C: 263′(208′) D: 272′(217′)		LOC (GS out) CDFA DA/MDA(H) 460′(405′)				
	FULL	ALS out		ALS out	Max Kts	MDA(H)	VIS
A	RVR 750m	RVR 1200m	RVR 1500m	RVR 1500m	100	600′(545′)	1500m
B					135	700′(645′)	1600m
C				RVR 1900m	180	900′(845′)	2400m
D	RVR 800m				205	1 900′(845′)	3600m

1 Not authorized South of rwy.

System minima increases DA

RVR minima calculated

  - Jeppesen is a fee-based commercial product and service.
- Others
  - There are other commercial republishers, who provide service similar to Jeppesen, but many of them are more limited geographically and in scope.

- Printed
  - It is possible to get printed charts and plates, with a monthly update cycle which need to be inserted in folders. This methodology was standard until electronic delivery became the norm, and is now unusual in GA.

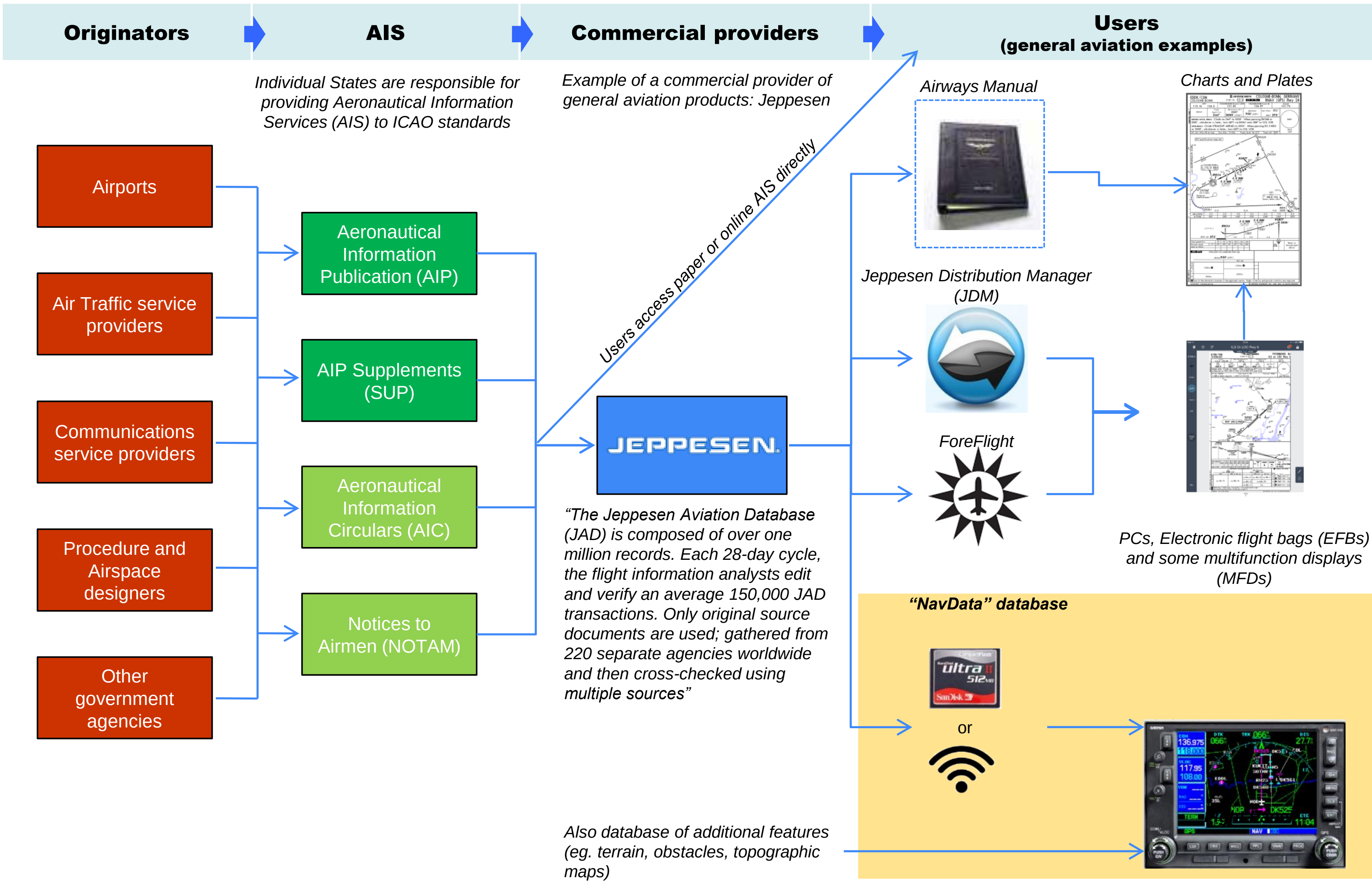
- Home printed
  - Many pilots like the security of carrying paper charts, but without the need to manually update books. They therefore print the charts required for a particular flight from a downloaded source. This reduces inflight flexibility, for example for diversions, so many people will also have a complete set of plates available electronically.

- Tablet/Electronic Flight Bag (EFB)
  - AIP, Jeppesen and other commercial plates are available in a number of formats on iPads and other tablets.
  - Some Apps georeference the plates (ie overlay the aircraft's current position).
  - Some App designers process the AIP plates (for example indexing.)

- Panel
  - Many avionic presentations on the flight panel can also show plates and may or may not georeference them.
  - They are available on both Multifunction Flight Displays (MFDs) and GNSS Navigators.

Extensive discussion on the pros and cons of all these methodologies is available on the PPL/IR website and forum.

Sources of Navigation Data
1. Concept of the "Aeronautical Data Chain"



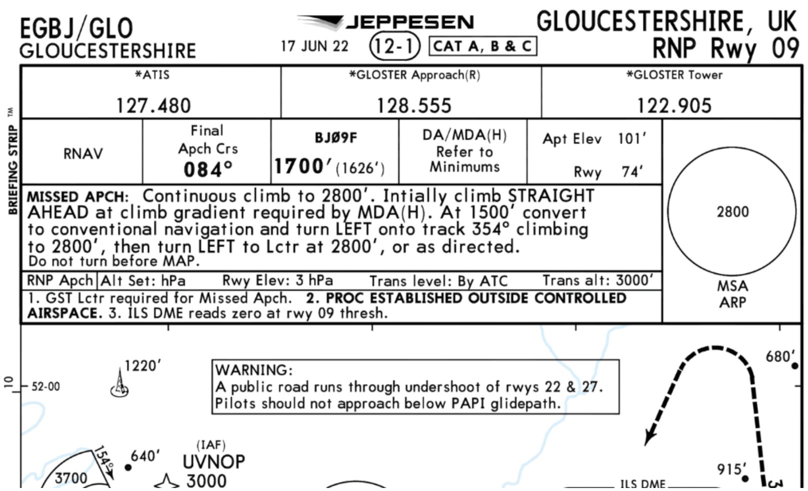
Sources of Navigation Data

2. Cross-checking Approved and Current Database with NOTAMs

Example: EGBJ Gloucestershire

EGBJ: RNP approach plate current in AIRAC cycle to 17 JUN 22	EGBJ: Airfield NOTAMs 1 Nov 2022

RNP Approach published, current and included in databases



…but RNP Approaches NOTAMed not available

EGBJ GLOUCESTERSHIRE GLO

REF: L0004/22
From:2022-Nov-01 Tue 10:57 To: 2022-Nov-08 Tue 10:00
ICAO:EGBJ GLOUCESTERHIRE
RNP APPROACHES NOT AVBL

Procedure Titles and Names
1. Overview

- Procedure names in Airway Manual paper charts are straightforward in principle, but a variety of different titles are used for terminal procedures, and there is some variation in how approach procedure names are constructed

3 kinds of procedure	Departures	Arrivals	Approaches
	collectively known as "Terminal Procedures"		
Paper chart procedure "titles"	• "SID" • "Departure"	• "STAR" • "Arrival" • "Transition" • "Initial Approach" • Continuation charts between a STAR and an approach	• Many types of approach: ILS, VOR, SRA, RNP etc • Some different standards for how names are constructed (eg. "ILS DME" vs "ILS" with DME requirement specified in chart notes)
Names and identifiers used in paper charts	• Procedure type in chart title • Procedure name on chart, plus….. • Procedure ICAO identifier in (curved brackets) • Database identifier in [square brackets] if different from ICAO identifier		• Chart title has the full procedure name

- The coding of procedure identifiers in GNSS databases is simpler. All Departure and Arrival procedure records have 3 selection attributes (or 'fields') and all approaches have 2 attributes

Procedure identifiers used in GPS databases	• Departure identifier • Transition identifier • Runway identifier	• Arrival identifier • Transition identifier • Runway identifier	• Approach identifier (which also specifies the runway) • Transition identifier or "Vectors"

Note that many procedures will only have one transition and/or runway selection available

- **The key links between published procedures and database coded procedures are the <u>procedure identifier</u> and <u>transition identifier</u>**
- **If the ICAO and database identifiers are not the same, the database identifier will be included on the paper chart in [square brackets]**

JACKO 1H [JACK1H]
RNAV ARRIVAL

Procedure titles and names
2. Background on Terminal Procedure Titles

- Terminal procedures always serve to provide safe obstacle and terrain clearance for flight in IMC (unless otherwise noted on the plate.)
  - “general” procedures, serving mainly this purpose, may be published in text and/or chart form, and may not have ICAO identifiers or even specific route names
- Terminal procedures may also be used for ATC and flight planning purposes: to standardise the transition between the enroute airway network and TMAs, and to standardise routes within TMAs, so that traffic flows may be efficiently managed and ATC communications simplified
  - procedures also serving this purpose are generally called “standard” instrument departures (SIDs) and “standard” arrivals (STARs)
- In practice, in Europe, most terminal procedures are SIDs and STARs, and “general” procedures, without the formal ATC function, are labelled “Departures” and “Arrivals”
- However, the nomenclature of terminal procedure titles is not perfectly standardised
- In particular, busy airports often use a more complex set of arrival procedure structures than just the basic model of STARs from the enroute segment to the IAF. These airports may also have arrival charts with a variety of titles such as “Arrivals”, “Transitions”, “Initial Approaches” etc. which have the same ATC status as STARs.
- Transitions can be named either after their start or end waypoint; there may be a naming discrepancy between that shown in the published chart and that displayed on the GNSS Navigator. If a Transition cannot be found on the Navigator, compare the name with the starting and ending waypoint on the published chart to see which is being used.
- The FAA also uses some slightly different procedure titles which are not detailed in this manual

Departures
1. Departure Names

Departure titles in Jeppesen charts:

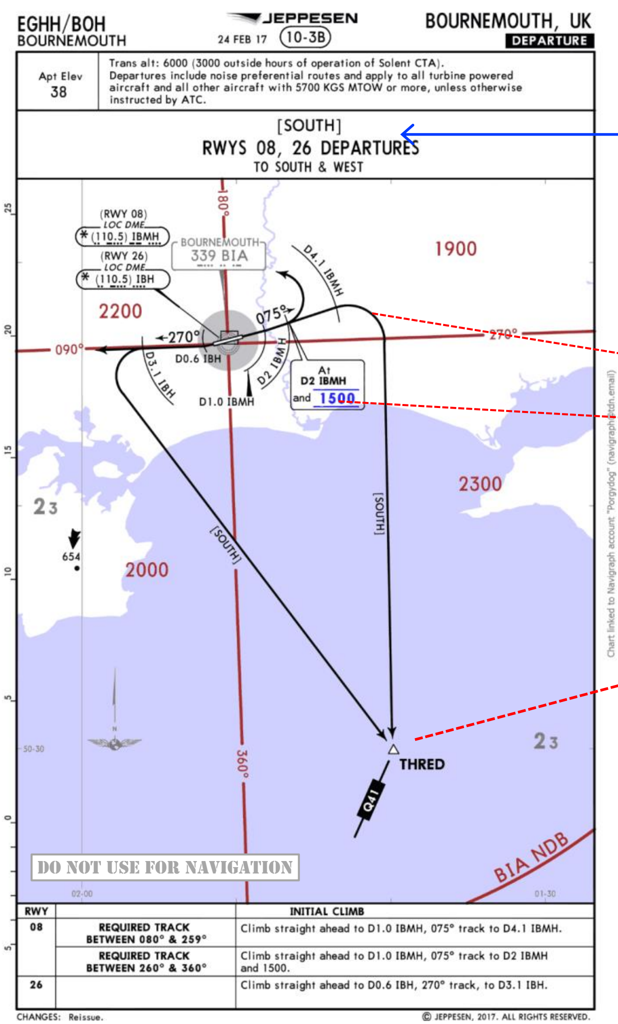
	'general' IFR procedures	standard IFR procedures
Traditional	DEPARTURE	SID
RNAV	RNAV DEPARTURE	RNAV SID

SID name format in Jeppesen charts:

	waypoint	1 digit	1 letter	(ICAO designator)	[database identifier]
Example:	BUZAD	THREE	JULIETT	(BUZAD 3J)	[BUZA3J]
	In Europe, usually the full name of the waypoint or fix at the end of the procedure	*Version number of the procedure, increased by 1 every time a change is made, cycling back to 1 after 9*	*Often the code letter for a particular departure runway. More than one letter may be used for the same runway, and the letter codes may have another meaning (eg. routes for Jet vs Prop aircraft)*	*The ICAO procedure "designator" is used for flight plan filing. It uses the ICAO identifier for the final waypoint instead of its full name (if these are different, eg. Lambourne Three Alpha vs. LAM 3A)*	*The ARINC 424 procedure name is limited to 6 characters. If the name of the final fix is a 3 letter VOR ident, the ICAO procedure identifier will be 5 characters (3+1+1) and used as the database identifier. If the final waypoint name is a Five Letter name Code (5LNC) (as in the example above), the database identifier will drop the last character of the 5LNC, and be printed separately in [square brackets]*

The structure of instrument departures is relatively simple and homogenous, they all start on the runway and generally end with an enroute waypoint

Departures
2. Example of a (non-SID) Departure



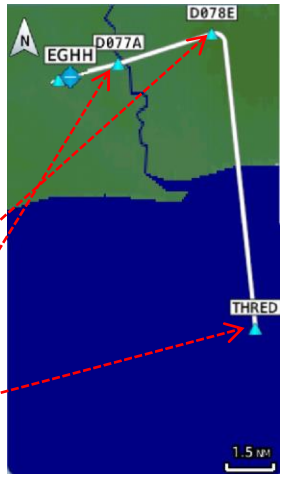
Note that, since these procedures are not SIDs and do not have an ICAO identifier, ATC will include the overall departure route as part of the clearance, eg. "G-ABCD, cleared to Jersey via THRED R41 ORTAC…" and not "G-ABCD, cleared to Jersey via Runway 08 South departure…"

DEPARTURE

RWYS 08, 26 DEPARTURES

TO SOUTH & WEST

Garmin GTN750 procedure selection page



The South departure is coded because it has a specific route (to THRED) and "South" is used as the database identifier even though there is no ICAO identifier. The West departure is not coded, since it lacks a specific route.

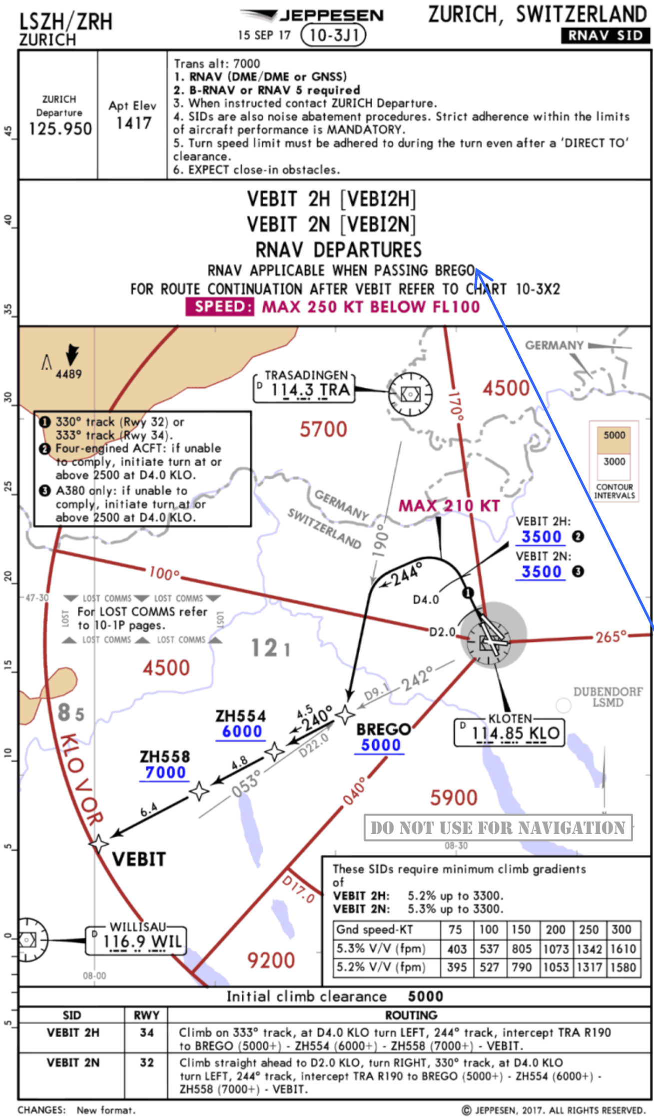
Garmin GTN flight plan waypoint list

Runway ID — RW08; *Bearing/Distance CNFs* — D077A, D078E

RW08	▲	___°	__._ NM
D077A	▲	077°	1.0 NM
D078E	▲	073°	3.1 NM
THRED	▲	174°	18.4 NM

Departures

3. Example of an RNAV SID



Gnd speed-KT	75	100	150	200	250	300
5.3% V/V (fpm)	403	537	805	1073	1342	1610
5.2% V/V (fpm)	395	527	790	1053	1317	1580

Initial climb clearance 5000

SID	RWY	ROUTING
VEBIT 2H	34	Climb on 333° track, at D4.0 KLO turn LEFT, 244° track, intercept TRA R190 to BREGO (5000+) - ZH554 (6000+) - ZH558 (7000+) - VEBIT.
VEBIT 2N	32	Climb straight ahead to D2.0 KLO, turn RIGHT, 330° track, at D4.0 KLO turn LEFT, 244° track, intercept TRA R190 to BREGO (5000+) - ZH554 (6000+) - ZH558 (7000+) - VEBIT.

CHANGES: New format.

This is an RNAV SID

RNAV SID

Zurich has mountains to the south. Notice the minimum climb gradients.

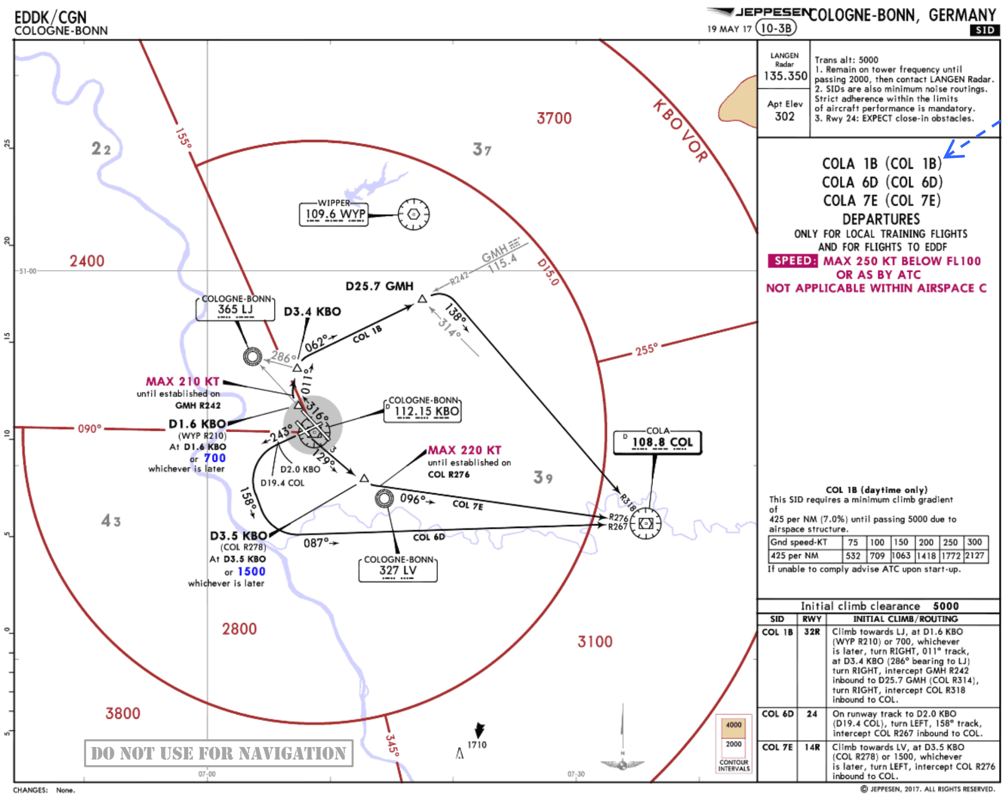
Note: The SID requires conventional VOR/DME navigation until reaching waypoint BREGO

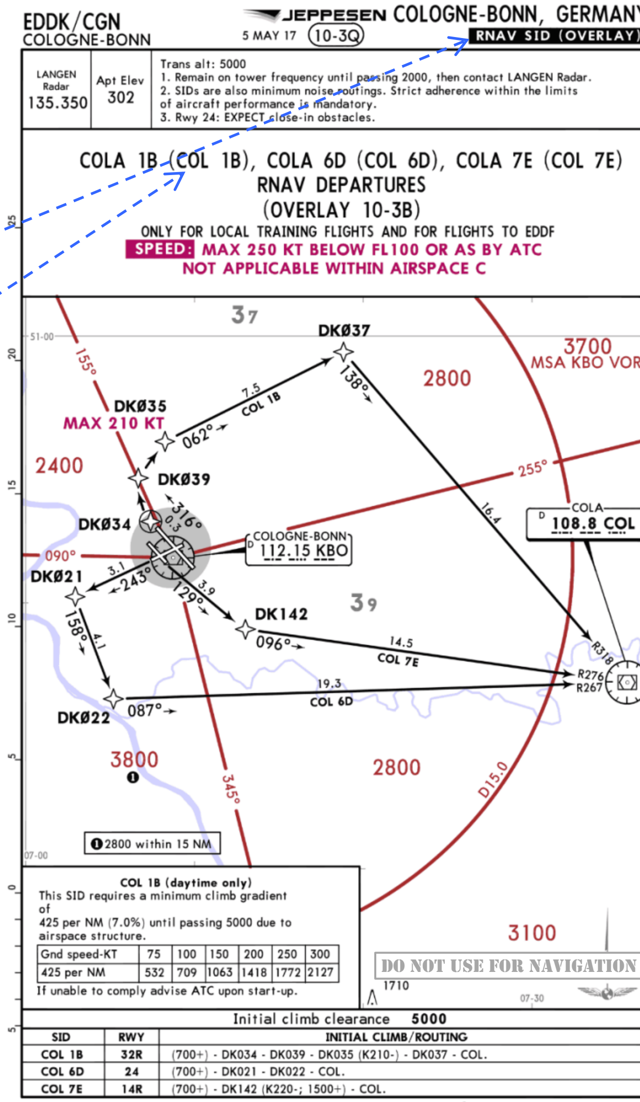
Departures

4. Example of an RNAV Overlay SID

Rather than design all-new RNAV SIDs, authorities often choose to overlay existing conventional SIDs with RNAV waypoints and CNFs.

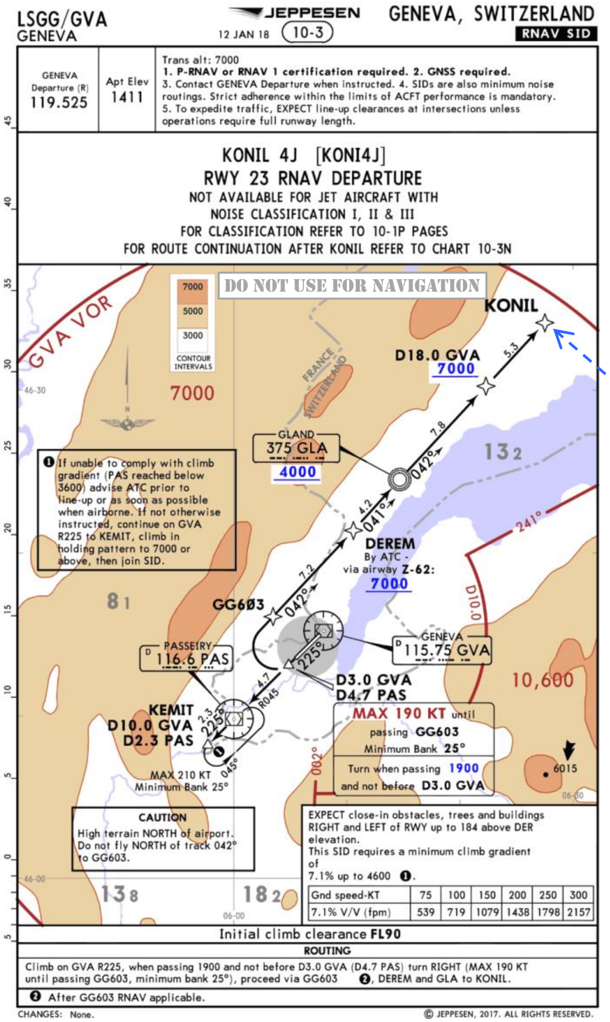
So far as flying the SID is concerned, the overlays are flown in exactly the same way as an RNAV SID, and the underlying conventional aids can be ignored.





Departures

5. Example of a SID Followed by Transition Routes

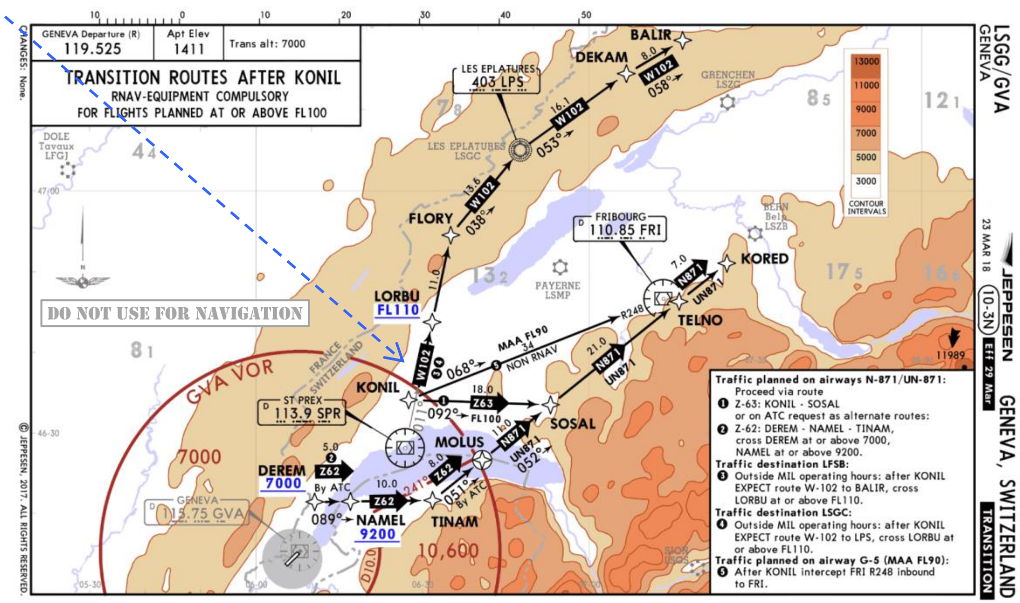


Some SIDs are followed by Transition routes onto the airways.

These Transitions may not be coded into the database, and the pilot may have to enter the waypoints manually into the flightplan.

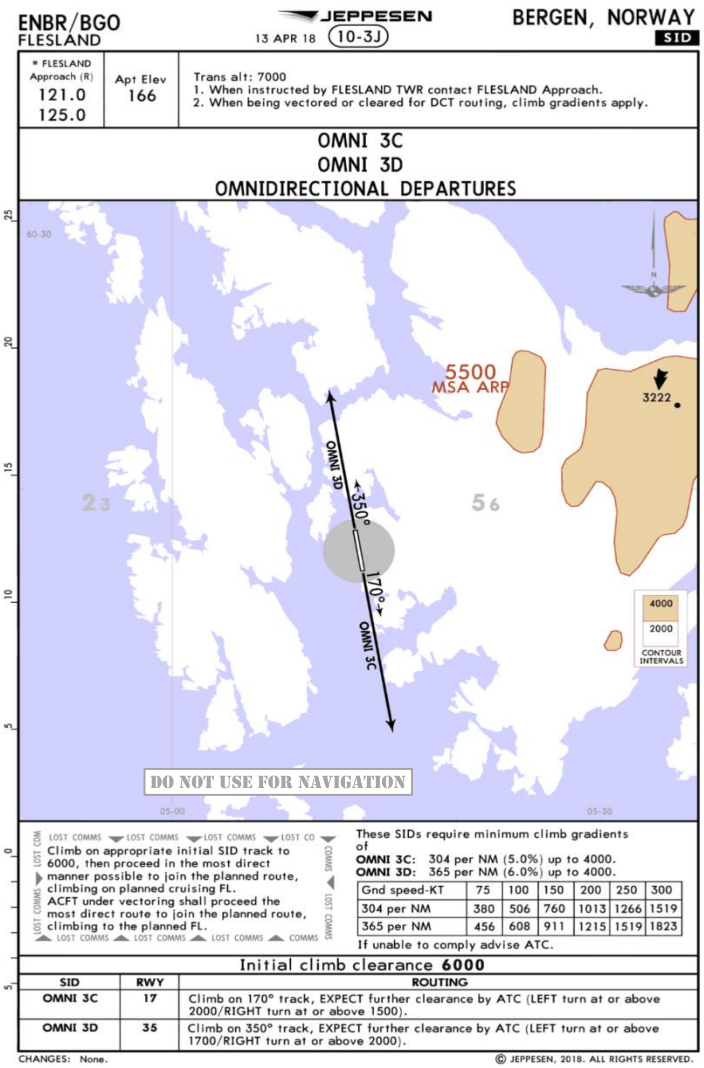
In the example below, route W102 is not retrievable from the Jeppesen database loaded into our navigators, because it does not pass through KONIL and we have no choice other than to enter KONIL FLORY manually, then load W102.

This is an example of why you need to check the flightplan waypoints before use. In the experience of both the authors, such gaps in the database can cause confusion and disorientation at a busy time!



Departures

6. Example of a SID which is not Coded in RNAV Databases

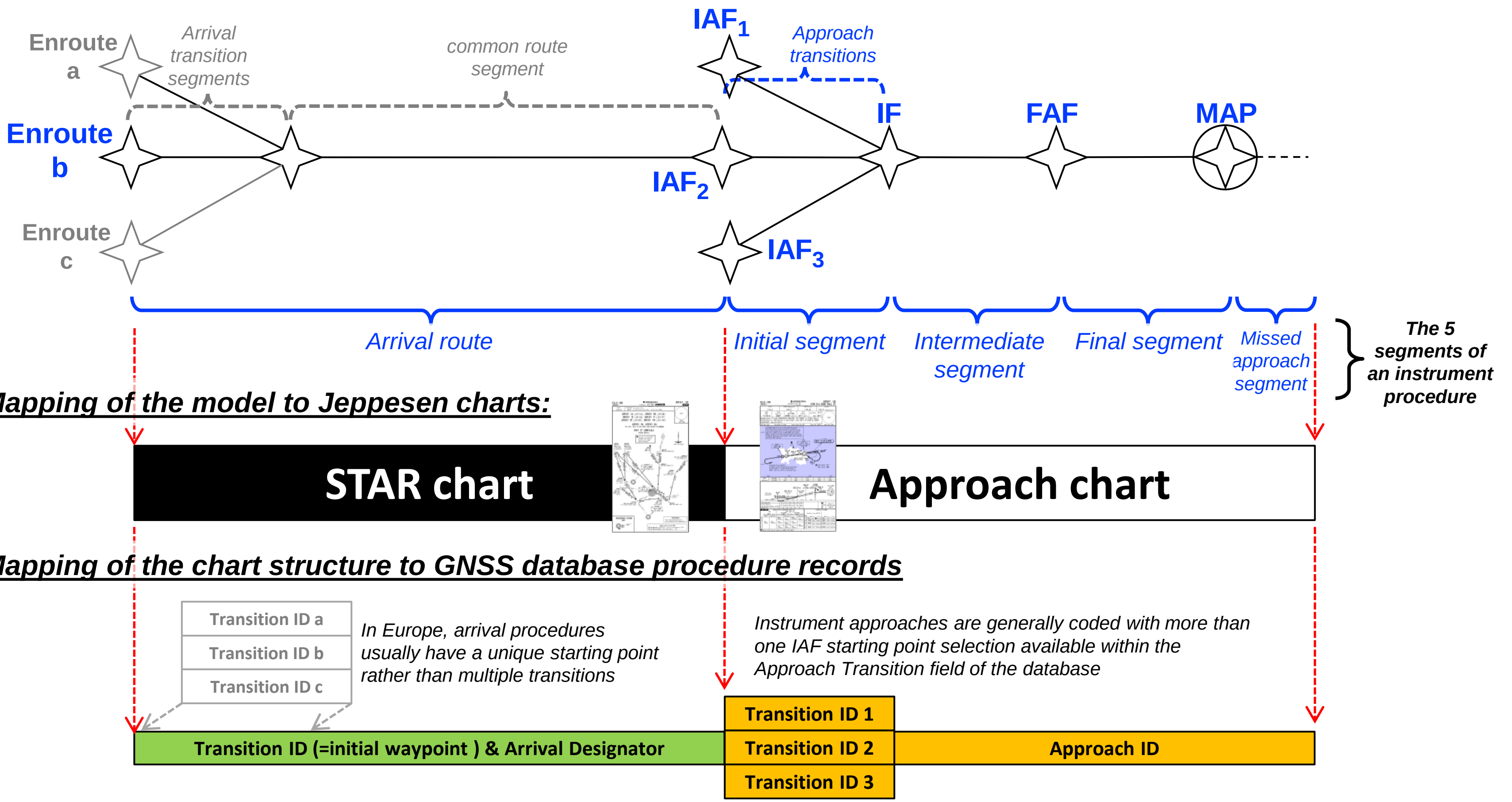


SID

Although this chart has a SID title, omnidirectional departures do not have a route structure, so they are not coded as a departure procedures in the database.

Structure of Arrival and Approach procedures
The ICAO model

The ICAO arrival and approach procedure model:



The typical arrival structure involves STAR routes beginning at enroute waypoints and ending at the IAF and Instrument Approach procedures starting at the IAF

Arrivals
1. Naming

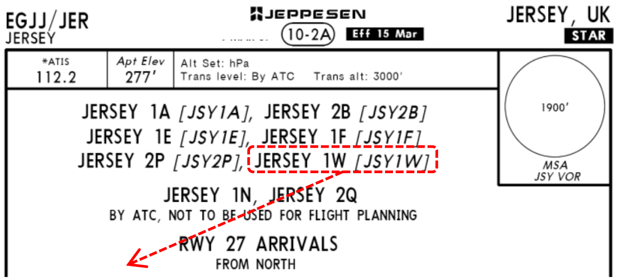
Summary of RNAV Arrival procedure titles in Jeppesen charts:

	‘general’ IFR procedures	<u>standard</u> IFR procedures
RNAV	RNAV ARRIVAL	RNAV STAR RNAV ARRIVAL RNAV TRANSITION RNAV INITIAL APPROACH

Note that an “Arrival” chart may be a ‘general’ route (not coded in the RNAV database), <u>or</u> a continuation route coded within the transition selections for an approach

Arrivals
2. Arrival Procedure Designators

Example: STAR designator



This is the name used by ATC, and also the ICAO designator if a shorter version is not printed in (curved brackets)

waypoint name ***1 digit*** ***1 letter*** ***[database identifier]***

Example: **JERSEY 1W** *[JSY1W]*

- Other than in the UK, usually the name of the waypoint or fix at the <u>start</u> of the procedure
- In the UK, usually the full name of the waypoint or fix at the <u>end</u> of the procedure. However the UK is now gradually changing towards the ICAO standard

Version number of the procedure, increased by 1 every time a change is made, cycling back to 1 after 9

A code letter for a specific arrival route. Important, because many different routes may share the same waypoint name. Otherwise, a route code, runway code or other ATC code.

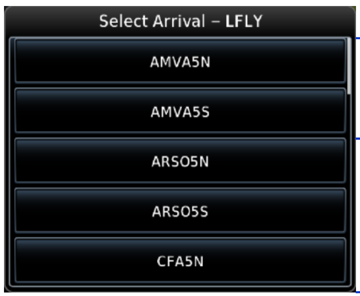
- the database identifier is printed in [square brackets]
- If the ICAO designator is a 5LNC, it will drop the last character
- If the ICAO name is a VOR, it will use the 3 letter ident of the VOR

- **Terminal procedure database identifiers are always in the format a a a n a or a a a a n a**
- **No other record uses this format. Other identifiers at the top of a "Transition" or "Initial Approach" arrival chart will denote a fix, waypoint or other kind of route name which, usually, means that the route is coded as a transition that is part of an <u>Approach procedure record</u>**

Arrivals
3. RNAV STARs and Arrivals

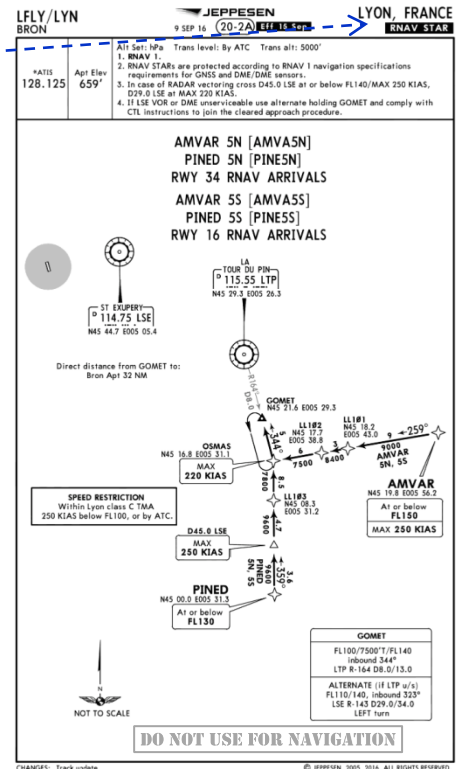
Some STARs and Arrivals are designed as RNAV procedures, but many are RNAV overlays of conventional procedures.

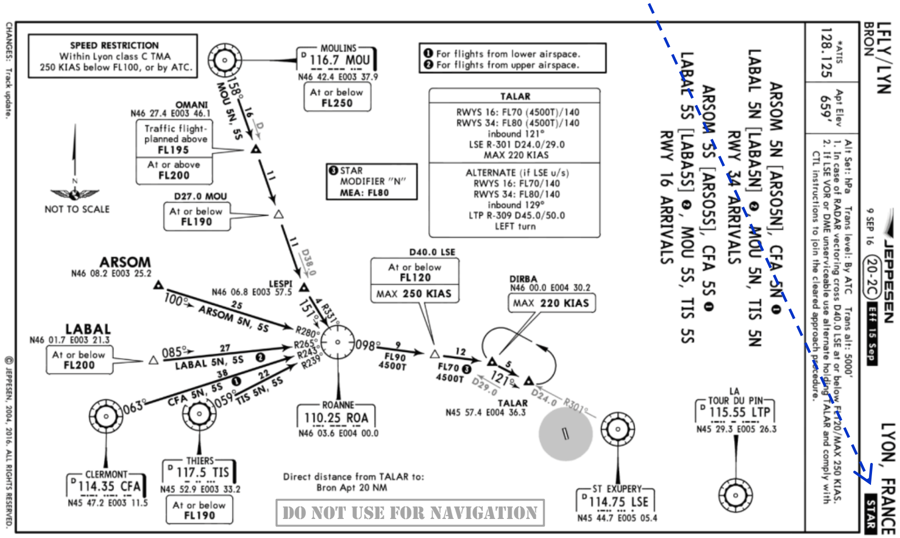
However, they are flown the same way. They are extracted from the database and the waypoints are loaded and flown using the same mechanisms.



RNAV STARS

RNAV Overlay STARS

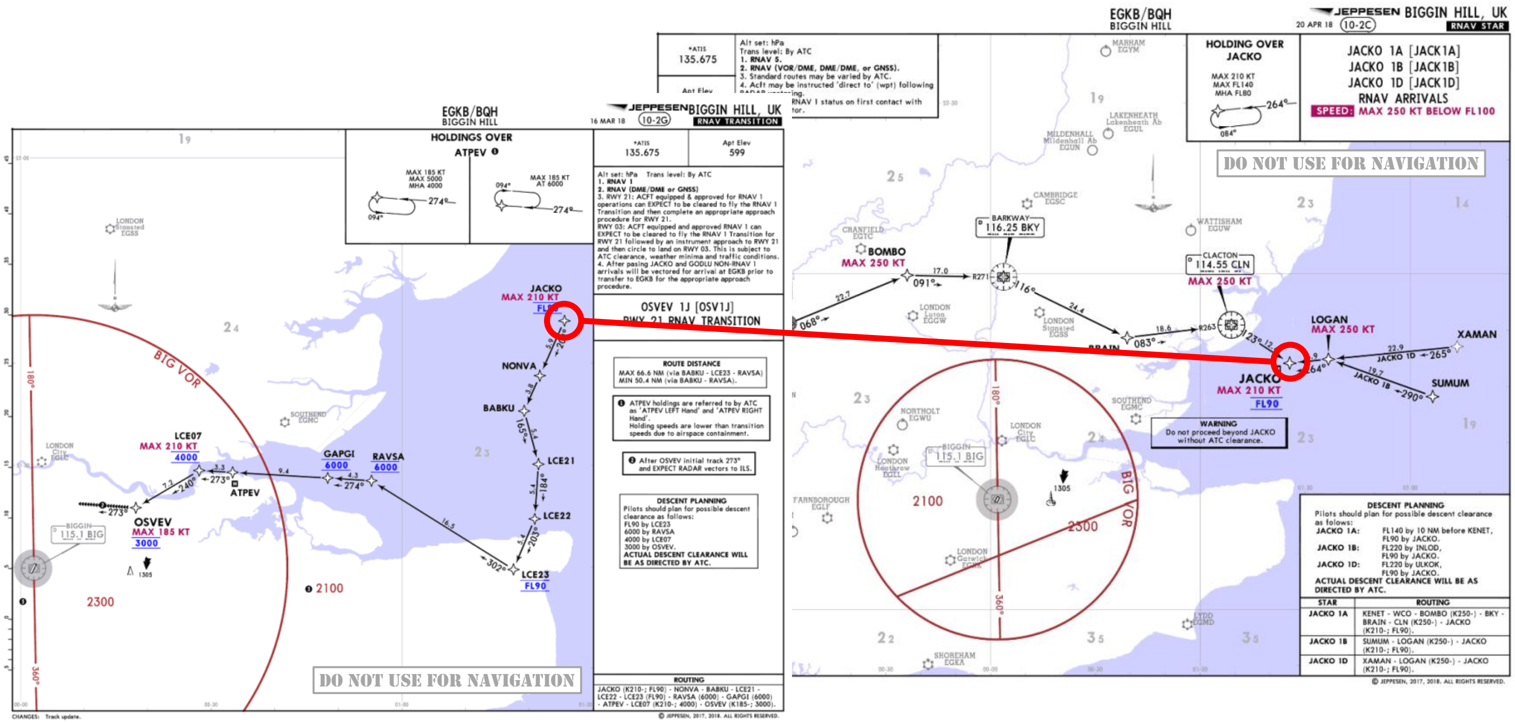




Arrivals

4. Example of RNAV STAR with Transition

Some Arrivals lead into Transitions between the end of the Arrival and the IAF.



Unfortunately, the database and GNSS receiver model does not allow for two consecutive procedures between the airway structure and the approach. For that reason, sometimes the Transition is combined with the STAR, and sometimes with the Approach, and naming conventions can be problematic.

This is another reason for careful advanced planning (for example, the OSVEV 1J Transition above is named as the JACKO Transition in Garmin receivers, and OSVEV1J is not mentioned.)

Approach Procedures - Names and Classifications
1. Introduction

- This section will review how conventional and RNP APCHs are coded and presented in GNSS databases, and the formats used for approach procedure names and database identifiers
- The examples illustrate the RNP APCH issues relevant to this section, but not every variety of procedure is detailed
- The description of Database Overlays does not mean that GNSS can be used as primary guidance for conventional approaches. The regulations state that the underlying aids must be used on final approach
- Some receivers do not provide guidance for some of the path-terminators used in database approach overlays. A pilot relying on such GNSS guidance may find that it is suspended, and no "magenta line" and CDI indication (or autopilot LNAV commands) are present during critical segments of approach or missed approach procedures
- We will present the formal ICAO model of approach classification on the following pages, but the table below is a simple summary

	Database Overlays	RNP APCHs
Approved flight procedure	• Only up to FAF	• Yes
Precision Approach Procedure (PA)	• Most ILS approaches are coded as database overlays	• GLS approaches (not used by GA) • LPV approaches with 200' DH
Approach with Vertical Guidance (APV)		• LPV approaches with higher DH • LNAV/VNAV approaches
Non-Precision Approach Procedure (NPA)	• Most published conventional non-precision approach procedures (VOR,NDB) are coded as database overlays • Radar approaches are not coded	• LNAV approaches • LNAV+V (Garmin – Advisory GS only)

Approach Procedures - Names and Classifications

2. Naming Conventions

- Given the rapid development of RNAV and PBN, not surprisingly there are differences in the way that approaches have been classified and named.
- Historically, GNSS based approaches have had chart titles including GPS, GNSS, RNAV, RNAV(GPS) and RNAV(GNSS). However, all these approaches have always required on-board self-contained performance monitoring and alerting, which means that they are all RNP procedures.
- ICAO has recognised that the historical naming conventions are not logical, and has decided that all GNSS based approaches should be modified to be named either RNP or RNP(AR). *(RNP(AR) is only used where operators need authorisation to use them and their details are outside the scope of this manual.)*
- Also, ICAO have changed the classification of approaches over the last few years
- Another point that can cause confusion is that the minima lines of an approach (eg LPV, LNAV/VNAV and LNAV) do not define the approach. Strictly speaking, we should say 'an RNP approach to LPV minima', but for simplicity, this is informally referred to as an 'LPV approach'. On R/T it should be referred to as an RNP approach, regardless of the minima line being used, as ATC does not know or care what minima can be used by the GNSS receiver; they will refer only to the approach described by the chart title.
- Even if the designation within the GNSS receiver remains RNAV, the designation on the AIP and Jeppesen plates is RNP, and that will the terminology used by ATC, and the pilot should use the same terminology.
- If the GNSS database in the aircraft receiver is up to date, then the discrepancy between the R/T designation used by ATC and the designation in the GNSS database can be ignored.

Approach Procedures - Names and Classifications
3. Overview of New Approach Classifications ICAO Annex 6

- ICAO has introduced a new method of classifying instrument approaches and approach operations, set out on the following page. This new classification is intended to simplify and more accurately describe the various types of approaches, harmonise the classification system with the introduction of RNP approaches and optimise runway requirements in relation to both RNP and conventional approach operations.
- The new classification is intended to separate:
  - the way the crew flies the approach in practice ("The Approach Operation")
  - the type of runway at the end of the approach ("The Approach Runway")
  - the specification of the underlying instrument approach technology ("The System Performance Procedure")
- Approach operations are divided into
  - 3D approach operations, in which a continuous indication of vertical deviation (ie glidepath), is available
  - 2D approach operations, in which it is not
- 3D approach operations are further divided into Type A or Type B depending on the DH (>= or < 250 ft)
- To illustrate the new classification with examples:
  - An RNP APCH APV approach may be designed to a non-instrument runway. It would be flown as a 3D Type A approach operation, with minima higher than those typically used to a precision approach runway (described in the table as "VMC")
  - An RNP APCH non-precision approach might be flown (both to the LNAV minima line):
    - As a 2D approach operation with the crew cross-checking level vs distance
    - As a 3D Type A approach operation, using advisory vertical guidance on the vertical deviation indicator (e.g. Garmin's LNAV+V mode)

Approach Procedures - Names and Classifications
4. Complete Classification

Below is the ICAO table giving all combinations of Type, DH, Runway and System Performance

<table>
<tr><td rowspan="4">Approach Operations
(Annex 6)</td><td rowspan="2">Classification</td><td colspan="2">Type A</td><td colspan="3">Type B</td></tr>
<tr><td colspan="2">(>=250’)</td><td>CAT I (>=200’)</td><td>CAT II (>=100’)</td><td>CAT III (<100’)</td></tr>
<tr><td>Method</td><td>2D</td><td colspan="4">3D</td></tr>
<tr><td>Minima</td><td>MDA/H</td><td colspan="4">DA/H</td></tr>
<tr><td rowspan="5">Approach Runways
(Annex 14)</td><td>M(DA/H)>=VMC</td><td colspan="2">Non-Instrument Runway</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>M(DA/H)>=250’
Visibility=1000m</td><td colspan="2">Non Precision Approach Runway</td></tr>
<tr><td>DA/H>=200’
Visibility>=800m
or RVR>=550m</td><td colspan="3">Precision Approach Runway, Category I</td><td colspan="2"></td></tr>
<tr><td>DA/H>=100’
RVR>=300m</td><td colspan="4">Precision Approach Runway, Category II</td><td></td></tr>
<tr><td>DA/H>=0’
RVR>=0m</td><td colspan="5">Precision Approach Runway, Category III (A, B & C)</td></tr>
<tr><td rowspan="3">System Performance Procedures
(Annex 10)</td><td>NPA</td><td colspan="2">NDB, LOC, VOR, Azimuth, GNSS</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>APV</td><td rowspan="2"></td><td>GNSS/Baro /SBAS</td></tr>
<tr><td>PA</td><td colspan="4">ILS, MLS,SBAS GBAS</td></tr>
</table>

Approach Procedures - Names and Classifications

5. ICAO Annex 10 Definition of Approach Types

- ICAO Annex 10 recognises three classes of instrument approach:

NPA	APV	PA
Non-Precision Approach	**Approach with Vertical Guidance**	**Precision Approach**
Based on a navigation system that provides course deviation information, but no glide path *Procedures have an MDA(H), but, increasingly, where continuous descent final approach (CDFA) techniques are to be used, a DA(H) may be published instead, however both EASA and FAA require the pilot to avoid flying below the MDA/H.*	Based on a navigation system that does not meet the precision approach standards of ICAO Annex 10 but which does provide course and glide path deviation. *Procedures have a DA(H) rather than an MDA(H)*	Based on a navigation system that provides course and glidepath deviation which meets the precision standards of ICAO Annex 10 *Procedures have a DA(H)*

Examples based on traditional radio aids and radar:

VOR, NDB, LOC, LDA, SRA	**LDA with glidepath** (an ILS-like installation not meeting PA criteria, eg. because of the localiser offset from the runway)	**LPV200, ILS, PAR**

Examples based on GNSS:

RNP approach procedures to LNAV minima “Published overlay” or “stand-alone” GPS non-precision approaches, which use LNAV minima	**RNP approach procedures to LNAV/VNAV minima** Vertical guidance provided by SBAS-GPS or Baro-VNAV systems available only in a few light aircraft **RNP approach procedures to LPV 250’+ minima** Vertical guidance provided by SBAS-GPS. Procedure may ‘downgrade’ to LNAV/VNAV minima if satellite signal or runway environment/lighting does not meet LPV criteria	**LPV200** LPV with a DH < 250’

6. Names

- Traditionally the aids to be used for an approach are specified in the approach title. For example, if the title is ILS/DME/NDB, then all three receivers must be available for the approach to be flown.

CAMBRIDGE
ILS/DME/NDB(L)
RWY 23
(ACFT CAT A,B,C,D)

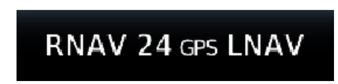
- In this manual we are focussing only on GNSS equipment, but RNP approaches are technology independent. Although RNP approaches are intended to be technology independent, at the time of writing only GNSS equipment is capable of meeting the performance criteria.
- ICAO has specified that all such approaches should be labelled RNP. However, the USA has, for the moment, not agreed this standard and will retain the RNAV(GPS) in its approach plate titles.

Approach Procedures - Names and Classifications

7. Names

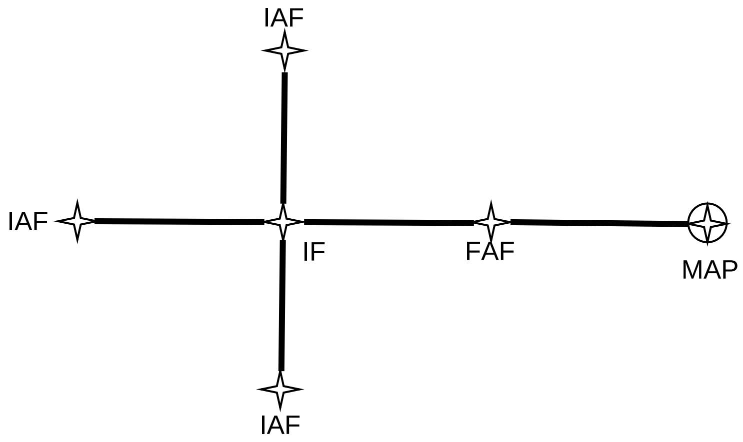
- All AIP and commercial approach plate titles outside USA have been changed to RNP RWY XX.

- However, the receiver databases will continue to show RNAV XX GPS until converted; at present there are no plans for this conversion process. **This can cause confusion with ATC, and the designation on the plate should be used in ATC communications.**



- AR Approaches
  - Approaches which require specific operator authorisation are called 'Authorisation Required' (AR).
  - For AR approaches, outside of the USA, 'Authorisation Required' approaches will gradually be renamed to RNP RWY XX (AR) in the AIP in line with the ICAO.
  - Additionally, at the time of this edition, the FAA will continue to use RNAV (RNP) RWY XX for AR approaches.
  - This has potential for confusion, as pilots in the USA need authorisation for approaches with RNP in their title, but, in the rest of the world, they may fly approaches named RNP. Outside the USA, “AR” in the title denotes the requirement for authorisation.

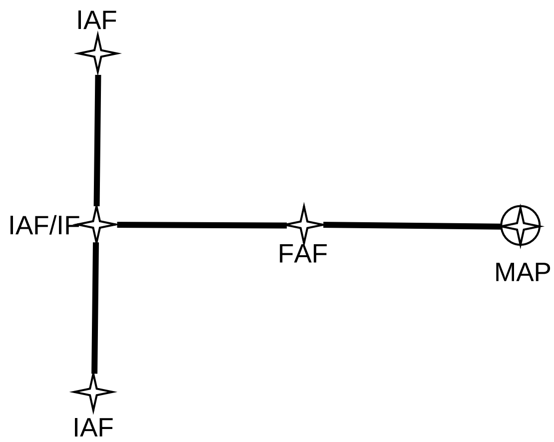
- The purpose of an instrument approach is for the aircraft to arrive at the DA in stable flight, at the correct place and pointing in the right direction.
- To achieve this, a Final Approach Fix (FAF) is created, generally on the extended centreline of the runway, from which a stable descent can be commenced.
- In order to ensure that the aircraft arrives at the FAF at the correct altitude, speed and track an Intermediate Fix (IF) is placed, normally between 3.3 and 5nm before the FAF, on the same track as the Final Approach. The altitude at the IF is the same as, or not far above the altitude at the FAF.
- To ensure that the turn at the IF is not so acute as to compromise the stability of the Intermediate Segment, Initial Approach fixes are normally established, such that the turn at the IF does not exceed 90°. *(Although the EASA rules permit a turn of 110° on a non-precision approach, that option is rarely used.)*
- The most “obvious” layout to achieve this is:



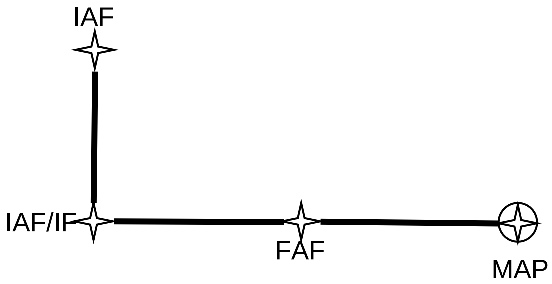
RNP Approach Procedures
2. Variations on a Theme

- However, this ideal shape often has to modified to take account of obstacles, airspace requirements etc

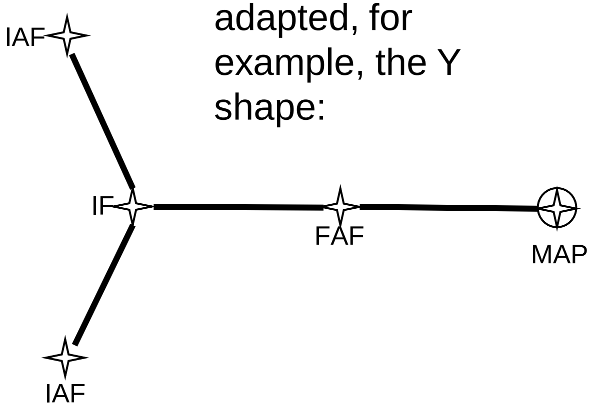
  - It is very common to see the IF also used as an IAF:



- Sometimes, whole legs, or IAFs are omitted, for example:



- Sometimes, the shape has to be adapted, for example, the Y shape:

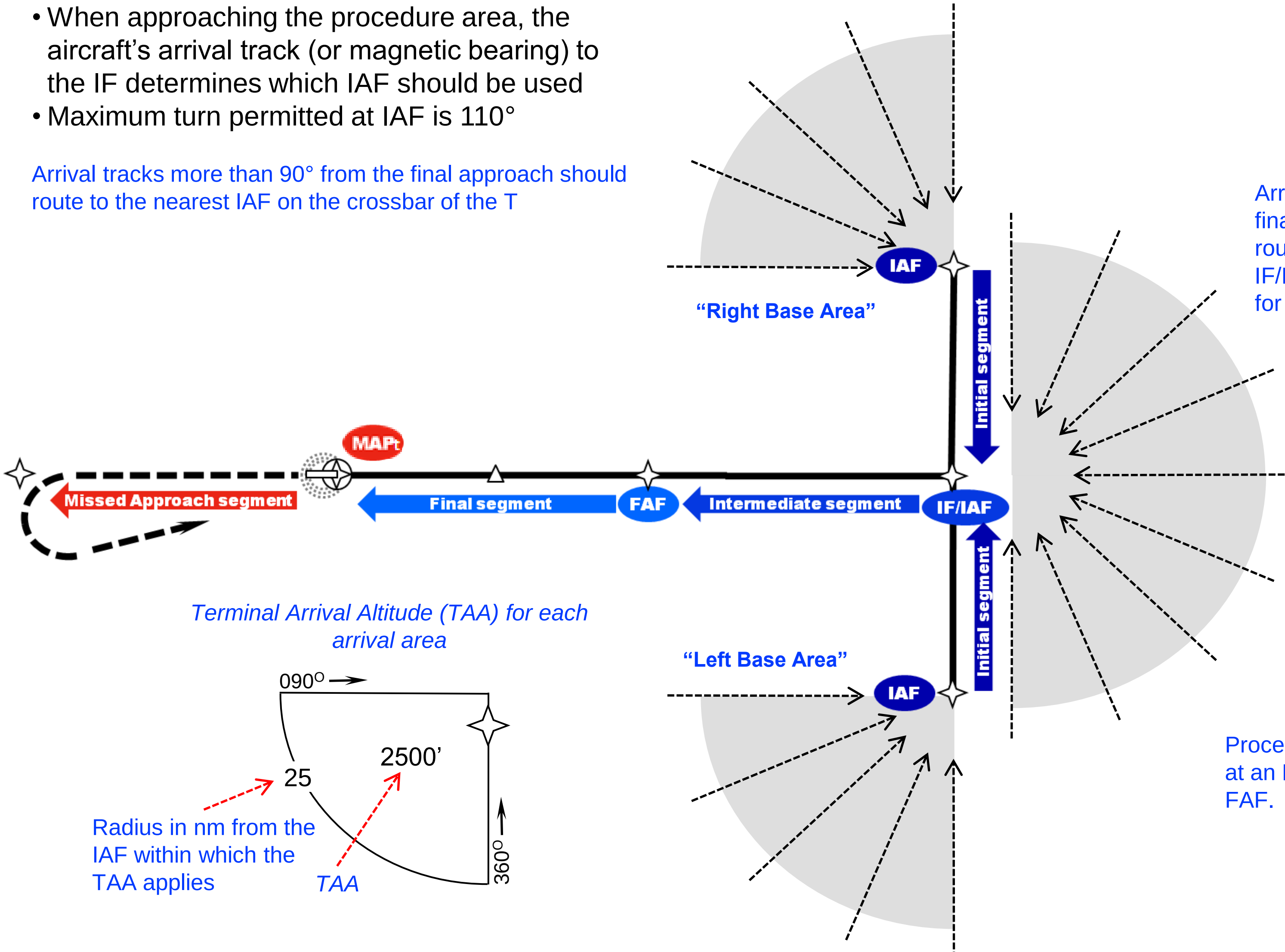


RNP Approach Procedures
3. Summary

- When approaching the procedure area, the aircraft's arrival track (or magnetic bearing) to the IF determines which IAF should be used
- Maximum turn permitted at IAF is 110°

Arrival tracks more than 90° from the final approach should route to the nearest IAF on the crossbar of the T

Arrivals within 90° of the final approach track should route to the dual purpose IF/IAF at the head of the T for a straight-in approach



Terminal Arrival Altitude (TAA) for each arrival area

Radius in nm from the IAF within which the TAA applies

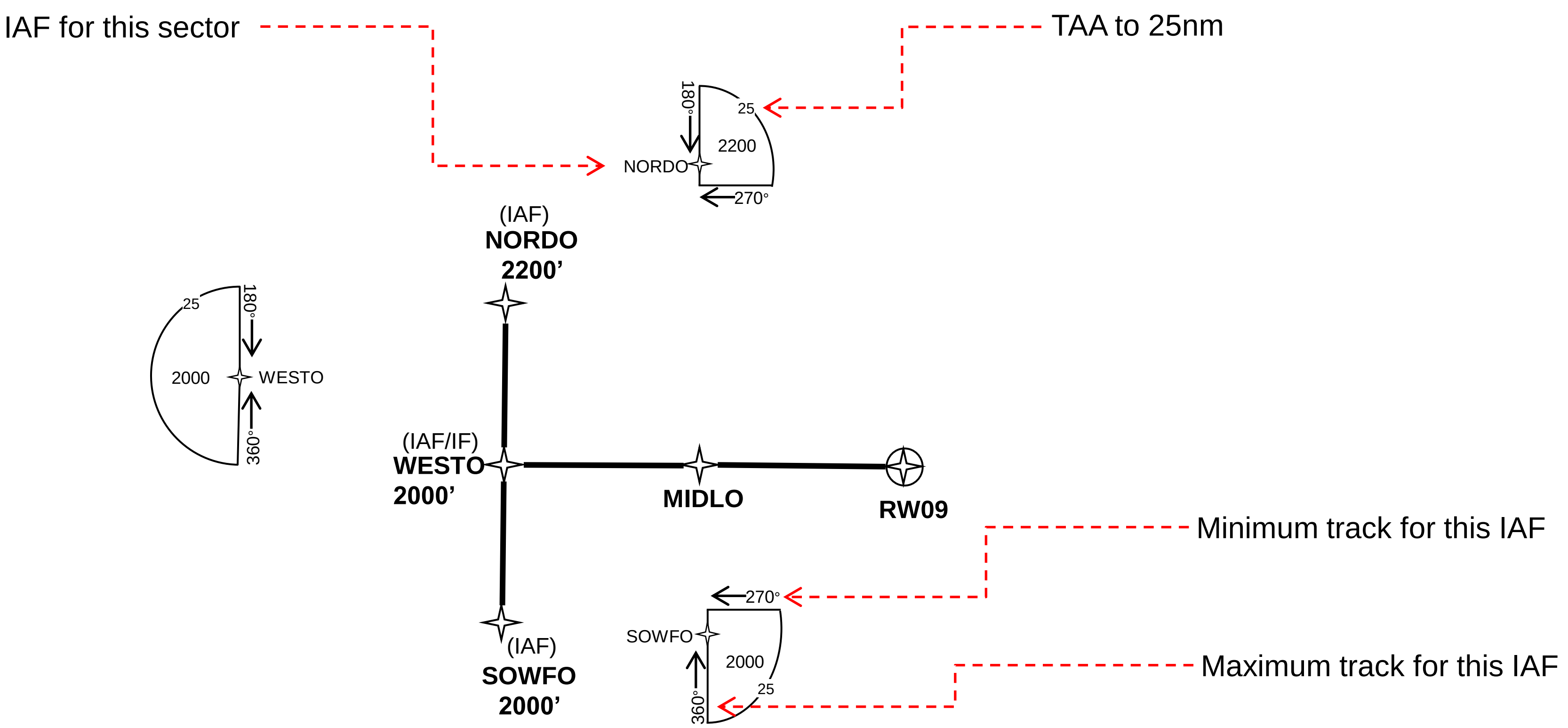
TAA

Procedures should commence at an IAF or IF, and not at the FAF.

RNP Approach Procedures

4. Choice of IAF and the Terminal Arrival Altitude (Simple)

- Normally, the decision as to which IAF is used will be determined by the track of the aircraft. This is to ensure that the turn at the IAF is not excessive (ie > 110°)
- The correct IAF is shown by adding segments to the charts, which show the acceptable track to each IAF and containing the Terminal Arrival Altitude for that segment.
- Note that the TAA segment extends slightly beyond the IAF towards the centreline, so that the entire 360° is covered.
- The TAA is the minimum terrain safe altitude; it is not the procedure altitude, which is marked separately.
- Once cleared for the approach, and inside the TAA sector, the pilot may descend to the TAA, and then follow the procedure altitudes.

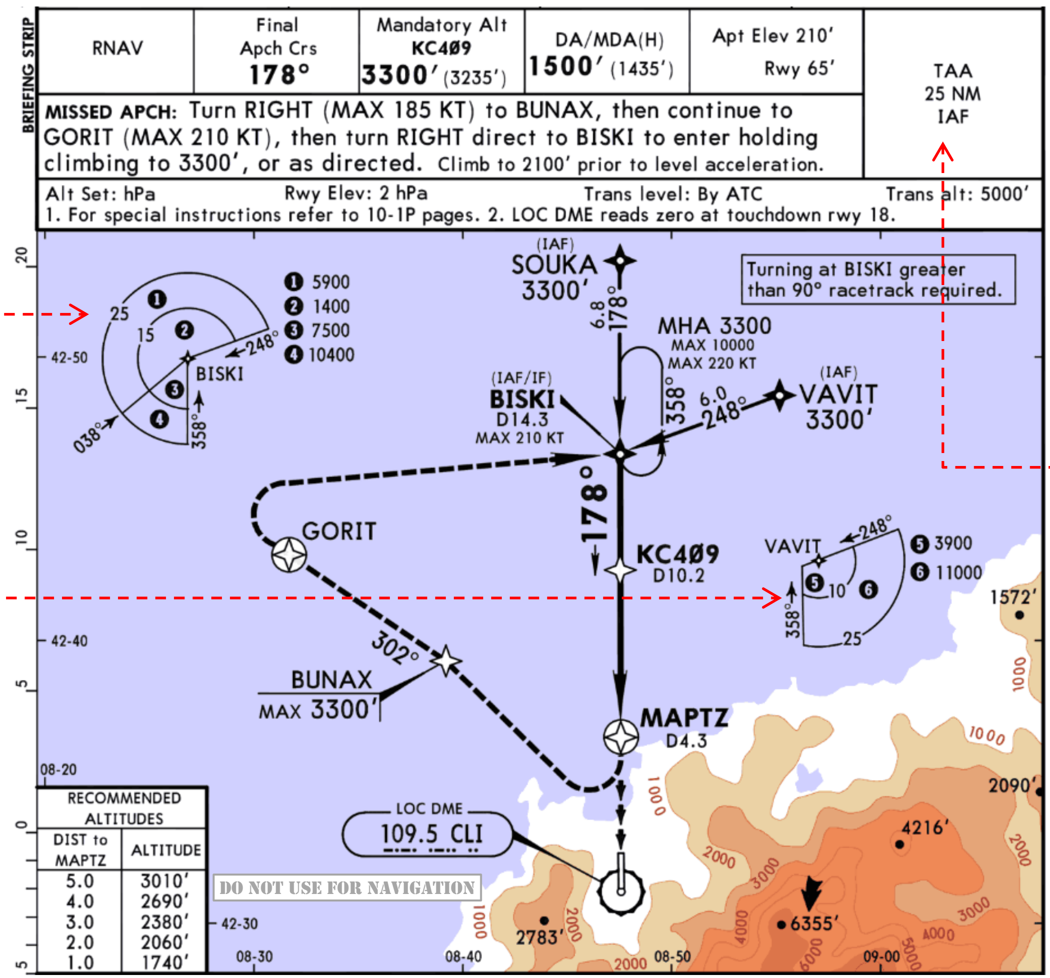


RNP Approach Procedures

5. Choice of IAF and the Terminal Arrival Altitude (Complex)

- Below is a more complex example of a TAA segment. Such complexity is usually applicable where there is significant terrain near the airfield.

Note the different altitudes at different ranges and segments



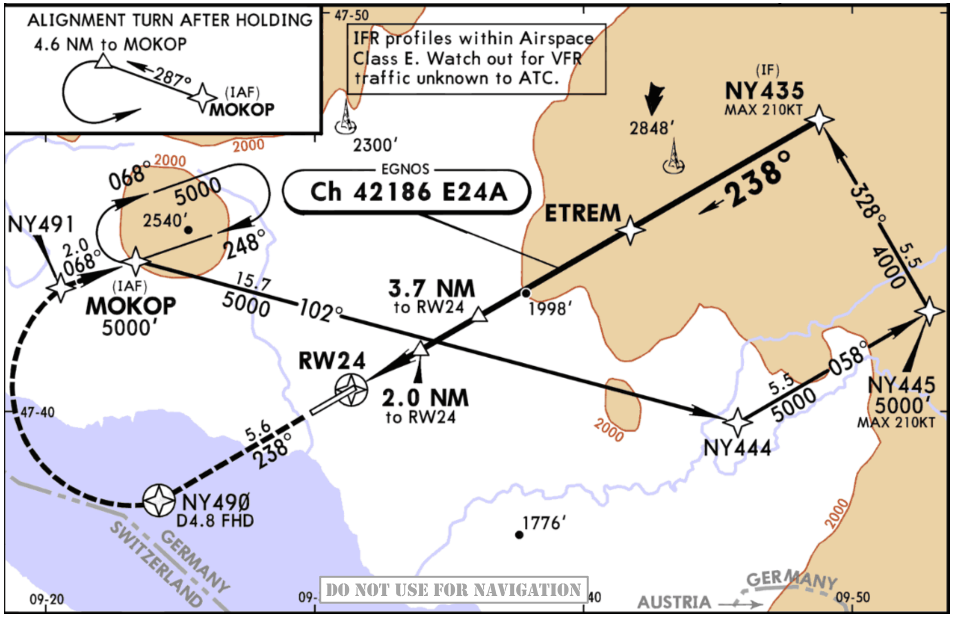
Although there is usually an MSA on each plate, for use before the aircraft is cleared for the approach, in this case it is omitted in favour of the TAA, presumably because the TAA is more detailed.

Please note that the TAA allows an initial track of 358° to VAVIT, which then requires a left turn of 110° (greater than 90°) to intercept the track of 248° from VAVIT to BISKI.

RNP Approach Procedures

6. The Standard Structures are not used in all RNAV Approaches

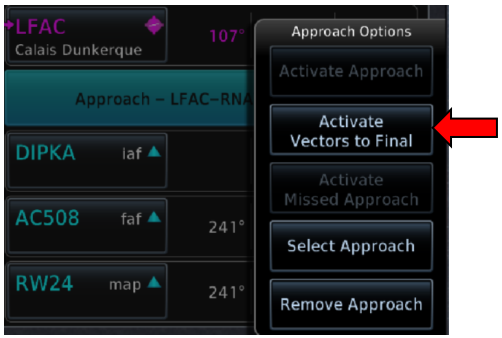
- Not all RNP approaches follow the Y, T or trident format. There are many variations, for example:

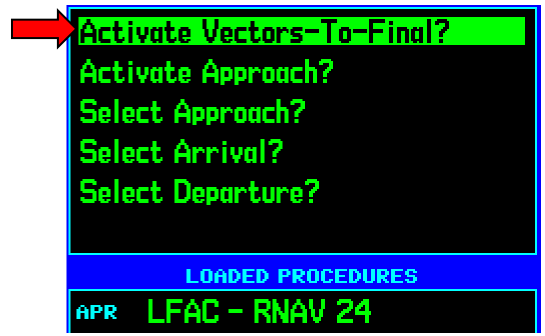


- In this example, there is only one IAF, regardless of arrival track, and, if necessary, an alignment turn must be made.
- This demonstrates the necessity of careful self briefing in good time before commencing the approach.

RNP Approach Procedures
7. Radar Vectors to Final Approach

- If, instead of being cleared for a procedural approach via an IAF, ATC gives radar guidance or vectors to the final approach, the pilot should “Activate Vectors to Final” when the first vector is given:

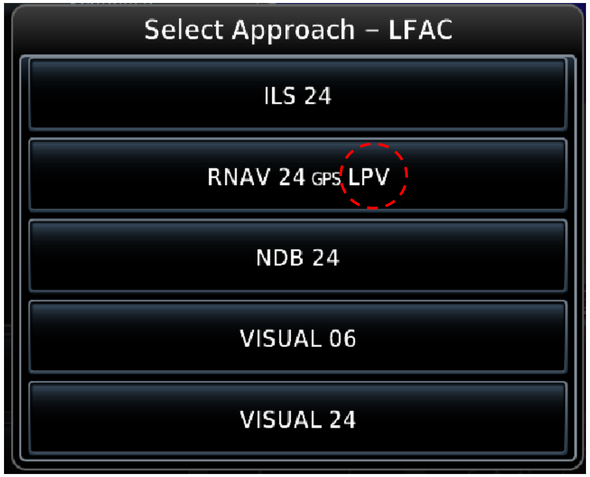




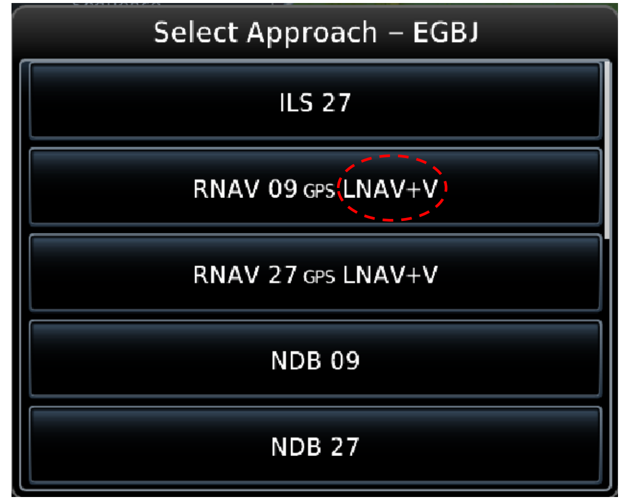
- Controllers must ensure that the turn at the IF does not exceed 90° for a precision approach or 110° for a non-precision approach.
- "Direct to" clearances to the IF may be accepted provided that it is clear to the pilot-in-command that the aircraft will be established on the final approach track at least 2 NM before the FAF.
- The following must <u>not</u> be accepted:
  - Vectoring to intercept the final track less than 2nm before the FAF
  - "Direct to" clearances to the FAF
  - "Direct to" clearances to a waypoint which does not belong to the procedure
- Manual input into the GNSS navigator by the pilot of user waypoints for use in the terminal area is not authorised

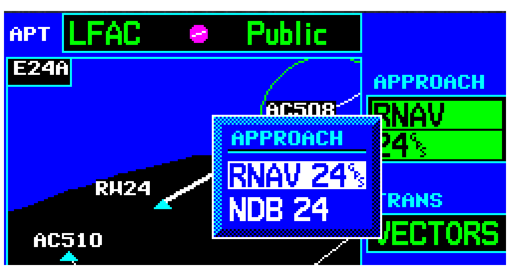
RNP Approach Procedures
8. Procedure Names in Navigators

- Some Navigators show the level of precision available on final approach, others only that it is an RNAV approach.
- Even though the AIP plate is titled RNP, it could appear as “RNAV” or “GPS” in the navigator:

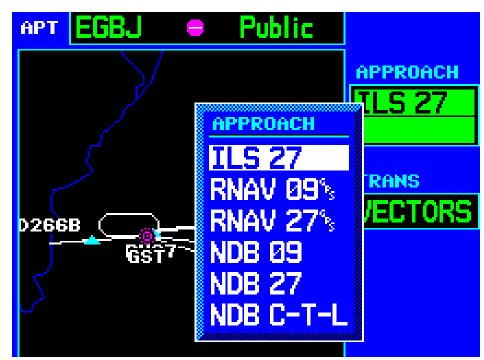


GTN shows precision and “GPS”





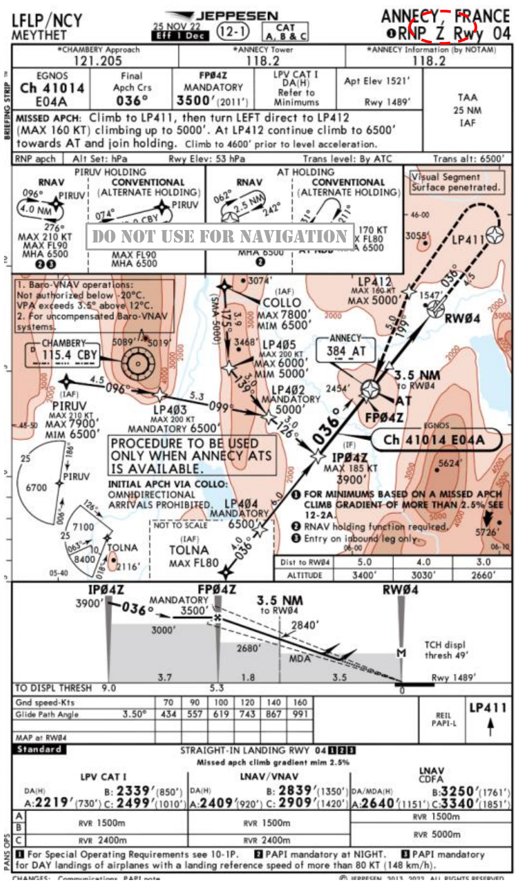
GNS does not show precision

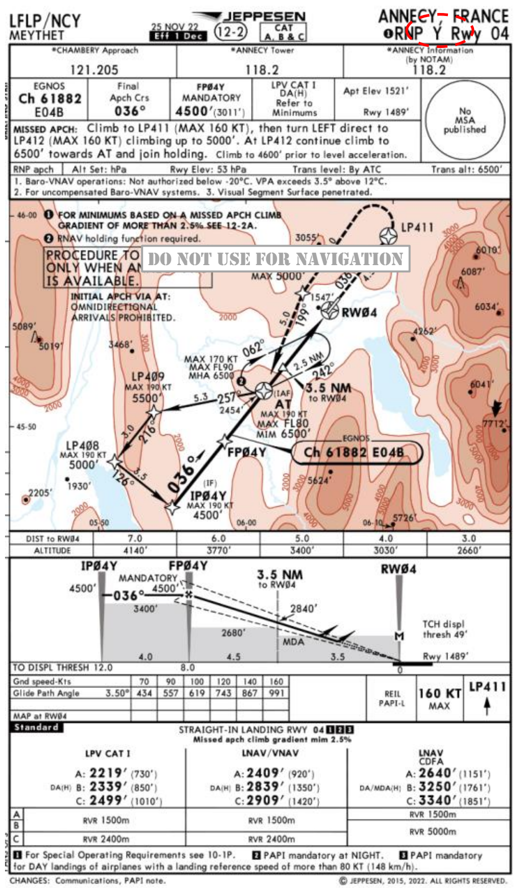


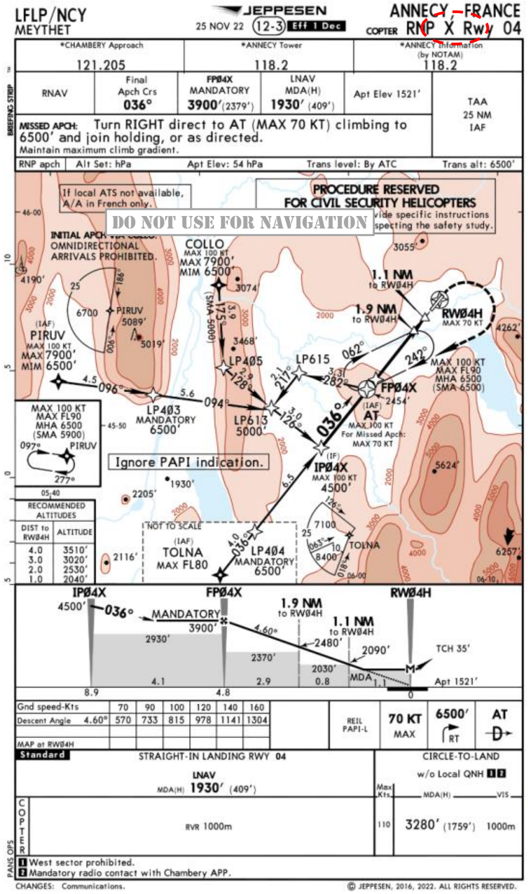
RNP Approach Procedures

9. Example of the "Z, Y, X…" approach procedure title convention

- If there are multiple procedures to the same runway, which are varied, either for aircraft approach category or for routing purposes, they are named Z, Y, X, W (in reverse starting with Z).
- If they are for different routings ATS will specify which approach is to be flown, or the pilot can request one, but if they are for aircraft approach category, it is the pilot's responsibility to inform ATS which is required.
- In some examples the waypoints on the approach will be the same, with just a different MAPt; sometimes the whole procedure is different.



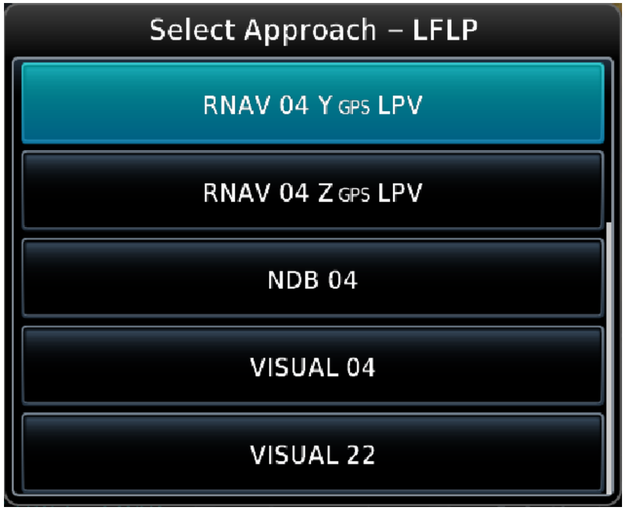




RNP Approach Procedures

10. "Z, Y, X…" not always all Coded

- In Annecy case, from the previous page, not all three procedures are included in the Jeppesen database; X is omitted, even though it has different waypoints, tracks and distances:



- That the procedures are different, and that a procedure is omitted demonstrates why it is important to cross-check the database with the procedure chart.

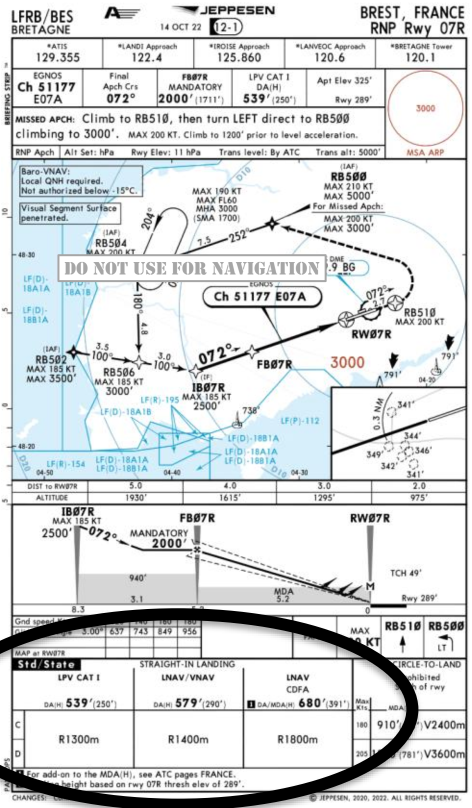
RNP Approach Procedures
11. Minima Lines - LNAV

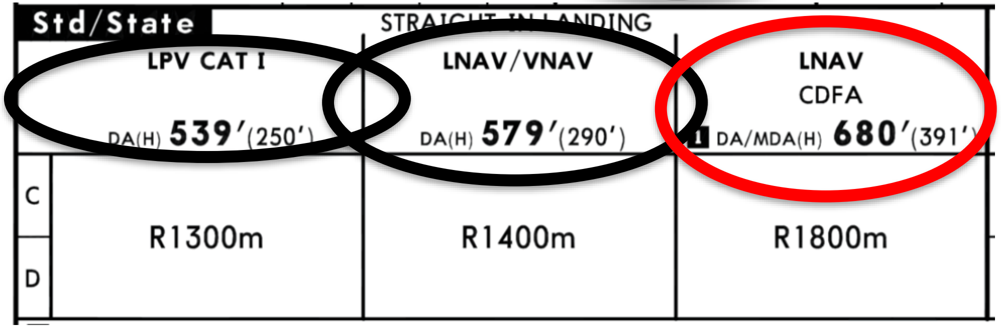
RNP approaches may have several minima lines; they all include **LNAV,** and can also include **LNAV/VNAV** and/or **LPV**

The **LNAV minima line** corresponds to a non-precision/2D approach.

- When flown with a TSO-C129() (non-SBAS unit)
  - ➢ linear deviation indication on CDI is provided
  - ➢ Garmin annunciation **APR**

- When flown with a TSO-C146() (SBAS unit)
  - ➢ angular deviation indication horizontally (localiser-like) and vertically (glideslope like)
  - ➢ Garmin annunciation **LNAV**
  - ➢ **LNAV+V** with advisory vertical guidance may also be available
  - ➢ pilot remains responsible for adherence to step down fix levels on the published approach plate for LNAV approaches even if a Garmin +V glideslope is provided by the GNSS receiver.
  - ➢ glidepath not necessarily obstacle free below MDA





Std/State	STRAIGHT-IN LANDING		
	LPV CAT I DA(H) 539′(250′)	LNAV/VNAV DA(H) 579′(290′)	LNAV CDFA DA/MDA(H) 680′(391′)
C D	R1300m	R1400m	R1800m

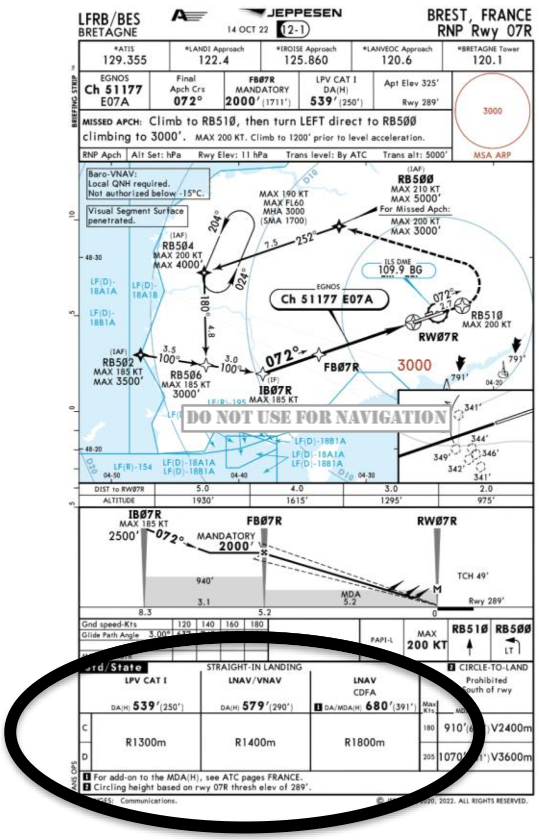
RNP Approach Procedures
12. Minima Lines - LNAV/VNAV and LPV

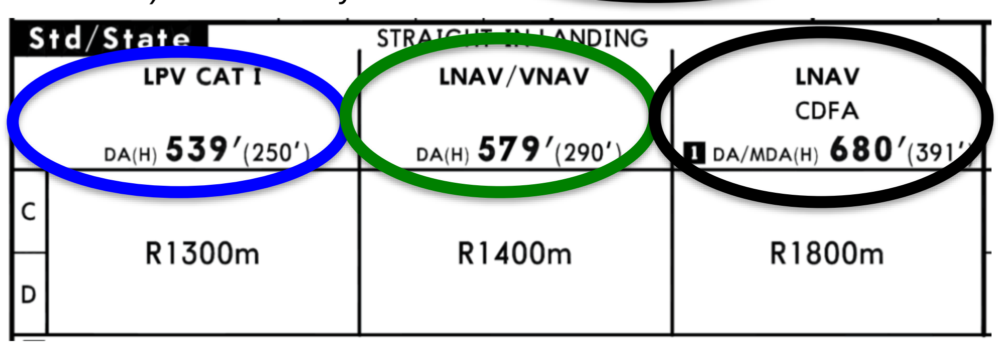
The **LNAV/VNAV minima line** corresponds to an approach with vertical guidance (APV)/3D.

- Operated “like an ILS”
- Aircraft with FMS use Baro-VNAV to fly LNAV/VNAV approaches
  - Vertical guidance using baro-altitude
  - Various scaling conventions
  - Minimum temperature
- When flown with a TSO-C146() (SBAS) unit
  - angular deviation indication horizontally (localiser-like) and vertically (glideslope like)
  - surveyed vertical guidance
  - Garmin annunciation **L/VNAV**

The **LPV minima line** also corresponds to an APV/Precision/3D Approach.

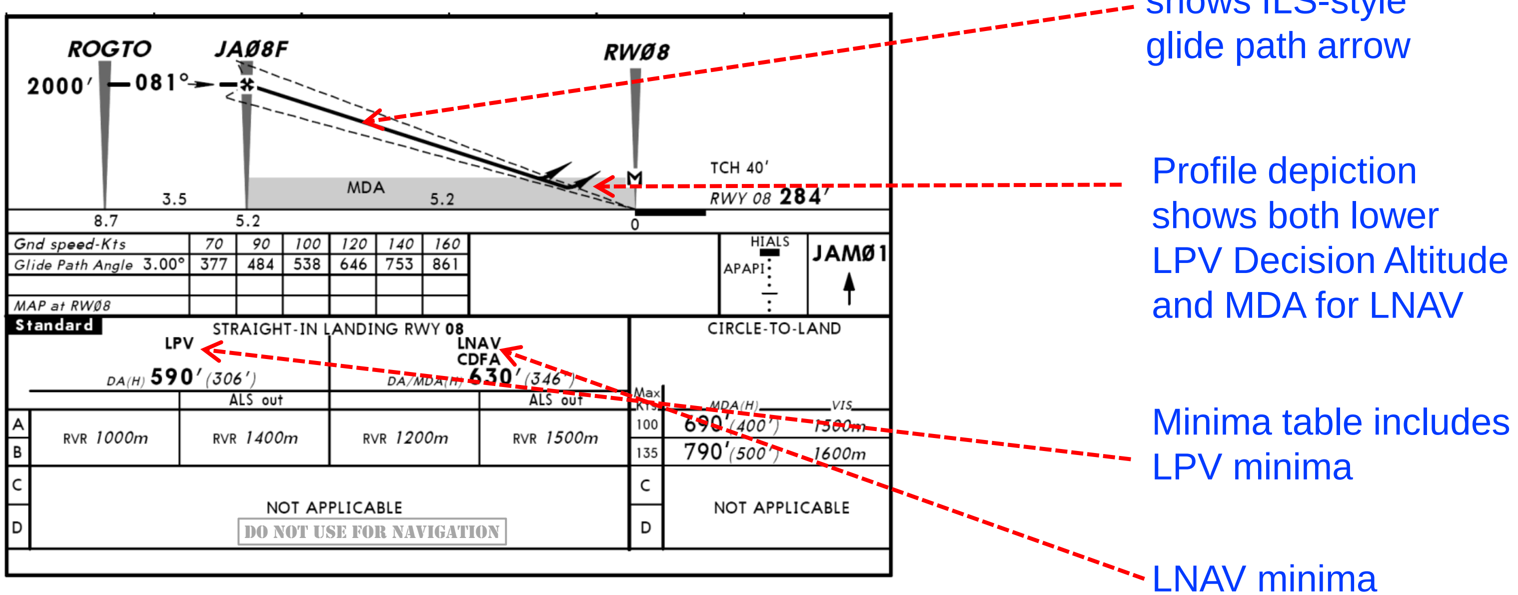
- Operated “like an ILS”
- Requires SBAS
- When flown with a TSO-C146() (SBAS) unit
  - angular deviation indication horizontally (localiser-like) and vertically surveyed vertical guidance
  - Garmin annunciation **LPV**
- Both LPV and LNAV/VNAV may fall back to LNAV if SBAS or integrity is lost.



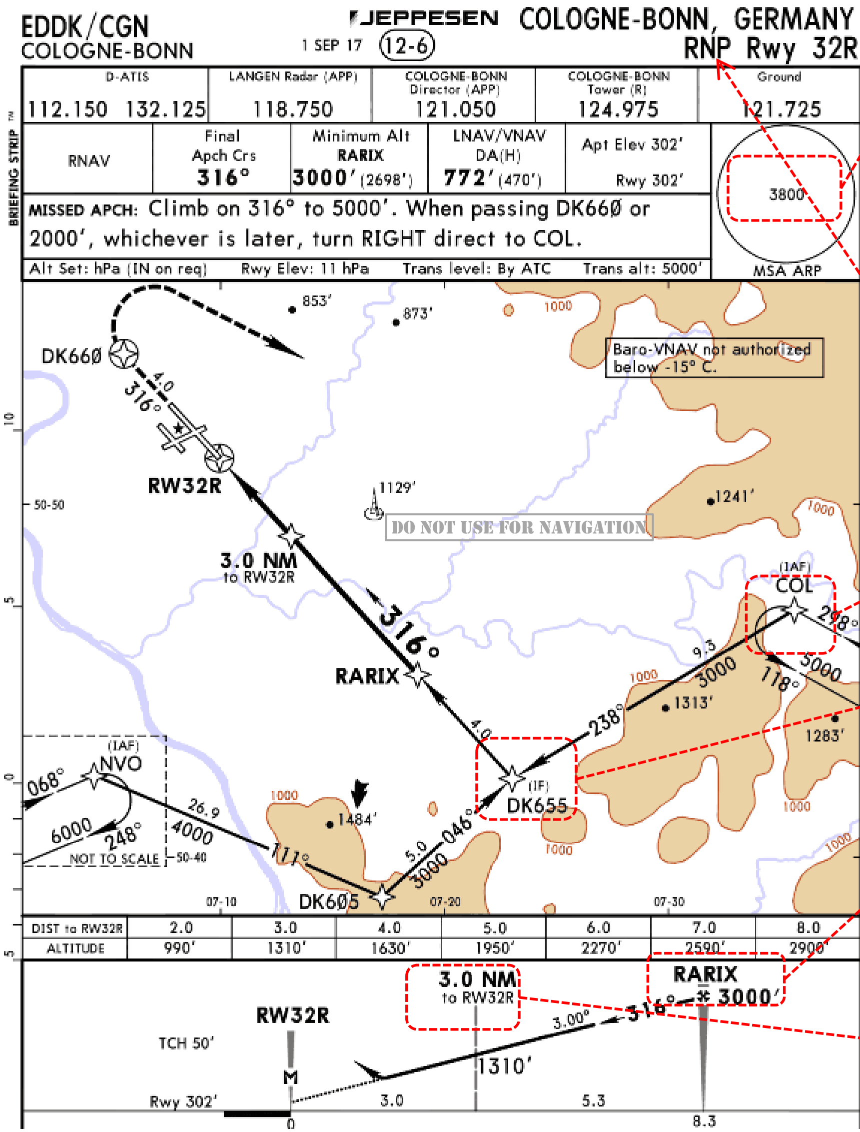


RNP Approach Procedures
13. Minima Lines - Example

The greater accuracy of SBAS allows tighter tolerances and resulting lower DAs, which can be as low as 200', equivalent to a CAT I ILS.



Since October 2022, for Non Complex operations, EASA guidance material permits the use of a DA in a LNAV CDFA approach, allowing the aircraft to descend briefly below the DA before going around. (The writers understand that this is the CAA approved procedure for the UK.) For non CDFA approaches, EASA still requires the use of an MDA which does not allow any descent below the MDA. (The FAA and many other countries treat the minima of LNAV's as MDA's.)
For LPV and LNAV/VNAV approaches, Jeppesen publishes a DA. For LNAV CDFA approaches without a glideslope, Jeppesen describes the altitude minima as a DA/MDA. National AIP charts have various different descriptions.



There are no TAA segments, because of the location of the IAFs, NVO and COL; so the MSA must be used.

This is not a standard "T" shaped RNP approach, instead the IAFs correspond to the arrival route structure at EDDK

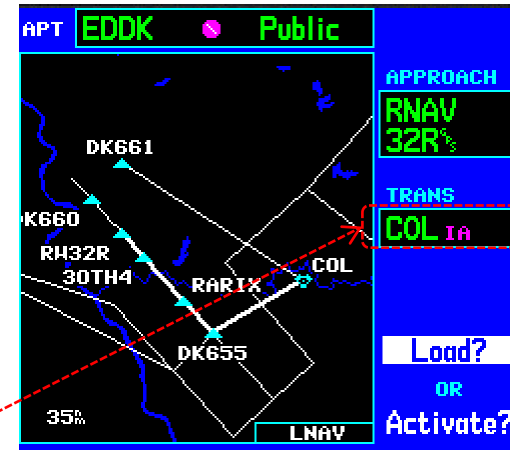
Note naming difference (see p105)

PBN procedures generally have an Intermediate Fix on the final approach track (as in this case) so a "C" type final approach track fix CNF is not needed

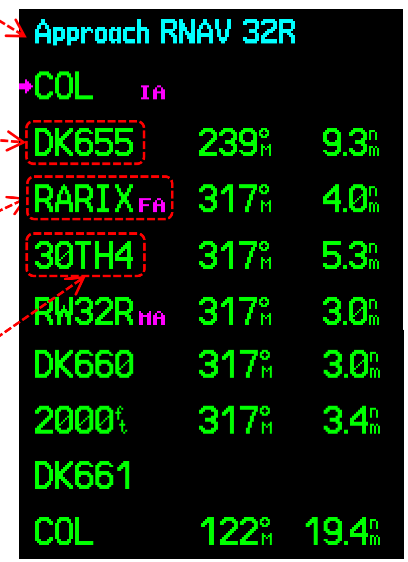
Note that in this procedure, RARIX is coded as the Final Approach Fix (see also p 126)

The step down fix is coded with the published CNF identifier: the "30" refers to 3.0nm to the "TH" (Threshold), the "4" is a code number to used to uniquely identify each of the CNFs at 3nm from threshold for different runways at EDDK

Garmin GNS530W procedure selection page

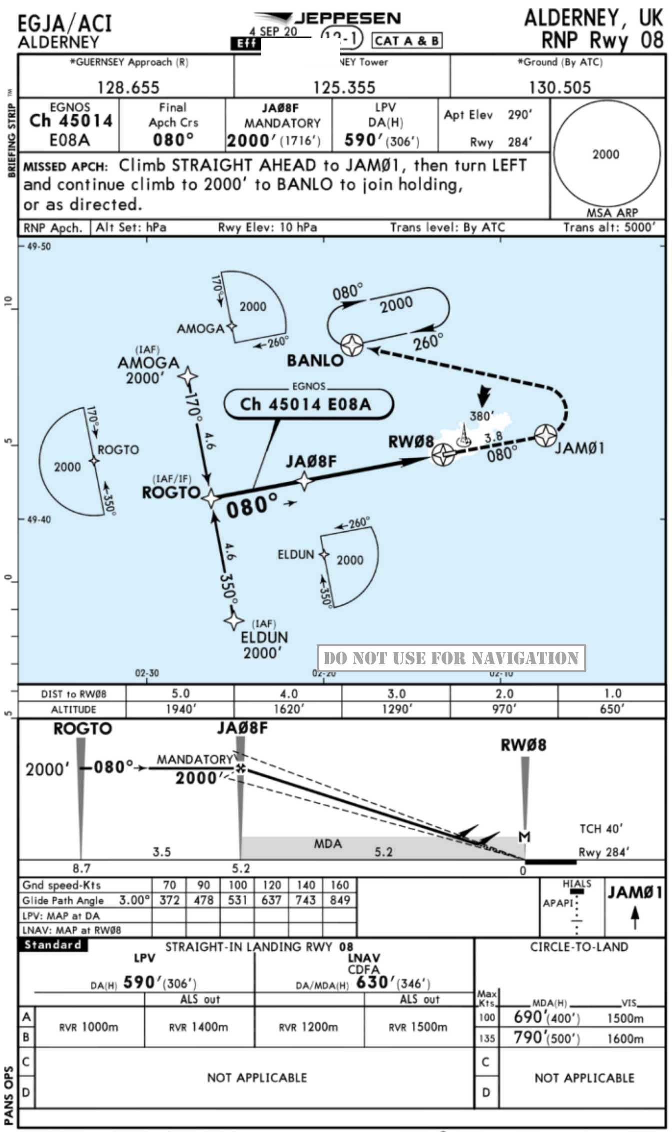


Garmin GNS530W flight plan waypoint list



RNP Approach Procedures

14. Briefing

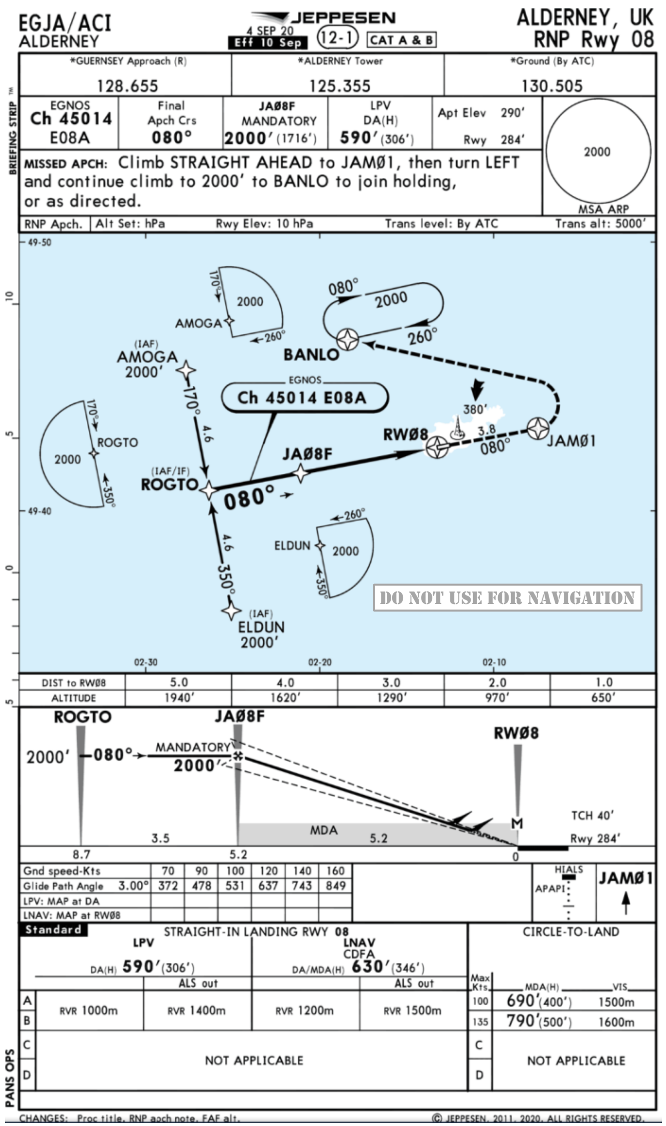


- Brief yourself thoroughly, from either Jepp plates or the AIP, well before commencing the approach. In particular, note the positions of the IAFs, the “cake slice” TAA/MSAs for each sector serving those IAFs and the minima lines available (LPV, LNAV, LNAV/VNAV) and their minima for your approach category.

- If you have a legacy (TSO-C129) navigator, such as a GNS430, check RAIM, either online or on the receiver.

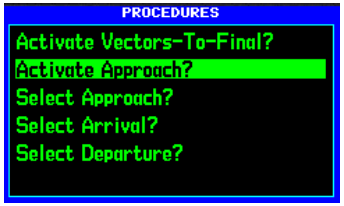
- Determine the IAF which serves your direction of arrival and load the approach from that IAF. As part of the loading process, read the page which shows the waypoint and graphic and check the visual layout of the graphic as well as every waypoint, track and distance, including missed approach and hold against the plate.

RNP Approach Procedures
16. Activating the Approach

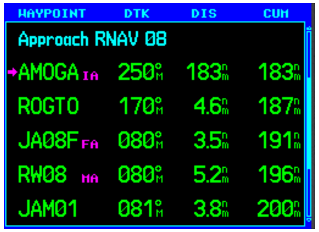


- Note that on many navigators, the destination airfield will be left in the flightplan after the approach has been loaded, above the IAF.

- Flightplans always sequence from top to bottom, so this would route the aircraft to the airfield before the IAF.
- To prevent this, the waypoint for the airfield must be removed, or the pilot can choose to fly DCT to the IAF (bypassing the airport waypoint) or the approach can be activated

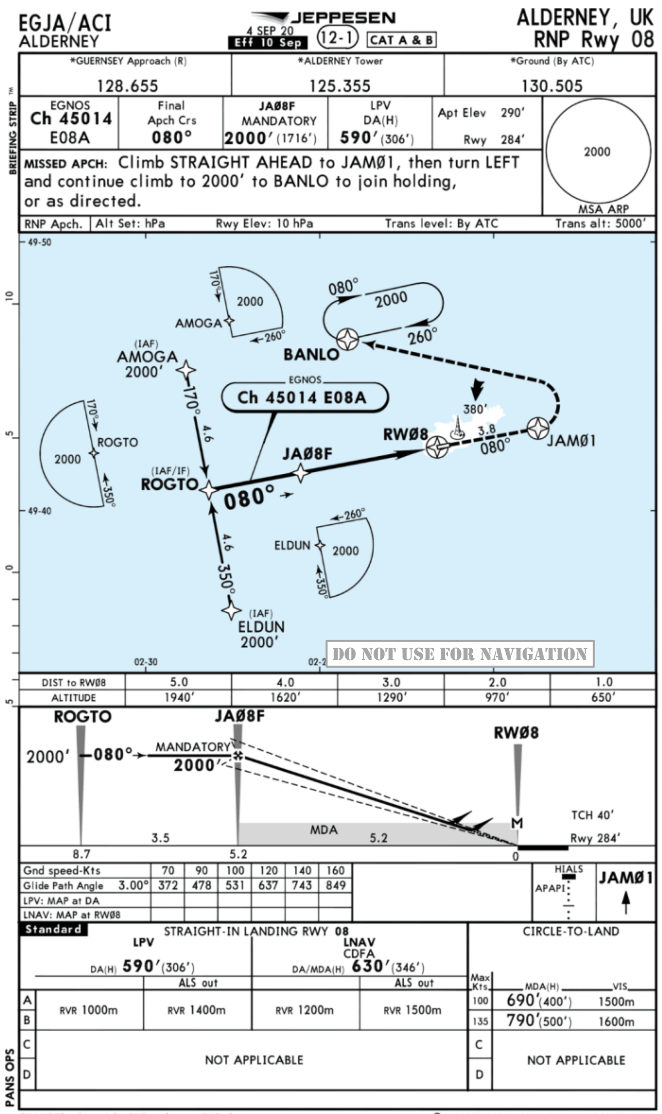


- The **only effect of activating the approach is to make the IAF the next waypoint in the sequence**. It has the same effect as DCT to the IAF.

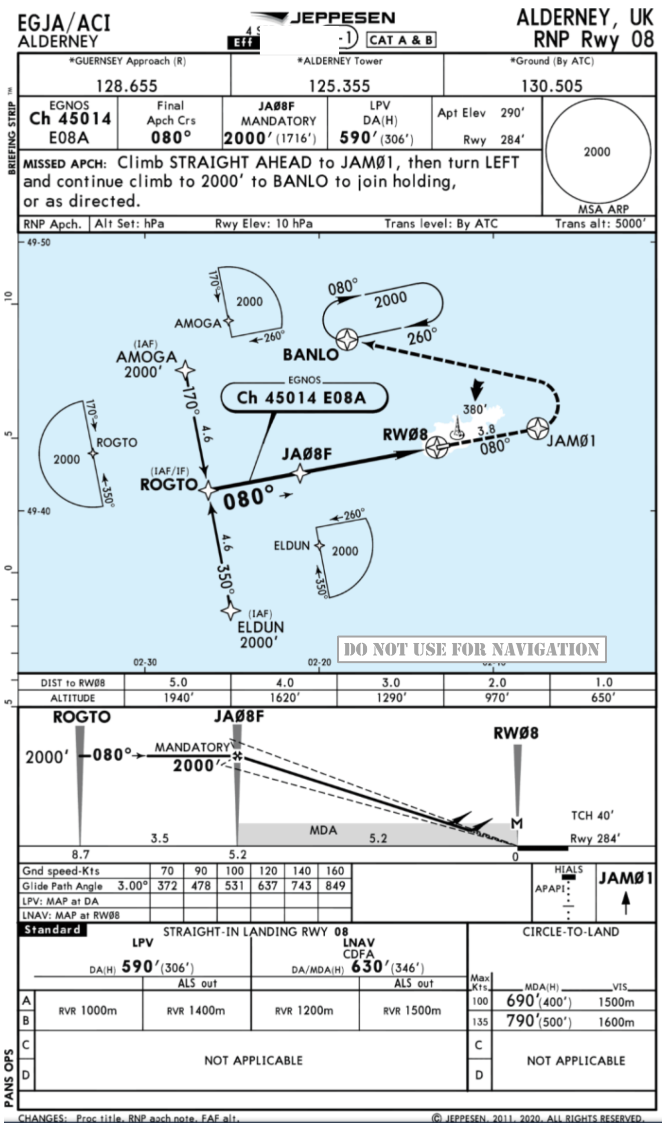


RNP Approach Procedures

17. Flying the Procedure



- Ensure that the CDI is selected to GPS.
- When you are cleared for the approach, route directly to the IAF, either by Activating the approach or by DCT to the IAF, descending to the IAF altitude remaining above the TAA/MSA.
  - Loading an approach puts the waypoints and their leg terminators into the flight plan of the navigator.
  - Activating the approach makes the IAF the next waypoint in the flightplan sequence
- Follow both the profile and the tracks carefully. If you have SBAS, keep the CDI centralised, even in the turns. If you have HSI without autoslew, turn it to the next track when prompted by the receiver.
- Only descend on the profile once the track has turned magenta and the CDI is within half scale deflection.
- Before the FAF, ensure that the expected annunciations (**APR**, **LPV**, **LNAV**, **LNAV+V** or **L/VNAV** and **GPS**) and that no unexpected ones (**LOI**, **INTEG**) are showing.
- At the FAF ensure that the final approach track goes magenta, the To flag is showing, the Glidepath indicator (if available) and the CDI are centralised and that there are no warnings.
- During the final approach, check regularly for warning annunciators and do not ignore them. Check any altitude restrictions.



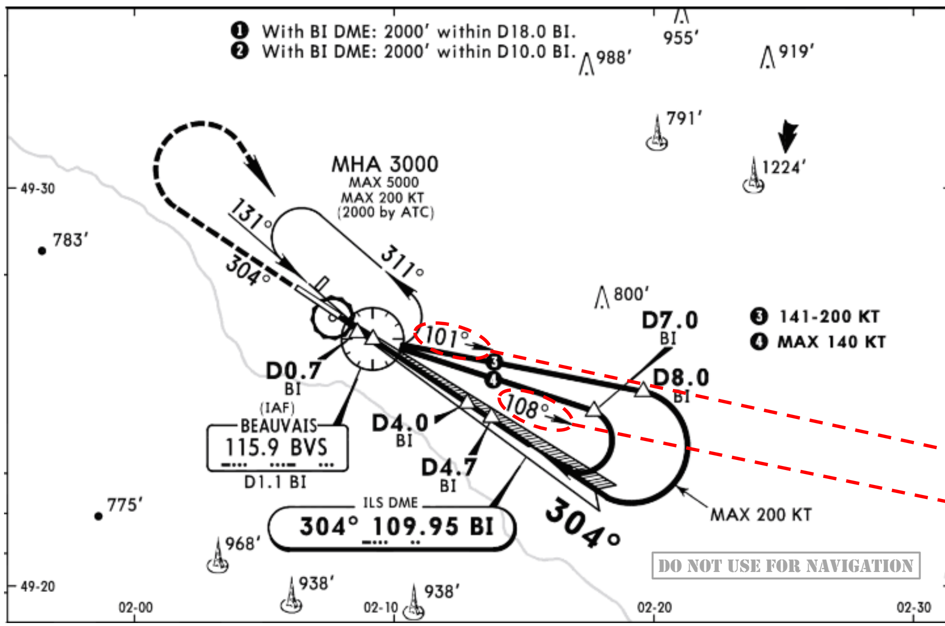
- If the annunciator changes to a lesser specification (eg **LPV** to **LNAV**) above 1000' AAL, providing it has been briefed, reset minima as appropriate and use the distance vs altitude table. If it changes below 1000' AAL, go around.
- The decision at DA is the same as for a conventional approach, but it should be noted that the MAPt for an RNP approach is normally located at the threshold, such that guidance is available. For this reason, in the event of a missed approach, the MAPt is passed some time after the go-around decision and the aircraft might have gained considerable altitude.
- On the missed approach, once past the MAPt, and above any altitude restriction before the first waypoint, unsuspend waypoint sequencing on the navigator. If you do not unsuspend, guidance continues straight ahead. The method varies according to the navigator. On the GTN you are prompted on a pop up screen, covering the map:

while on the GNS you have to notice the SUSP annunciator and press the OBS button beneath it:

- Using a non-SBAS (TSO-C129) navigator, do not turn before reaching the altitude specified in the MA Procedure.
- The missed approach will then sequence in the flightplan.
- Note that some older RNP approaches require conventional aids (eg NDB) in the missed approach. If these aids are not carried, the pilot should ask for an alternative missed approach before reaching the FAF.

Database Overlay Approaches
1. Coding in Database

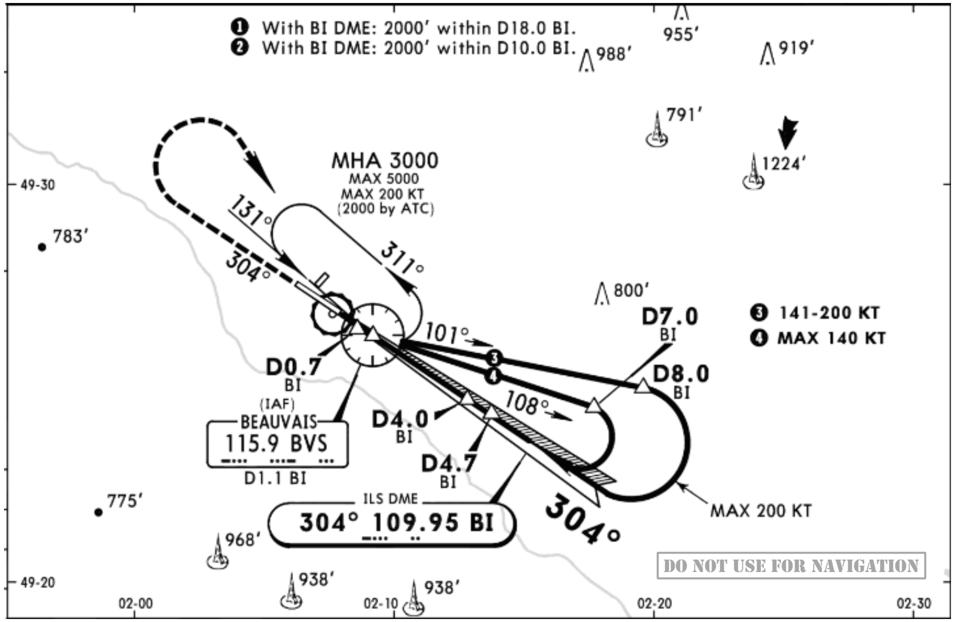
- Most conventional approaches (ILS, NDB etc) are coded into the GNSS database, and it is permissible and normal to use RNAV guidance to fly the procedure until the FAF. After the FAF, the aid named in the procedure title **must** be used.
- That means that for NDB procedures the ADF must be tuned and, at least, monitored, throughout the final approach and that aircraft without ADF must not fly an NDB procedure.



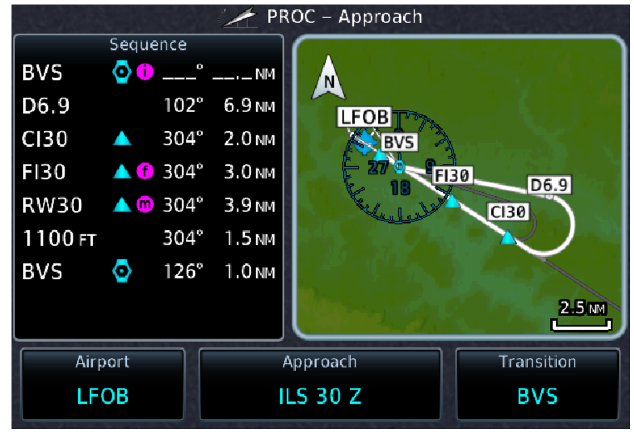
- Each leg is coded in the database and is followed, as in an RNP approach.
- If there are different procedures for different aircraft approach categories, each is normally included in the database.
- They usually start from the same IAF, and so need to be differentiated in the navigator. Normally, the **slowest** approach category is **lowest** in the list.

- Thus, in this case, the upper button will be for the 101° outbound track and the lower button for 108°

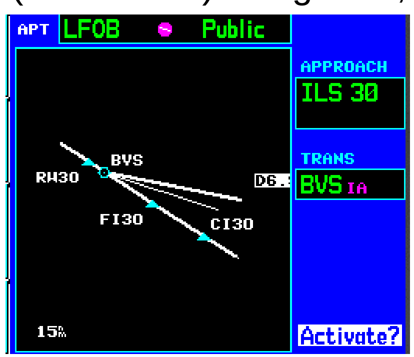
Database Overlay Approaches
2. View in Navigator



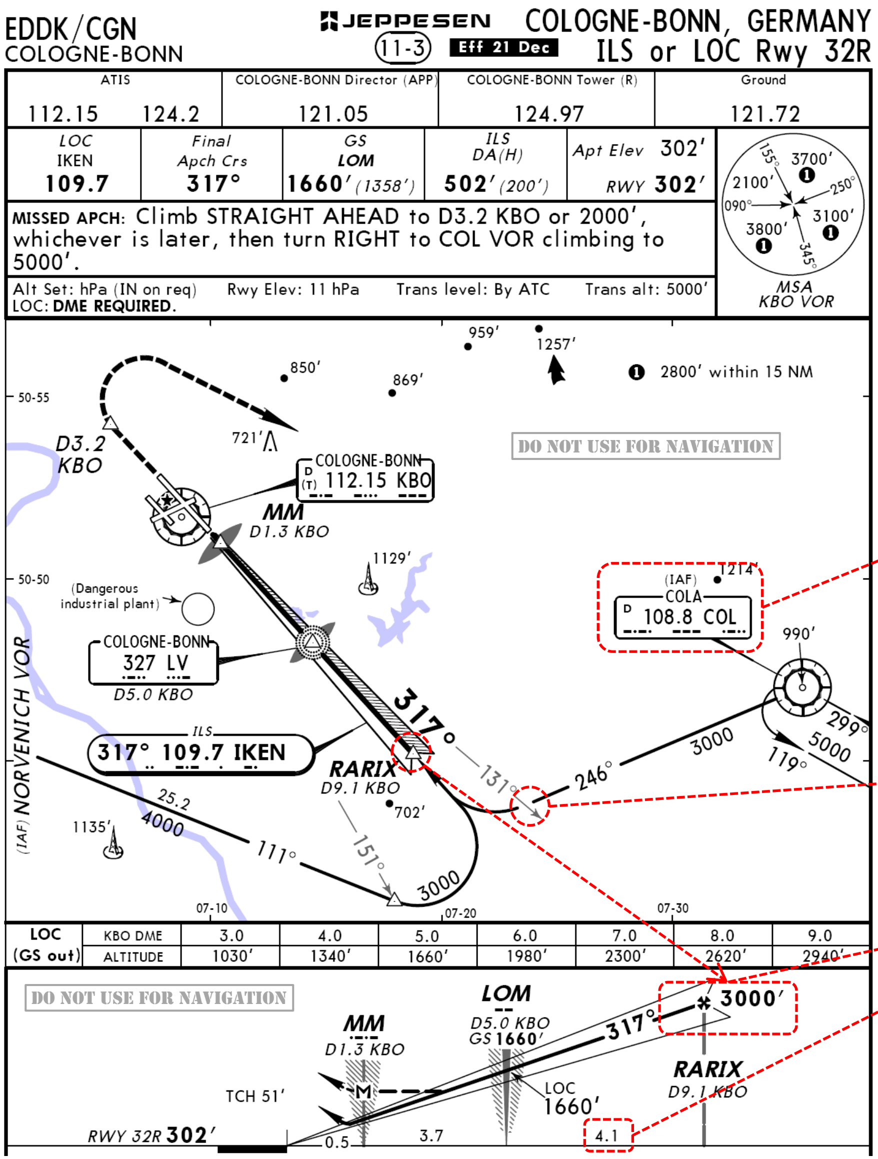
Once the IAF is selected, only the appropriate pattern will show in the preview pane.



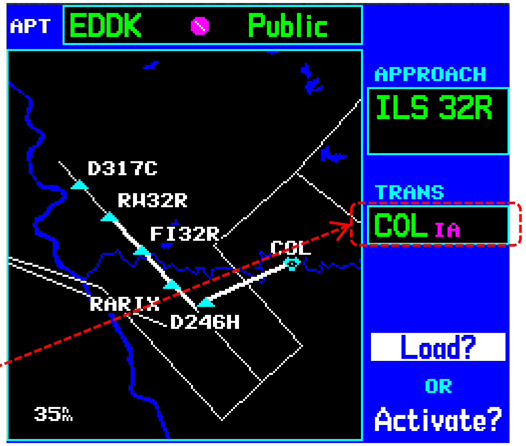
In SBAS (TSO-C146) navigators, the base turn is shown and can be navigated using the CDI. However, in non-SBAS (TSO-C129) navigators, the base turn is not included and must be flown manually:



Database Overlay Approaches
3. Example of an ILS approach

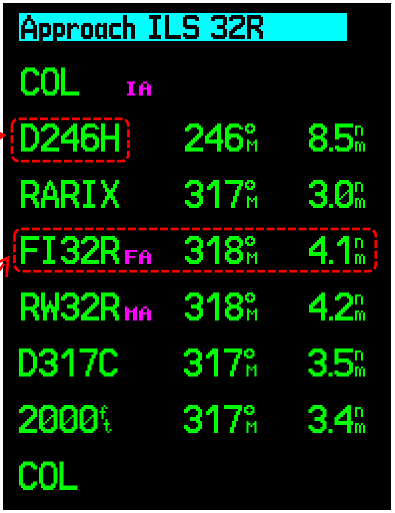


Garmin GNS530W procedure selection page



This is a conventional transition, the transition selections available for this procedure also include 'long' RNAV arrivals

Garmin GNS530W flight plan waypoint list



A CNF is created in the coded procedure corresponding to the intersection between the COL 246 radial and the lead-in radial for the turn to the final approach (131 radial KBO)

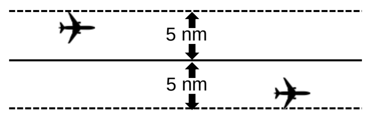
Note that RARIX, the charted final approach fix, is preceded by a turn from either of the two IAFs. Older FMS units cannot support a final approach fix without a prior waypoint on the final approach track. Hence, the database procedure uses RARIX as the final approach track fix and a CNF at the outer marker (FI32R) as the FAF. This is "discrepancy" exists only to support a technicality of older FMS units and illustrates why non-approved database overlays must not be used for primary guidance – **a pilot flying this procedure must observe the published FAF at RARIX**

CDI Sensitivities
1. Introduction

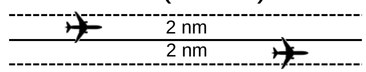
- In this page and next two, CDI scale refers to full scale deflection.
- The CDI (HSI or OBS) has different sensitivities at different stages of the flight. These sensitivities also vary between RAIM and SBAS receivers, as shown graphically below for RAIM and on the following page for SBAS.
- **ENR** is the annunciation for Enroute mode and has a scale of 2 nm for SBAS and 5 nm for non SBAS receivers. ENR is set anytime the aircraft is more than 30 nm radius from the departure or destination airport, unless it is on a RNAV 1 or RNP 1 route (in which case it annunciates TERM, with a scale of 1 nm). If no departure or destination airport is set in the flight plan or as a DCT, the receiver will enunciate **ENR** with the applicable ENR sensitivity.
- **TERM** is the annunciation for Terminal mode CDI sensitivity with a scale of 1 nm whenever the aircraft position is within 30nm radius of the departure or destination airport, until it reaches the final approach track of an approach.
- The 30nm is **Radius**, not track miles.
- Note that the scaling doesn't change instantly; the change is gradual to prevent pilot or autopilot "chasing" a small deviation that has suddenly turned into a big one (on a non SBAS receiver going from ENR (RNAV 5) to TERM, a one dot deviation becomes 5 dots.)

Full Scale Deflection (FSD) abbreviated to "**Scale**"

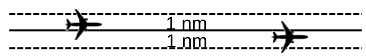
ENR (non-SBAS)



ENR (SBAS)



TERM

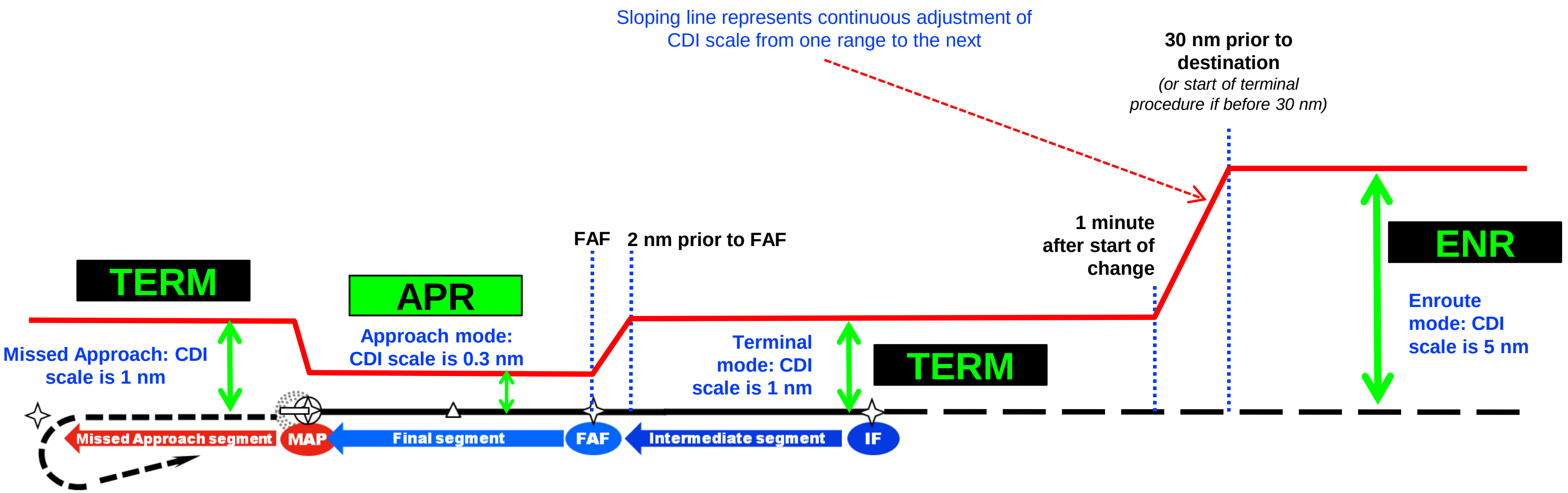


Mode annunciator: indicates how the GNSS is automatically adjusting the scale and the position integrity alert to the limit appropriate to the phase of flight

External CDI source annunciator: GPS vs Nav Receiver

CDI Sensitivities
2. Non-SBAS

CDI scaling on a non-SBAS receiver is relatively simple:



CDI Sensitivities
3. SBAS

Blue bubbles highlight how SBAS sensitivities vary from non-SBAS

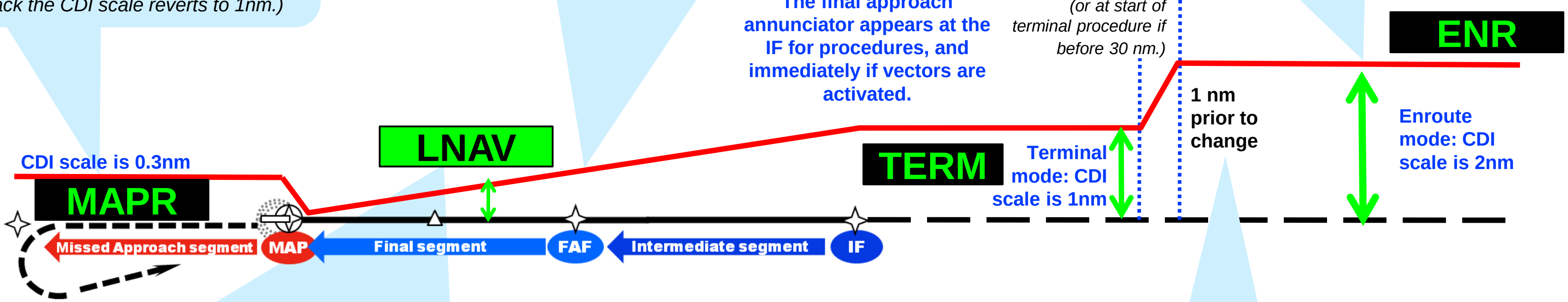
CDI scaling on the FAT of GNSS approaches is angular ± 2°*, similar to that provided by a localiser. On all LPV and LNAV/VNAV approaches, an ILS type glidepath is provided, and on some LNAV approaches an advisory angular synthetic glidepath is calculated by Garmin TSO-C146() units.

**(except when 2° angular displacement is greater than 1nm, when scale becomes linear 1nm, and when, close to the runway, it reduces to 100m, scale becomes linear 100m.)*

Missed approach mode: CDI scale is 0.3NM

(If the initial missed approach track is more than 3° off the final approach track the CDI scale reverts to 1nm.)

Scaling in ENR mode is 2nm, not 5nm



Different approach mode annunciations, based on the procedure available and the position accuracy available:

LNAV	***use LNAV minima, no glidepath available***
LNAV+V	***use LNAV minima, advisory glidepath will be displayed on HSI***
L/VNAV	***use LNAV/VNAV minima, glidepath will be displayed on HSI***
LPV	***use LPV minima and both track and vertical guidance on HSI***

1nm as opposed to 1 minute. Starting at 31 nm not 30 nm

RNP APCH operating procedures
1. Introduction

The table below is a suggestion of operating procedures for RNP Approaches

Phase of Flight	Operating Procedure required or recommended (in addition to conventional IFR procedures and checks)
1. Pre-Flight Planning	• IFR approval and serviceability of GNSS and alternative navigation equipment • Availability of GNSS Approach and alternative conventional procedures • Weather forecasts for destination and alternate. GNSS approach and alternate minima • RAIM prediction (if non-SBAS) • NOTAM check (including SBAS)
2. Pre-Flight Checks	• GNSS database currency and coverage • Chart currency and coverage • Check coding of expected GNSS approach procedure against published charts • GNSS receiver self-test, Instrument Panel Self Test, • Check CDI scaling is Auto, SBAS selected on, North/Track up and auto-zoom as required • Flight plan entry and RAIM prediction (if necessary) • Check GNSS position before take-off
3. Pre-Arrival	• Select and check the Arrival/Approach procedures • Check MSA/TAA • Determine the appropriate IAF • Load the procedure
4. Flying the RNP APCH procedure	• Gross error check approaching the IAF, and check that the GNSS is in **TERM** mode • GNSS and Navigation instrument mode CDI selection • Check activation of **APP**, **LNAV**, **LNAV+V**, **L/VNAV** or **LPV** mode as applicable • Check Magenta line, TO Flag, CDI Centred, SUSP.
5. Flying the Missed Approach	• Activation of the Missed Approach procedure and the need to manually unsuspend waypoint sequencing • Mode selection and pilot actions in non-RNAV missed approach segments
6. ATC communications	• Communications during normal procedures • Communications in the event of a GNSS navigation failure
7. Contingencies in the event of a GNSS navigation failure	• Immediate actions • Reverting to alternative procedures

- **Each of these procedures is detailed in the following pages**
- ***This section includes only the key elements needed for GNSS Approaches in addition to conventional IFR operating procedures and checks***

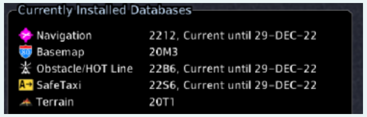
RNP APCH operating procedures
2. Pre-Flight Planning

Operating Procedure	Notes and comments
IFR approval and serviceability of GNSS and conventional navigation equipment	• The pilot is responsible for ensuring that the GNSS installation is approved for IFR and RNP approaches - the aircraft flight manual (or equivalent) is the primary source of this information • *The operator must ensure that the flight manual and installation is kept current: the receiver manufacturer may, at times, require mandatory software and hardware upgrades, or issue updates to the flight manual* • Unless a VFR alternate is available, the pilot must also ensure that appropriate conventional navigation equipment is serviceable and IFR-approved

Availability of GNSS and alternative non-GNSS procedures	• The pilot should review and brief both the RNP and conventional procedures available at the destination and alternate. This is useful even though a GNSS satellite system failure is unlikely:
	  • Conventional navaids may be used for gross error checks and monitoring of GNSS guidance
	  • ATC may require a non-RNP procedure to be flown for operational reasons, eg a conventional procedure or radar vectoring may be shorter and quicker

Weather forecasts for destination and alternate. RNP and alternate minima	• The normal IFR planning requirements apply to RNP APCH • Note that different minima apply for different types of RNP APCH. The approach plate will indicate the different minima applicable. The type of approach chosen, and its related minima, will depend upon the approved equipment and whether SBAS is available. • Under EASA rules, either the destination or the alternate *must have a non-RNP instrument approach procedure* which is anticipated to be operational and available at the estimated time of arrival, and which the aircraft is equipped to fly.
RAIM prediction (SBAS not available)	• If SBAS is not available, RNP NPAs require RAIM prediction to be performed and to indicate that RAIM will be available at the destination ETA. The UK CAA recommend that RAIM should be available for a 15 minutes either side of ETA. In Europe, http://augur.eurocontrol.int/ec/status may be used for RAIM prediction, and is preferable to using the Receiver's built-in prediction software
NOTAM check (incl. SBAS)	• The pilot's review of applicable pre-flight NOTAMs should include a check of the availability of GNSS, SBAS, conventional and missed approach procedures and of radio aids.

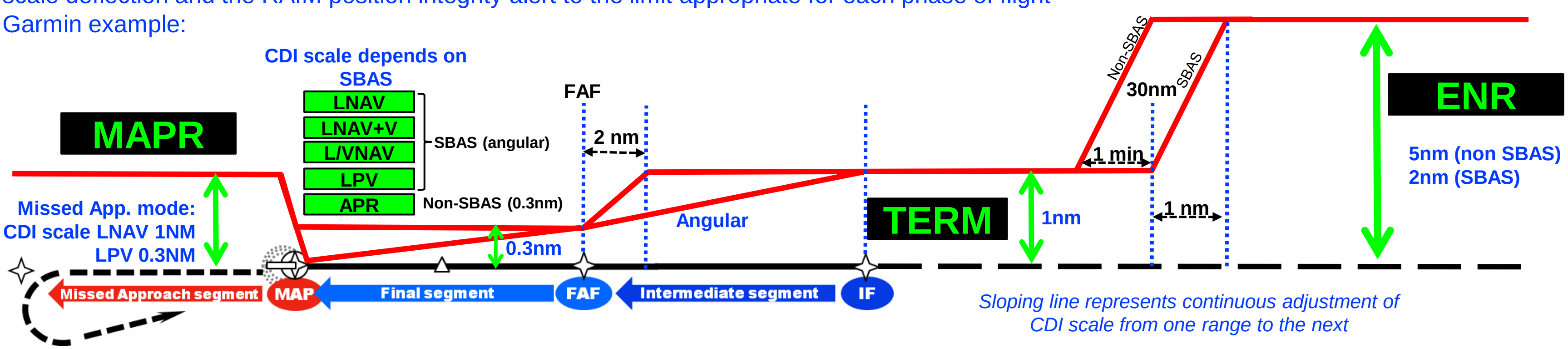
RNP APCH operating procedures
3. Pre-Flight Checks

Operating Procedure	Notes and comments
GNSS database currency and coverage	• The receiver must use a current database, supplied from a source approved by the manufacturer • As well as checking the overall geographic coverage, the pilot must ensure the database includes the specific airports and the individual procedures that may be required • Plates and charts must also be checked for availability and currency 
GNSS receiver self-test, user selectable settings, LOI monitoring	• When the GNSS unit is powered-up, the pilot should verify that the self-test procedure is successful • After a position fix has been acquired, the pilot should monitor the receiver for Loss of Integrity alerts at all times • User-definable receiver settings should also be checked, in particular where an aircraft is flown by a more than one pilot or it is used for training, when features may deliberately be changed or switched off. • Such checks may include: Set CDI scaling to 'automatic'; SBAS is on; Check setting of alarms, airspace and altitude buffers; Check Map display settings, de-clutter and map orientation; Check heading and track display (magnetic, true etc…); Check the units of measure of distance, speed, altitude, barometric pressure and position format; Select display to show at least: Desired Track (DTK) / Groundspeed (GS) / Distance to next waypoint (DIS); Check date and time format; Check setting of other units of measure such as fuel quantity.
Flight plan entry and RAIM prediction (non SBAS)	• When the enroute flight plan is entered it should be checked against the filed flightplan • Check the flightplan on the GNSS map for gross errors (eg waypoint of similar name in different country.) • If SBAS is not available, and Augur has not previously been checked, GNSS RAIM prediction should be performed. • The RAIM prediction should be repeated whenever the destination ETA changes by more than 15 minutes
Requirement to use a database coded procedure for RNP APCH	• RNP terminal and approach procedures must only be flown using guidance from the database • **A terminal and approach procedure created from user-entered waypoints may never be used** (RNAV 5 waypoints may be entered manually).

RNP APCH operating procedures
4. Pre-Arrival

Operating Procedure	Notes and comments
Selecting and checking the Approach procedure **Determining the appropriate IAF**	• When the runway is known, the likely procedures should be selected from the database but not activated or armed. If ATC do not provide a clearance to a specific IAF, the correct IAF should be determined based on the aircraft's bearing to the IF and the arrival quadrant information in the approach chart. This IAF should be selected. • ATC clearances should be read back carefully; some TMAs have a large number of similar sounding RNAV waypoints • At this point, a cross-check of the selected procedure should be performed - firstly, checking that the correct Airport, Procedure, Transition and Runway identifiers have been selected - secondly, checking that the database waypoints correspond to the published chart
Activation of the procedure and CDI scaling	• If the PBN procedure is satisfactory, it may be activated in the active flight plan • "GPS" (rather than "VLOC") mode should be selected for the receiver CDI output, and the correct annunciator display should be verified • Within 30mn of the destination, the CDI should scale to 1nm (max deflection) and "TERM" mode (or equivalent) should be displayed Example: Garmin 530 mode annunciation *CDI sensitivity 1nm in Terminal mode* *CDI output toggled from VLOC to GPS*

- When database terminal and approach procedures are active, IFR units automatically adjust the CDI full-scale deflection and the RAIM position integrity alert to the limit appropriate for each phase of flight
- Garmin example:



Sloping line represents continuous adjustment of CDI scale from one range to the next

RNP APCH operating procedures
5. Flying the Approach

Operating Procedure	Notes and comments
Checks approaching the IAF	• Prior to the IAF the pilot should perform a gross error check of the aircraft position (using non-GNSS navigation if possible) • Recheck that the procedure is active and the receiver is in TERM mode • The receiver will provide excellent "micro" situational awareness in tracking from one waypoint to the next. The pilot must also maintain "macro" situational awareness with respect to the destination airport, radio aids, airspace boundaries, traffic, weather and terrain • Set up any conventional radio aids required for the missed approach. If the missed approach is an RNP procedure, also brief a non-RNAV missed approach in case of GNSS failure (or determine a safe course of action if a non-RNAV MAP is not available)
GNSS and Navigation instrument mode selection and flight guidance	• Prior to the first waypoint, the pilot should reconfirm the CDI output to the HSI is toggled to "GPS" mode, and that the GNSS Map or Nav page settings are suitable for guidance during the procedure • The pilot should establish a "mini checklist" for each procedure segment, for example: - approaching a waypoint, self-brief on the next track, distance and level - when the receiver announces 10s to next waypoint, set the HSI to the next track - monitor the receiver (not the HSI) during the 10s countdown, and be prepared to promptly establish a Rate 1 turn as soon as the display says "Turn now to XXX°" • In particular, note that most receivers display only distance to the next waypoint during a procedure, not DME-style distance to the runway threshold
Use of the receiver if a hold or vectors to an intermediate waypoint on the approach are required	• The operating logic of most receivers makes it relatively easy to learn how to load and activate a procedure and follow the guidance from waypoint to waypoint • Conversely, the same operating logic can be quite difficult and confusing when inevitable 'real world' disruptions occur (ATC vectors and holds; changes of IAF, procedure or runway; direct clearances to intermediate waypoints) • A pilot should be familiar with managing such tactical changes to the flight plan
Check activation of APP mode prior to the FAF	• Within 2nm of the FAF, the pilot must check that the appropriate approach mode is active – this is a critical check which also ensures that the CDI scaling is adjusting correctly and, if SBAS not available, that RAIM is predicted to be available for the approach. **Descent on the final approach must not commence unless the approach mode is active** • After the FAF, if alert limits are exceeded, LPV will degrade to LNAV using RAIM, at which point LNAV minima apply, and if RAIM is lost, an integrity warning is annunciated and a missed approach commenced.

➡ **In addition to this brief summary, any pilot intending to fly RNP APCH should study the appropriate official guidance material.**

RNP APCH operating procedures

6. Flying the Missed Approach

Procedure	Notes and comments
Activation of the Missed Approach procedure and the need to manually re-initiate waypoint sequencing	• A strict logic applies in GNSS receivers. Up to the coded MAPt, waypoint sequencing is automatic. At the coded MAPt, automatic sequencing is suspended, while the CDI provides guidance straight ahead, and the pilot must manually re-initiate guidance for the missed approach. • GNSS database procedures are coded so that the Runway Threshold waypoint is always the Missed Approach Point 'MAPt'. • For Continuous Descent Final Approach LNAV approaches and SBAS approaches with vertical guidance, **the DA is always before the MAPt at the runway threshold**. If a landing cannot be made, at the DA a climb must be initiated. The receiver (on Garmin units) will announce 'ARRIVING WPT' approaching the MAPt at the threshold. The **SUSP** (on Garmin units) is displayed indicating that automatic sequencing of waypoints has stopped; the CDI goes to FROM and the vertical deviation indicator is flagged off. The **MAPR** (on Garmin units) is annunciated with CDI scaling switched to +/- 0.3 nm for SBAS missed approaches and 1nm for non SBAS missed approach. • For non SBAS receivers, **follow the published missed approach instructions for any climb that may be required before pushing the OBS (SUSP) button** at the specified turning height to reinitiate automatic sequencing so as to receive course guidance to the next waypoint. • For SBAS receivers and LPV approaches, the first waypoint on an LPV missed approach is always aligned with the runway direction. Accordingly, the SUSP key can be pushed immediately after **SUSP** (on Garmin units) is displayed at the MAWP. In addition, SBAS receivers , unlike non SBAS receivers, defer giving course guidance to the next waypoint until the published altitude for the turn to the next waypoint is reached. • Until sequencing is re-initiated, the GPS receiver will continue providing guidance along the final approach track and extended centreline. • Even if the Missed Approach procedure mode is initiated before the MAPt (eg. with a direct-to the MAPt), waypoint sequencing will be suspended at the MAPt. • This logic may appear somewhat strange, but it is essential– it means that there is no risk of automatic waypoint sequencing unexpectedly changing the guidance at a critical point late in the final approach or early in the go-around when the aircraft may be too low or slow to change track safely. • Therefore, a pilot flying the Missed Approach procedure must always manually re-initiate waypoint sequencing after the MAP is reached and the "**SUSP**" annunciator is displayed.

RNP APCH operating procedures

7. Flying the Missed Approach - Continued

Procedure	Notes and comments
Mode selection and pilot actions in non-RNP missed approach segments	• During the missed approach, the GNSS Navigator will always provide track guidance and waypoint sequencing for "RNAV friendly" path-terminators such as a TF (Track to Fix) segments. • However, even standalone RNP APCHs often need to use path-terminators that are not fully supported by GNSS receivers. Such procedure segments will be listed in the flight plan, but some combination of the following is possible – automatic waypoint sequencing is suspended (for example, the GNSS navigator may not "know" when a conditional terminator, such as "2000' or 4DME - whichever is earlier", is reached). – track guidance through the CDI is not provided, neither is autopilot LNAV guidance available. – the GNSS receiver Map may not display a 'magenta line' for the segment. • Path-terminator support is specific to individual GNSS receiver models (and sometimes different software versions for the same receiver). A pilot must be familiar with the user manual instructions on waypoint sequencing and path-terminator support, and prepared to fly the missed approach procedure using conventional navigation if RNAV guidance is not available.

RNP APCH operating procedures
8. ATC communications

Operating Procedure	Phraseology
Communications during normal procedures	Pilots should request clearance to fly the procedure using the phraseology: ***'(Aircraft c/s), request RNP approach, via (Initial Approach Fix Designator), runway xx'*** Where traffic conditions permit, air traffic controllers shall clear the pilot to follow the procedure using the following phraseology: ***'(Aircraft c/s), cleared RNP approach, runway xx, (report at [Initial Approach Fix designator])'*** For traffic sequencing and to aid situational awareness, air traffic controllers may request the pilot to report when established on final approach track or to report at any other relevant point in the procedure. For example: ***'(Aircraft c/s), report established on final approach track'*** ***'(Aircraft c/s), report 2 miles from final approach fix'*** Air Traffic Controllers, to instruct the pilot to report at the final approach fix, use the phraseology: ***'(Aircraft c/s), report final approach fix'*** After reaching the final approach fix, the pilot will continue to fly the procedure towards the next waypoint (normally the runway threshold). At the appropriate time, the pilot will either continue with the air traffic clearance received or will execute the Missed Approach Procedure (MAP). All reference to range must be to the next waypoint, and should not require DME, unless DME is specified in the procedure description.
Communications in the event of a GNSS navigation failure	When Air Traffic Control is aware of problems with the GNSS system, the following phraseology shall be used: ***'(Aircraft c/s), GNSS reported unreliable (or GNSS may not be available [due to interference]): In the vicinity of (location) (radius) [between (levels)] OR In the area of (description) [between (levels)]'*** ***'(Aircraft c/s), GNSS unavailable for (specify operation) [from (time) to(time) (or until further notice])'*** Following a RAIM or Integrity indication, pilots shall inform the controller of the event and subsequent intentions. ***'(Aircraft c/s) Unable RNP (due to [reason eg Loss of RAIM OR RAIM alert]) [intentions]'*** ***'(Aircraft c/s) Loss of RAIM or RAIM alert [intentions]'***

In general, the ICAO standard is that if a pilot can not comply with RNP requirements or experiences an GNSS failure, the radio call to ATC should be *"(Aircraft c/s), Unable RNP due equipment*" followed by a request for an alternative course of action as appropriate

RNP operating procedures
9. Contingencies in the event of a GNSS navigation failure

- Before an RNP approach has commenced, there are three additional contingencies a pilot should plan for in addition to the conventional IFR approach contingencies
  - a GNSS Loss of SBAS/Loss of Integrity alert or a GNSS position alert, warning that the aircraft has deviated beyond the required lateral or vertical protection limit
  - A failure of the receiver to automatically sequence to the correct Approach mode at the FAF
  - any uncertainty about whether the procedure may be continued safely; for example: a navigation cross-check discrepancy, a pilot's confusion about the GNSS guidance or mode status, excessive deviation from the vertical profile

	Illustration of contingency procedures
Immediate actions	If GNSS receiver falls back from LPV or LNAV/VNAV to LNAV on the approach above a height of 1000' you may continue the approach as an LNAV approach using LNAV minima. If below 1000' you must go around. If GNSS receiver fails: **Aviate**: stop any descent and configure the aircraft appropriately **Navigate (if prior to the Intermediate fix)** continue on current heading if able to immediately contact ATC and request vectors to an alternative procedure, otherwise turn to the MAP **Navigate (if after the Intermediate fix)** continue on final approach track, check the missed approach procedure, select non-GNSS aids as required and continue (or turn to) to the MAP. If a non-RNP missed approach is not available, the pilot should have determined an appropriate course of action prior to the approach **Communicate**: advise ATC *"(Aircraft c/s), Unable RNP due equipment*" and/or as appropriate
Reverting to alternative procedures	The "default" contingency in the event of a GNSS failure is to fly the missed approach and request ATC clearance for a conventional procedure at the destination airfield. If no conventional procedure is available, the flight will have been planned with an alternate airport that does have a conventional procedure or where VFR conditions are forecast In practice, ATC may be able to provide vectors directly to a conventional approach if the failure is early in the procedure. If a conventional procedure is not available, and fuel reserves permit, the pilot may request a hold to allow the receiver to be reprogrammed or to wait for RAIM availability to be restored.

The pilot should ensure that appropriate documentation/User Manual for the receiver is available, and must follow any limitations or contingency procedures it specifies

EASA Learning Objectives

- This following pages list the Learning Objectives (LOs) of the EASA CBIR theoretical knowledge (TK) syllabus that are relevant to PBN. The PBN LOs are part of the IR Radio Navigation syllabus and are set out in the Appendix to AMC & GM to Part-FCL – Issue 1, Amendment 10, ED Decision 2020/018/R.
- We have decided to omit the IR LOs, as we struggle to think who might do the EASA IR Exam, so those in the IR syllabus, but not in the CBIR or BIR, which were in previous editions have gone.
- However, we have added in the GNSS LOs, as they are largely covered in this manual
- **E** indicates that it is in the Exam, **B** that it is required Background Knowledge
- There is also a column to indicate whether each LO is included in the BIR syllabus. There are a few in BIR syllabus but not the CBIR, which we suspect might be an error at EASA, but don't know.
- Each LO is referenced to the relevant page of the book in which it is explained.
- For existing EASA IR pilots yet to gain "PBN privileges", it covers all the learning required for the TK element of obtaining them - whether through oral examination during an IR proficiency check, or a written exam at an ATO
- For those training towards the EASA CBIR or BIR, it may be used to revise for the PBN elements of the Radio Navigation exam.
- Some topics which are unlikely to be relevant to most GA fixed-wing pilots, but are in the LOs, are included in Appendix 1. We have kept explanation of such topics to an absolute minimum, so that you have enough information to pass any relevant exam questions.

EASA Learning Objectives

Section	Learning Objective	CBIR	BIR	Page
GNSS				
General	State that there are four main GNSSs. These are: − USA NAVigation System with Timing And Ranging Global Positioning System (NAVSTAR GPS); − Russian GLObal NAvigation Satellite System (GLONASS); − European Galileo; − Chinese BeiDou).	E	E	47
	State that all four systems (will) consist of a constellation of satellites which can be used by a suitably equipped receiver to determine position	B	B	47
Operation	State that there are currently two modes of operation: standard positioning service (SPS) for civilian users, and precise positioning service (PPS) for authorised users.	E	E	47
	SPS was originally designed to provide civilian users with a less accurate positioning capability than PPS.	E	E	47
	Name the three GNSS segments as follows: − space segment; − control segment; − user segment.	B	B	48

EASA Learning Objectives

Section	Learning Objective	CBIR	BIR	Page
	GNSS			
Space Segment	State that an ionospheric model is used to calculate the time delay of the signal travelling through the ionosphere.	B	B	162
	State that satellites are equipped with atomic clocks which allow the system to keep very accurate time reference.	B	B	163
Control Segment	State that the control segment comprises: − a master control station; − a ground antenna; − monitoring stations.	B	B	48
	State that the control segment provides: − monitoring of the constellation status; − correction of orbital parameters; − navigation data uploading	B		48
User Segment	State that GNSS supplies three-dimensional position fixes and speed data, plus a precise time reference.	B	B	48
	State that a GNSS receiver is able to determine the distance to a satellite by determining the difference between the time of transmission by the satellite and the time of reception.	B	B	165
	State that a GNSS receiver is able to determine the distance to a satellite by determining the difference between the time of transmission by the satellite and the time of reception.	B	B	165

EASA Learning Objectives

Section	Learning Objective	CBIR	BIR	Page
GNSS				
User Segment	State that the initial distance calculated to the satellites is called pseudo-range because the difference between the GNSS receiver and the satellite time references initially creates an erroneous range.	*	B	165
	State that each range defines a sphere with its centre at the satellite.	B	B	167
	State that there are four unknown parameters (x, y, z and Δt) (receiver clock error) which require the measurement of ranges to four different satellites in order to get the position.	B	B	165
	State that the GNSS receiver is able to synchronise to the correct time reference when receiving four satellites.	B	B	165
	State that the receiver is able to calculate aircraft ground speed using the space vehicle (SV) Doppler frequency shift or the change in receiver position over time.	*	B	165
	Define 'receiver autonomous integrity monitoring (RAIM)' as a technique that ensures the integrity of the provided data by redundant measurements.	E	E	54
	State that RAIM is achieved by consistency checks among range measurements.	E	E	54
	State that basic RAIM requires five satellites. A sixth one is for isolating a faulty satellite from the navigation solution.	E		55

(Oddly, this is a requirement for BIR, but not CB-IR, which we think is probably a typo at EASA Towers.)*

Section	Learning Objective	CBIR	BIR	Page
	GNSS			
Errors and factors affecting accuracy	List the most significant factors that affect accuracy: − ionospheric propagation delay; − dilution of precision; − satellite clock error; − satellite orbital variations; − multipath.	E		51

PPL/IR EUROPE

Section	Learning Objective	CBIR	BIR	Page
Ground-, satellite- and aircraft-based augmentation systems				
Ground-based augmentation systems (GBASs)	Explain the principle of a GBAS: to measure on the ground the errors in the signals transmitted by GNSS satellites and relay the measured errors to the user for correction.	E		57
	State that the ICAO GBAS standard is based on this technique through the use of a data link in the VHF band of ILS–VOR systems (108–118 MHz).	B		57
	State that for a GBAS station the coverage is about 20 NM.	E		57
	State that GBAS provides information for guidance in the terminal area, and for three dimensional guidance in the final approach segment (FAS) by transmitting the FAS data block.	E		57
Satellite-based augmentation systems (SBASs)	Explain the principle of an SBAS: to measure on the ground the errors in the signals received from the satellites and transmit differential corrections and integrity messages for navigation satellites.	B	B	57
	State that the frequency band of the data link is identical to that of the GPS signals.	B	B	57
	Explain that the use of geostationary satellites enables messages to be broadcast over very wide areas.	B	B	57
	State that pseudo-range measurements to these geostationary satellites can also be made, as if they were GPS satellites.	B	B	57
	State that SBAS consists of two elements: − ground infrastructure (monitoring and processing stations); − communication satellites.	B	B	57

EASA Learning Objectives

Section	Learning Objective	CBIR	BIR	Page
Ground-, satellite- and aircraft-based augmentation systems				
Satellite-based augmentation systems (SBASs)	State that SBAS allows the implementation of three-dimensional Type A and Type B approaches	E	E	59
	State the following examples of SBAS: − European Geostationary Navigation Overlay Service (EGNOS) in western Europe and the Mediterranean; − wide area augmentation system (WAAS) in the USA; − multi-functional transport satellite (MTSAT)-based augmentation system (MSAS) in Japan; − GPS and geostationary earth orbit augmented navigation (GAGAN) in India.	B	B	57
	State that SBAS is designed to significantly improve accuracy and integrity.	B	B	56
	Explain that integrity and safety are improved by alerting SBAS users within 6 seconds if a GPS malfunction occurs.	E	E	59
Aircraft-based augmentation systems (ABASs)	Explain the principle of ABAS: to use redundant elements within the GPS constellation (e.g. multiplicity of distance measurements to various satellites) or the combination of GNSS measurements with those of other navigation sensors (such as inertial systems) in order to develop integrity control.	E	E	54
	State that the type of ABAS using only GNSS information is named Receiver Autonomous Integrity Monitoring (RAIM)	E	E	54
	State that a system using information from additional onboard sensors is named aircraft autonomous integrity monitoring (AAIM).	E	E	54
	Explain that the typical sensors used are barometric altimeter and inertial reference system (IRS).	B	B	54

Section	Learning Objective	CBIR	BIR	Page
PBN Concept (as described in ICAO Doc 9613)				
PBN principles	List the factors used to define area navigation (RNAV) or required navigation performance (RNP) system performance requirements (accuracy, integrity and continuity)	E	B	32
	State that these RNAV and RNP systems are necessary to optimise the utilisation of available airspace		B	13
	State that it is necessary for flight crew and air traffic controllers to be aware of the on-board RNAV or RNP system capabilities in order to determine whether the performance of the RNAV or RNP system is appropriate for the specific airspace requirements		B	20
	Define accuracy as the conformance of the true position and the required position		B	32
	Define continuity as the capability of the system to perform its function without unscheduled interruptions during the intended operation	E	E	32
	Define integrity as a measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid alerts to the user	E	E	32
	State that, unlike conventional navigation, performance-based navigation is not sensor specific	E	E	17
	Explain the difference between raw data and computed data	E	E	157
	Define availability as the percentage of time (annually) during which the system is available for use	E	E	52

EASA Learning Objectives

Section	Learning Objective	CBIR	BIR	Page
Navigation Specifications				
RNAV and RNP	State the difference between RNAV and RNP in terms of the requirement for on-board performance monitoring and alerting	E	E	20
Designation of RNP and RNAV specifications	Interpret X in RNAV X or RNP X as the lateral navigation accuracy (total system error) in nautical miles, which is expected to be achieved at least 95 per cent of the flight time by the population of aircraft operating within the airspace, route or procedure	*	E	20
	State that aircraft approved to the more stringent accuracy requirements may not necessarily meet some of the functional requirements of the navigation specification having a less stringent accuracy requirement	E	E	20
	State that RNAV 5 is used in the enroute and arrival phase of flight	E	E	29
	State that RNAV 1 and RNP 1 are used in the arrival and departure phases of flight	E	E	29,30
	State that RNP APCH is used in the approach phase of flight	E	E	24,26
	State that RNP AR APCH is used in the approach phase of flight	E	E	159

(Oddly, this is a requirement for BIR, but not CB-IR, which we think is probably a typo at EASA Towers.)*

Section	Learning Objective	CBIR	BIR	Page
Use of PBN				
Specific RNAV and RNP system functions	Recognise the definition of an RF leg	E	E	46
	Recognise the definition of a fixed radius transition (FRT)	E	E	27
	State the importance of respecting the flight director guidance and the speed constraints associated with an RF procedure	E	E	46
	Explain the difference between a fly-by-turn and a flyover	E	E	42
	Define the term ‘offset flight path’	E	E	157

Section	Learning Objective	CBIR	BIR	Page
PBN Operations				
PBN principles	Define 'path definition error' (PDE)	E	E	33
	Define 'flight technical error' (FTE) and state that the FTE is the error in following the prescribed path, either by the auto-flight system or by the pilot	E	E	33
	Define 'navigation system error' (NSE) and state that the accuracy of a navigation system may be referred to as NSE	E	E	33
	Define 'total system error' (TSE) and state that the geometric sum of the PDE, FTE and NSE equals the TSE	E	E	33
On-board performance monitoring and alerting	State that onboard performance monitoring and alerting of flight technical error is managed by onboard systems or crew procedures	E	E	59
	State that on board performance monitoring and alerting of navigation system error is a requirement of on-board equipment for RNP	E	E	59
	State that on board performance monitoring and alerting of path definition error are managed by gross reasonableness checks of navigation data	E	E	59
Abnormal situations	State that abnormal and contingency procedures are to be used in case of the loss of PBN capability	E	E	53
Database management	State that, unless otherwise specified in the operations documentation or acceptable means of compliance (AMCs), the navigational database must be valid for the current aeronautical information regulation and control (AIRAC) cycle	E	E	72

EASA Learning Objectives

Section	Learning Objective	CBIR	BIR	Page
Requirements of specific RNAV and RNP specifications				
RNAV5	State that manual data entry is acceptable for RNAV 5	E	E	75
RNAV/RNP1/2	State that pilots must not fly an RNAV 1, RNAV 2, RNP 1 or RNP 2 standard instrument departure (SID) or standard instrument arrival (STAR) unless it is retrievable by route name from the on-board navigation database and conforms to the charted route.	E	E	29
	State that the route may subsequently be modified through the insertion (from the database) or deletion of specific waypoints in response to ATC clearances	E	E	74
	State that the manual entry, or creation of new waypoints by manual entry, of latitude and longitude or place/bearing/distance values is not permitted	E	E	74
RNP APCH	State that pilots must not fly an RNP APCH unless it is retrievable by procedure name from the on- board navigation database and conforms to the charted procedure	E	E	74
	State that an RNP APCH to LNAV minima is a non-precision instrument approach procedure designed for 2D approach operations	E	E	102, 103

EASA Learning Objectives

Section	Learning Objective	CBIR	BIR	Page
RNP APCH	State that an RNP APCH to LNAV/VNAV minima has lateral guidance based on GNSS and vertical guidance based on either SBAS or BaroVNAV	E	E	118
	State that an RNP APCH to LNAV/VNAV minima may only be conducted with vertical guidance certified for the purpose	E	E	118
	Explain why an RNP APCH to LNAV/VNAV minima based on BaroVNAV may only be conducted when the aerodrome temperature is within a promulgated range if the barometric input is not automatically temperature compensated	E	E	154
	State that the correct altimeter setting is critical for the safe conduct of an RNP APCH using BaroVNAV	E	E	154
	State that an RNP APCH to LNAV/VNAV minima is a 3D operation	E	E	118, 103
	State that an RNP APCH to LPV minima is a 3D operation	E	E	118, 103
	State that RNP APCH to LPV minima requires a FAS datablock	E	E	153
	State that RNP approaches to LPV minima require SBAS	E	E	104
	State that the FAS data block is a standard data format to describe the final approach path	E	E	153
RNP AR APCH	State that RNP AR APCH requires authorisation	E	E	159

This Appendix contains information required by the EASA 2013-25 Learning Objectives, but are unlikely to be relevant to most GA fixed wing pilots.

FAS Data Block

- The parameters that define the approach path for a single precision approach or APV is contained in the Final Approach Segment data block.
- For SBAS, FAS data blocks are stored in airborne databases. The data is formatted to allow for validation by a cyclic redundancy check
- A cyclic redundancy check (CRC) is an error-detecting code commonly used in digital networks and storage devices to detect accidental changes to raw data. Blocks of data entering these systems get a short check value attached, based on the remainder of a polynomial division of their contents. On retrieval the calculation is repeated, and corrective action can be taken against presumed data corruption if the check values do not match.
- CRCs are so called because the check (data verification) value is a redundancy (it expands the message without adding information) and the algorithm is based on cyclic codes. CRCs are popular because they are simple to implement in binary hardware, easy to analyse mathematically, and particularly good at detecting common errors caused by noise in transmission channels.

SBAS FAS DATA BLOCK LIRF RNAV (GNSS) RWY34R

INPUT DATA	
PARAMETERS	**VALUES**
Operation Type	0
SBAS Provider	1
Airport Identifier	LIRF
Runway	34
Runway Direction	1
Approach Performance Designator	0
Route Indicator	
Reference Path Data Selector	0
Reference Path Identifier	E34A
LTP/FTP Latitude	414844.7950N
LTP/FTP Longitude	0121631.8910E
LTP/FTP Ellipsoidal Height (metres)	49,5
FPAP Latitude	415048.7165N
Delta FPAP Latitude (seconds)	123.9215
FPAP Longitude	0121540.0295E
Delta FPAP Longitude (seconds)	-51.8615
Threshold Crossing Height	57.4
TCH Units Selector	0
Glidepath Angle (degrees)	3
Course Width (metres)	105
Length Offset (metres)	104
HAL	40
VAL	50

OUTPUT DATA	
Data Block	10 06 12 09 0C 62 00 00 01 34 33 05 F6 A6 F1 11 26 A1 44 05 EF 15 23 C8 03 D5 6A FE 3E 02 2C 01 64 0D C8 FA 92 6E 2E 78
Calculated CRC Value	926E2E78

PPL/IR EUROPE

LNAV/VNAV

- An RNP APCH to LNAV/VNAV minima has lateral guidance based on GNSS and vertical guidance based on either SBAS or BaroVNAV and may only be conducted with vertical guidance certified for the purpose

Baro/VNAV

- Baro-VNAV computes vertical navigation based on barometric pressure, rather than on GPS-based SBAS altitude.
- The barometric altimeter feeds digital altitude information into the RNAV/VNAV unit, and the RNAV/VNAV unit provides vertical navigation information to the pilot by computing a synthetic glidepath, to guide the airplane from the FAF down to DH above the runway. (LNAV/VNAV approach).
- One major factor for Baro-VNAV is temperature, which cannot be set into the altimeter; so these approaches have a minimum OAT at which they can be used.
- For aircraft using barometric vertical navigation without temperature compensation to conduct the approach, cold temperature limits are reflected in the procedure design and identified along with any high temperature limits on the published charted procedure. Cold temperatures reduce the actual glide path angle, while high temperatures increase the glide path angle. Aircraft using barometric vertical navigation with temperature compensation may disregard the temperature restrictions.
- BaroVNAV is usually only found in aircraft with FMS (Flight Management Systems) and is uncommon in smaller GA aircraft, although the latest version of the Garmin G1000 system now has Baro VNAV capability.

Fixed Radius Transition (Advanced RNP)

- The fixed radius transition (FRT) is intended to be used in enroute procedures. These turns have two possible radii, 22.5 nm for high altitude routes (above FL195) and 15 nm for low altitude routes. Using such path elements in an RNAV route enables improvement in airspace usage through closely spaced parallel routes.

PinS Approach and departure (For Helicopters)

PinS Departure

- A PinS departure procedure includes either a “proceed VFR” or “proceed visually” instruction from the heliport or landing location to the Initial Departure Fix ‘IDF’:
  a) For PinS departure with a “proceed VFR” instruction, no obstacle protection is provided from the landing location to the IDF. The pilot shall remain in VFR conditions to see and avoid obstacles in this part of the flight up to the IDF, at or above the Minimum Crossing Altitude (MCA). PinS departures with a “proceed VFR” instruction can serve multiple heliports or landing locations.
  b) For PinS departure with a “proceed visually” instruction, a visual manoeuvring area is identified from a single heliport or landing location to the IDF and obstacle protection is provided within this area. Pilots shall navigate by visual reference to the surface and the visibility shall be sufficient to see and avoid obstacles and to return to the heliport or landing location if it is not possible to continue visually to cross the IDF at or above the IDF MCA.
- After passing the IDF, instrument departure criteria provide obstacle protection. The following requirements apply to entry of the instrument flight structure at the IDF:
  a) For PinS departure with a “proceed VFR” instruction, the helicopter shall depart from the heliport or landing location and fly VFR until crossing the IDF at or above the IDF MCA. An IFR clearance shall be obtained prior to reaching the IDF.
  b) For a PinS departure with a “proceed visually” instruction, the helicopter shall depart on an IFR clearance from the heliport or landing location and fly visually until crossing the IDF at or above the IDF MCA.

PinS Approach

– A PinS approach is an instrument RNP APCH procedure flown to a point-in-space. It may be published with LNAV minima or LPV minima. The PinS approach procedure includes either a “proceed visually” instruction or a “proceed VFR” instruction from the MAPt to the heliport or landing location.

- Proceed visually:-
  - The PinS instrument approach segment delivers the helicopter to a MAPt. A visual segment connects the MAPt to the heliport or landing location, by a direct visual segment in which there is obstacle protection. If the heliport or landing location and visual references associated with it can be acquired visually prior to the MAPt, the pilot may decide to proceed visually to the heliport or landing location otherwise a missed approach shall be executed.

- Proceed VFR:-
  - There is no obstacle protection in the visual segment. The pilot shall comply with VFR to see and avoid obstacles when proceeding from the MAPt. to the heliport or landing location.
  - The visibility for these approaches is the visibility published on the chart, or VFR minima as per the requirement of the class of airspace or State regulations.

Definition of an offset flight path

- Aircraft ability to comply with tactical parallel offset instructions as an alternative to radar vectoring. For example, if a fast aircraft is following a slow aircraft on the same track, an instruction by ATC to ‘Fly Offset by X nautical miles’ can allow the faster aircraft to overtake and be climbed/descended through the slower aircraft. This is a useful alternative to radar vectoring.

The difference between Raw data and Computed data

- Raw data is a term for data collected from a source. Raw data has not been subjected to processing.
- While all navigational receivers convert raw signals into a readable form, conventional navigational receivers such as ADFs, and VORs do not perform any calculations on the raw signals.
- Computed data is data that has been determined by calculation.
- For example, GNSS receivers use the raw data of satellite signals to calculate position, velocity, and time estimates.

Holding Pattern

- Usually a racetrack pattern flown by aircraft to delay their progress for ATC, operational or emergency reasons.
- Historical used on ground based aids, which can be substituted and/or augmented by RNAV waypoints.

Advanced RNP

- Advanced RNP is a route specification that is intended for use from terminal area to enroute to terminal area. Advanced RNP uses a variable RNP value from 2.0NM to 0.3NM and is inclusive of Standard Instrument Departures (SIDs) and Standard Arrival Routes (STARs) and RNP APCH – LNAV and LNAV/VNAV approach procedures.
- Advanced RNP encompasses the following PBN navigation specifications:
  - a) RNAV 5,
  - b) RNAV 1 and RNAV 2,
  - c) Basic RNP 1,
  - d) RF Turns, and
  - e) RNP APCH – LNAV and LNAV/VNAV.
- It is intended that Advanced RNP would also include RNP 2 as an enroute component of the specification once the navigation specification for RNP 2 has been finalised.
- The additional functional requirements of A-RNP are outlined on Page 27

RNP AR APCH

- The RNP AR APCH specification are for developing instrument approach procedures to airports where limiting obstacles exist and/or where significant operational efficiencies can be gained.
- These procedures require additional levels of scrutiny, control and authorisation. The increased risks and complexities associated with these procedures are mitigated through more stringent RNP criteria, advanced aircraft capabilities and increased aircrew training.
- An RNP AR APCH authorisation is based on GNSS as the primary navigational system. RNP AR APCH shall not be used in areas of known navigation signal (GNSS) interference.
- RNP AR APCH implementations do not require any specific communication or ATS surveillance considerations.
- The State AIP will indicate that the navigation application is an RNP AR APCH procedure and that specific authorisation is required. If distinct approvals are required for specific RNP AR APCH procedures or aerodromes, this will be clearly identified in the AIP. An RNP AR APCH operational approval (letter of authorisation, appropriate operations specifications (Ops Spec) or amendment to the operations manual) will be issued by the State annotating RNP AR APCH as appropriate.
- No single point of failure: No single point of failure can cause the loss of guidance compliant with the navigation accuracy associated with the approach. Typically, the aircraft must have at least the following equipment: dual GNSS sensors, dual flight management systems, dual air data systems, dual autopilots, and a single inertial reference unit (IRU).

Appendix 2: How does GPS work?
1. The satellites broadcast a signal for civilian receivers called "L1"

The Navigation Message

The Navigation Message consists of 5 subframes of 10x 30bit words (1500bits total) transmitted at 50bits/s, ie. every 30 seconds. See next page for detail.

C/A (Coarse/Acquisition) code

..is the ranging code, used by the GPS receiver to measure distance to the satellite; also called "the "Standard Positioning Service" or SPS

The C/A code is a 1,023bit "pseudorandom number" (PRN) transmitted at 1.023Mbit/s, ie. repeating every millisecond.

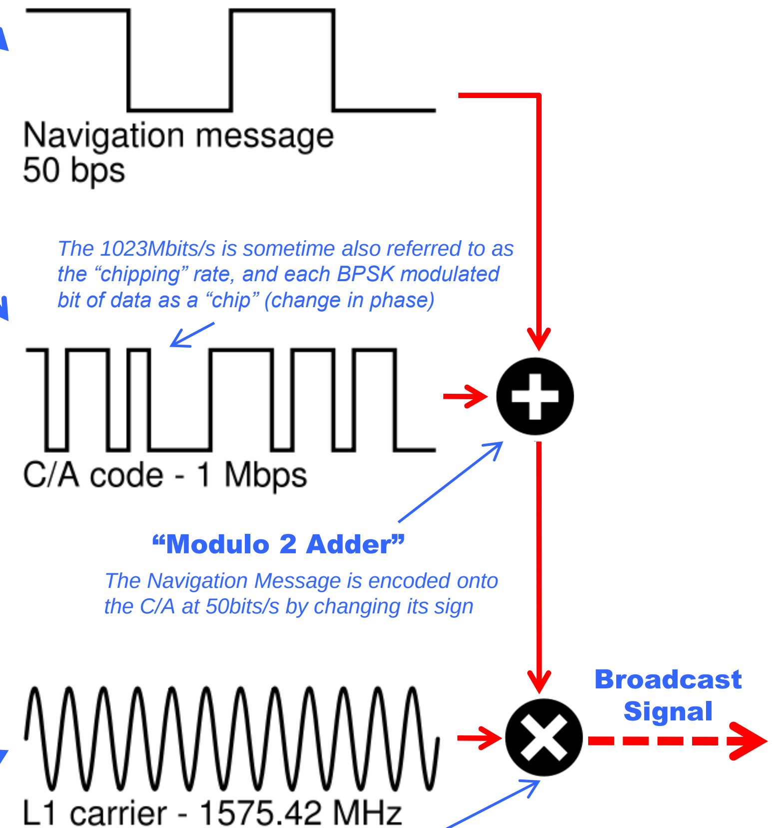
The PRN is unique to each satellite, and all the PRNs are stored in GPS Receiver memory. Because they are long pseudorandom numbers designed to be "orthogonal", any two different PRNs will "correlate" poorly (ie. when multiplied together, give a value near zero).

The Receiver isolates any given satellite's transmission by multiplying the incoming L1 signal by that satellite's PRN at different time shift intervals, within the 1 millisecond sequence, until it finds a match or 'lock-on' (when a particular time shift results in a high multiplication value). It can thus "filter out" all the other satellites from the L1 frequency, and use the time shift required for lock-on to calculate the satellite's range and also extract (demodulate) the Navigation Message from the C/A code. See later pages for detail.

L1 Carrier

The Navigation message is encoded onto the C/A code, and the C/A is then modulated on to a carrier frequency of 1575.42 MHz, called "L1"

The fundamental frequency of the system, Fo, is 10.23Mhz. The carrier and code frequencies are multiples of this , eg. L1 = Fo x 154. All radio frequencies and codes generated in the satellite are from the same 10.23MHz crystal, controlled by an atomic clock



"BPSK" Modulation

A digital (binary) signal is transmitted by changing (modulating) a (sinusoidal) carrier wave in one of three ways: amplitude, frequency or phase. The latter is called Phase Key Shifting (PSK). Binary is the simplest PSK method (BPSK) which "switches" between 2 carriers 180^{O} out of phase

Appendix 2: How does GPS work?

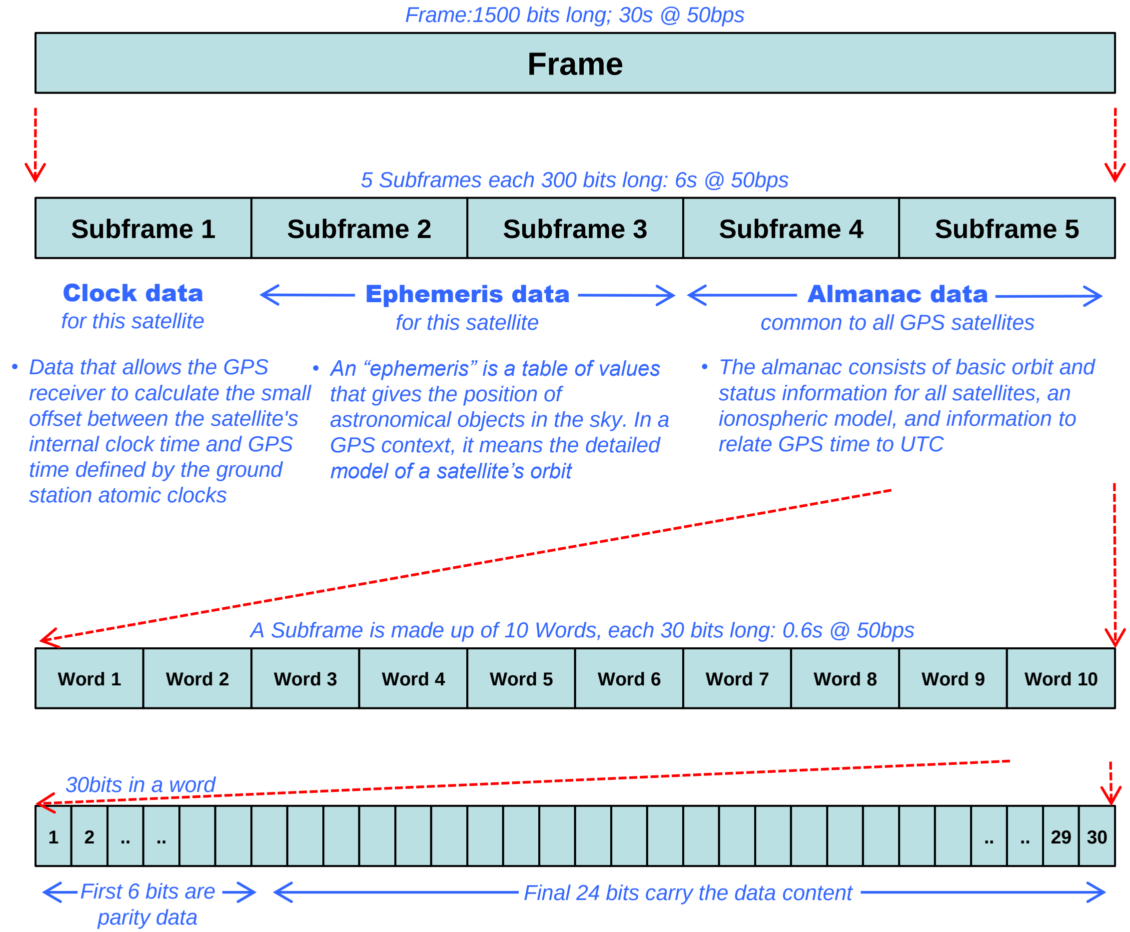
2. The structure of the Navigation Message

- The **Navigation Message** is transmitted as a stream of digital data organised into a sequence of **Frames**
- Each satellite begins sending a Frame exactly on the minute and half-minute, according to its internal clock

- Each **Frame** is made up of 5 **Subframes**
  - Subframes 1,2 and 3 are repeated in consecutive Frames and updated every 1-2 hours, on the hour
  - The almanac data in Subframes 4 and 5 is "sub commutated"; it takes a cycle of 25 Frames (with different Subframe 4&5 data) for the receiver to assemble the full almanac
  - The almanac is thus repeated every 25 Frames and is updated approximately every 24hrs

- Each **Subframe** is made up of 10 **Words**
  - Words 3-10 carry the data content of the frame as described above
  - Word 1 is called the "Telemetry" word and contains a sync pattern used by the receiver to synchronise itself with the Navigation Message and thus decode the data content
  - Word 2 is the "Handover" word, analogous to a counter that increments by 1 in each Subframe

- Each **Word** is made up of 30 **Bits** of data

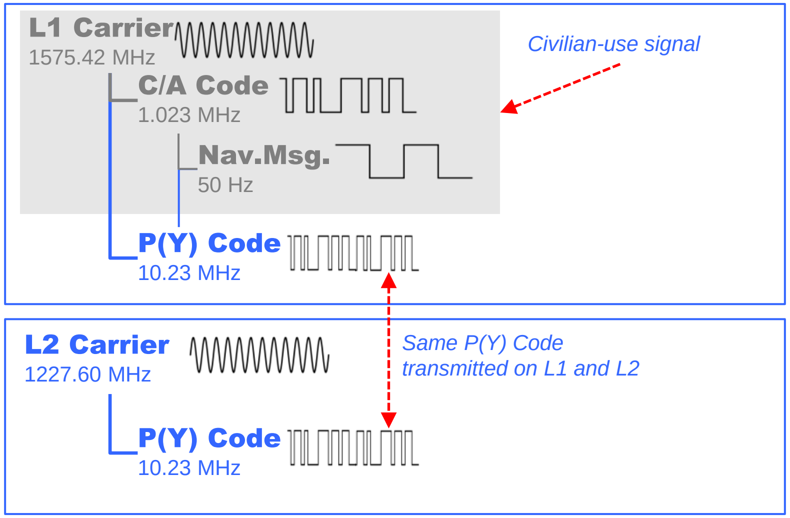


The Navigation Message is the 'real-time reference manual' for the GPS receiver, which helps it calculate an accurate position based on the C/A Code ranging signals

Appendix 2: How does GPS work?

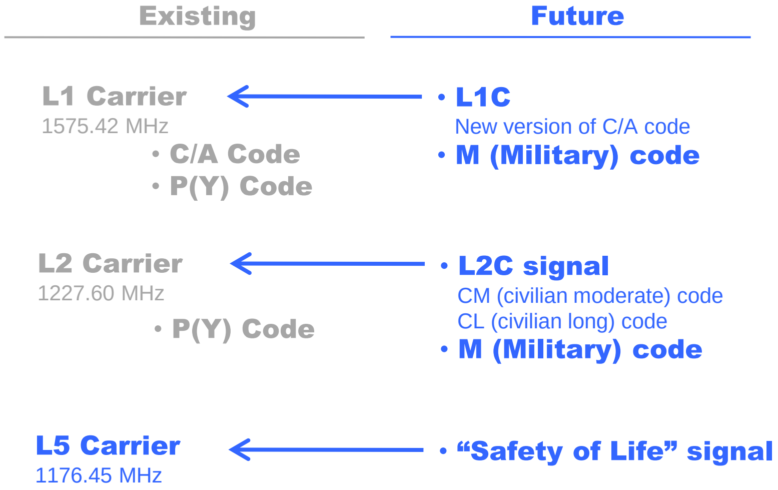
3. Other (non-civilian) signals and future enhancements to the system

Non-civilian GPS transmissions



- The P (Precise) code is a 10,230bit psuedo-random number, it is a 10x more accurate version of the C/A code
- Normally, the P code is encrypted by a "Y" code, creating the 10.23 MHz P(Y) signal which can only be decrypted by military users – known as the "Precise Positioning Service" (PPS)
- The encryption is an "anti-spoofing" technique ,which provides some assurance that the signal received is not being sent by a non-GPS "spoofing" transmitter. The C/A code is potentially vulnerable to such spoofing.
- The ionosphere delays or "disperses" radio signals differently according to their frequency. Military (and some specialised civilian) receivers can compensate for this by comparing P(Y) signal reception between the L1 and L2 carriers.

Future enhancements



- These new signals are being implemented progressively by new satellite launches
- L1C will be compatible with existing receivers but include better interoperability with other GNSS systems and other improvements
- L2C is the more accurate "v2.0" civilian GPS signal and allows civilian ionospheric compensation through comparison of L1C and L2C signals
- The M code is the improved military signal
- The L5 "Safety of Life" signal is specifically for civil aviation use and is transmitted in the protected Aeronautical Radio Navigation Services (ARNS) band

Appendix 2: How does GPS work?

4. International time and the GPS time system

PPL/IR EUROPE

International Atomic Time (TAI)

- The standard international scientific time scale
- The length of a second is defined by a frequency property of the cesium-133 atom, and atomic clocks are used to "count" or "accumulate" seconds
- TAI is derived from 230 atomic clocks in 65 sites around the world, and 11 different laboratory caesium frequency standards
- The data is collated by the BIPM (Bureau International des Poids et Mesures) in Paris, who calculate TAI and promulgate the results to various international centres

Universal Coordinated Time (UTC)

- "Earth time" ("UT1") defines the earth's angular position with respect to the celestial sphere; this is the most useful time scale for navigation and astronomy
- Fluctuations in the earth's spin mean that UT1 deviates from the precise TAI reference
- UTC, the "official world time" is a compromise between Earth time and TAI; it uses the TAI second, but introduces leap seconds to account for changes in the earth's spin and maintain a useful consistency with UT1
- At any given time, UTC equals TAI minus an integer number of seconds. In January 2008, UTC was 33s behind. Typically, a leap second is subtracted once a year

"GPS Time"

- The GPS system uses a time reference ("GPS Time") maintained by the Master Control ground station's atomic clocks
  - GPS time uses the TAI second, and was set equal to UTC in 1980. It does not introduce leap seconds, and in 2008, for example, was 14s ahead of UTC (the difference between TAI & UTC was 19s in 1980, hence in 2008, 33s-19s=14s). The Navigation Message transmits a correction for UTC, so that GPS receivers can display UTC and local time zones.
- Each satellite carries its own atomic clock, which will have a small error or "offset" from GPS Time. This is known as SV (Satellite Vehicle) time
- SV clock offset information is broadcast in each satellite's Navigation Message
- The GPS "calendar" is a counter of weeks and days of the week. 'Date zero' was 6 January 1980

Time measurement is the basis for GPS navigation, because the range from a satellite to a receiver can be determined by the time delay in receiving a signal, and with multiple range fixes, a position can be calculated

Appendix 2: How does GPS work?
5. The GPS Receiver: Overview

Simplified GPS receiver diagram *(not Garmin specific, photos are illustrative)*

- The antenna is designed to provide equal sensitivity to all satellite signals above (typically) 5° of elevation, and is shielded from lower elevation signals to avoid "multi path" error (reflections from terrain or from the airframe)

- Preamplifier: amplifies the Radio Frequency (RF) signal and sets the noise level to reject other RF interference
- Down Converter: converts the RF signal to an Intermediate Frequency (IF)

- A modern multi-channel receiver simultaneously detects and processes signals from all visible satellites
- Locks on to the PRN code and extracts the Navigation message
- Calculates the relationship between GPS time and Receiver time
- Determines position and velocity (method described on next page)

Antenna

Preamplifier and Down Converter

Demodulation and Code control

C/A code generator

Clock

Navigation Message

C/A Code Measurement

Time Measurement

Navigation and Signal Processor

Data decoding
Satellite positions
Pseudo-range calculation
Receiver position, velocity and time calculations

Position, Velocity, Time

Nav functions and user interface

Aviation navigation database and charts. Radios and other sensors.

- Oscillator provides the receiver's time and frequency reference
- Frequency synthesiser converts this reference to a signal providing clock information to the Processor

The Navigation processor's task is complicated, because the GPS receiver has no accurate time or position reference other than the satellite signals it decodes. These specify the exact "GPS Time" of *transmission* – but the receiver doesn't directly "know" its own GPS Time of *reception*. The calculation method is described on the next page.

Appendix 2: How does GPS work?

6. The GPS Receiver: Calculation of time and position

Stage 1: The "pseudorange"

- When the GPS receiver is started-up, its internal or "local" clock will be inaccurate by an unknown error, called clock *bias* or *offset*, compared to the reference GPS Time
- A modern quartz clock may be accurate to one part in a million (ie. drift by one microsecond every second). This means that after only 1s, the internal clock error can be the equivalent of hundreds of metres (1μs = ~300m at the speed of light). A unit that's been switched off for a week or two could be inaccurate by ~1s or hundreds of thousands of km.
- The first stage of the navigation problem is to calculate "pseudoranges" from the visible satellites to the GPS, ignoring the local clock offset. These ranges are "pseudo" because they are all known to be wrong by the same (unknown) local clock error
- For any given satellite, the Receiver generates the satellite's PRN code internally, based on its "code book", and starts the code sequence at the time its local clock says the satellite should have started its PRN transmission. The internal PRN code is then time-shifted until it matches (locks-on) to the PRN code signal from the satellite. This time-shift, or *offset,* is the (pseudo) elapsed time between transmission and the reception Time of Arrival (TOA)
- The Pseudorange is derived from the TOA, assuming a given speed for radio wave travel and the decoded time of transmission from the satellite
- The 1023 bit PRN code is transmitted at 1000 times per second, and the Receiver can judge the "start" of a bit to about 1%, so the maximum accuracy of the C/A code is ~3m
- By decoding the Navigation Message, the Receiver gets data that allows it to correct Pseudorange for the following errors
  - The SV (Satellite Vehicle) time offset from GPS time
  - Basic ionospheric corrections from the Almanac
  - Relativistic effects and receiver noise
- The Receiver calculates pseudoranges from different satellites simultaneously, so they are all subject an identical local clock error

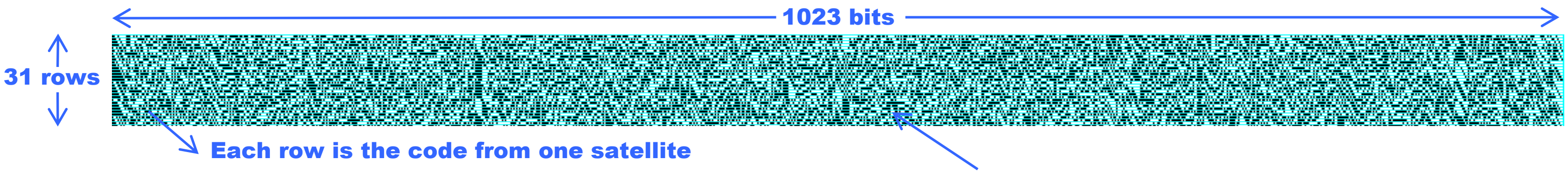
Stage 2: The accurate fix

- The Receiver then uses the ephemeris (orbital) data in each satellite's Navigation Message to establish the satellite's position in space at the time of the Pseudorange calculation
- It requires a minimum of 4 satellite pseudoranges to determine a 3D navigational fix for the Receiver.
- The GPS system specification is that 5 satellites should always be available above a mask (elevation) angle of 7.5° (usually it is 6 or more)
- With 4 satellite positions known and 4 pseudoranges calculated, the navigation problem can be expressed as 4 equations with 4 unknowns (the unknowns being the x,y,z position of the receiver and t, the clock bias error)
- The Receiver calculates a solution to these equations and establishes a position fix
- With true (rather than pseudo) ranges, it would only require 3 satellite position spheres to determine a fix intersect. However, with pseudoranges, a 3 sphere solution would give the wrong range. 4 pseudoranges spheres won't intersect at a point – because the ranges are not true and consistent with a single point in space. The receiver, in effect, solves the equations to determine which value of local clock error creates the best intersect of the 4 spheres
- The receiver also calculates a Geometric Dilution of Precision (GDOP), based on the relative position of the satellites (satellites close together provide a weaker fix)
- When more than 4 satellites are available, modern receivers use various other algorithms to provide a better fix
- Finally, the x,y,z position from the centre of the earth is translated into latitude, longitude and altitude using the WGS84 datum, and GPS Time is converted into UTC. *(See page 48 on WGS84)*
- Velocity (ie. ground speed and ground track) is calculated using a combination of rate of change of position and Doppler shift measurement of the L1 carrier frequency of different satellites, compared to the receiver's L1 oscillator frequency

7. Illustration of the GPS navigation calculation

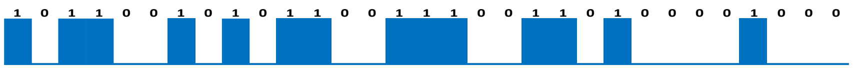
Stage 1: The "pseudorange"

Sample of the C/A PRN codes

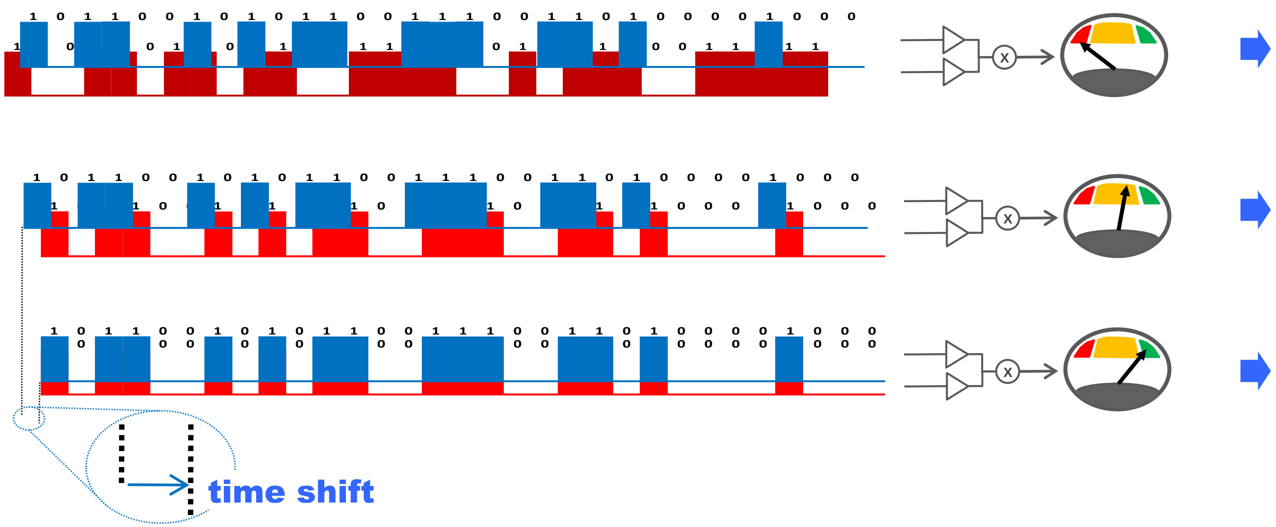


- *All 31 satellites use the same L1 carrier frequency to transmit their C/A codes using the Code Division Multiple Access (CDMA) method of multiplexing that allows them to "share" the same carrier.*
- *A particular C/A code can be extracted from the "noise" of 31 superimposed signals by multiplying the inbound carrier with the desired PRN code generated internally, and time-shifting the internal PRN until a correlation "spike" is achieved*
- *A full description is beyond the scope of this course. The diagrams are illustrative rather than technically rigorous*

The Receiver generates the C/A PRN code for the satellite it is trying to lock on to….



…and seeks a time-shift that will provide the best correlation between the L1 C/A signal and the internally generated code



- **Low correlation: wrong PRN code**
- **Better correlation: correct PRN code, but time shift wrong**
- **Best correlation: correct PRN code and best time shift**

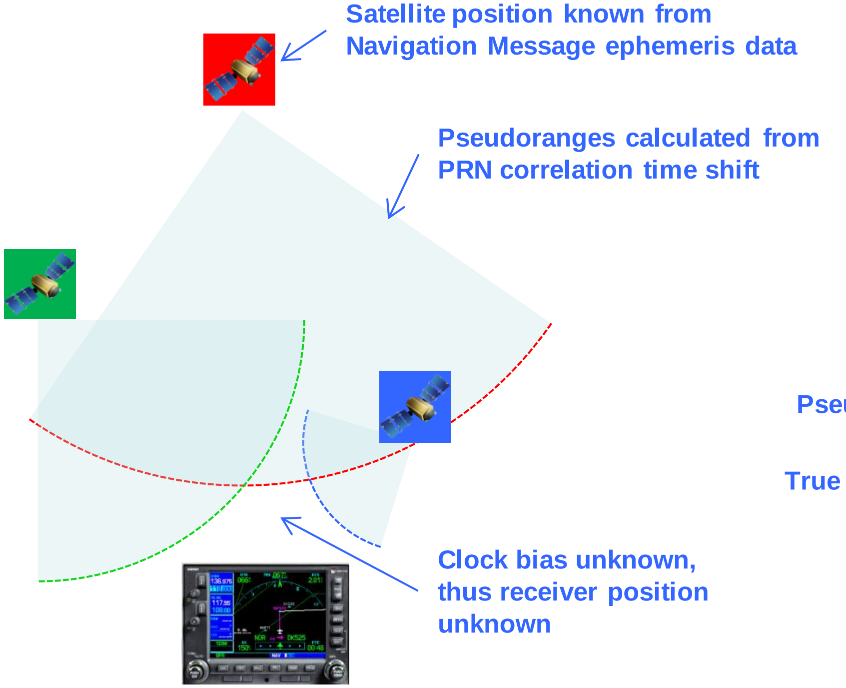
Appendix 2: How does GPS work?
8. Illustration of the GPS navigation calculation

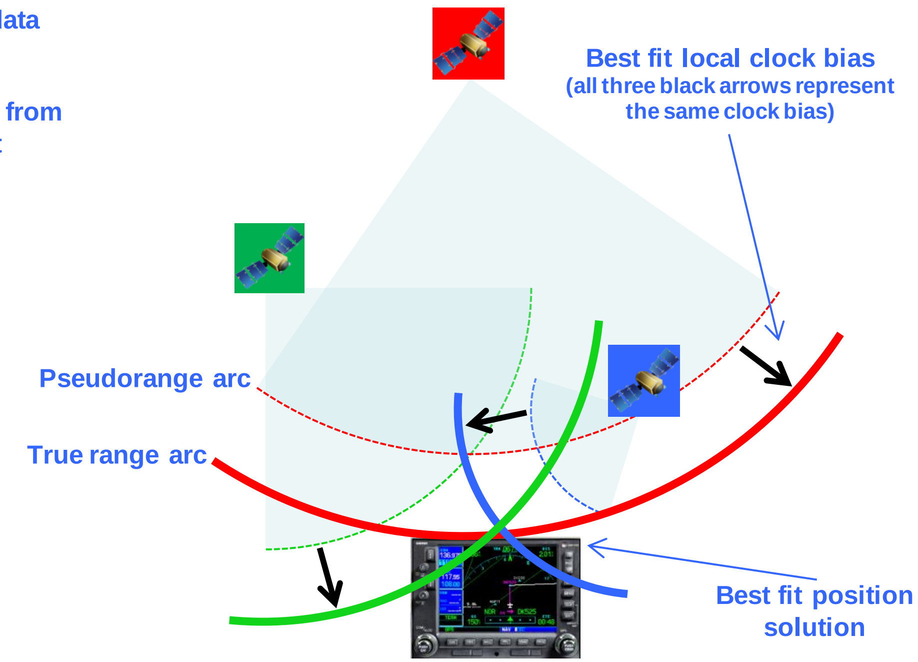
Stage 2: The accurate fix

Two dimensional illustration of the GPS navigation calculation

Determining pseudorange from 3 satellites results in 3 equations with 3 unknowns: the x,y position of the receiver and t, the local clock bias

The navigation processor solves these equations to determine a clock bias which gives the best intersect between the three bias-adjusted "true" range arcs





The actual method used is analogous to this; 4 satellites provide 4 range spheres, and thus 4 equations to solve for the unknown 3D x,y,z position of the receiver and its clock bias

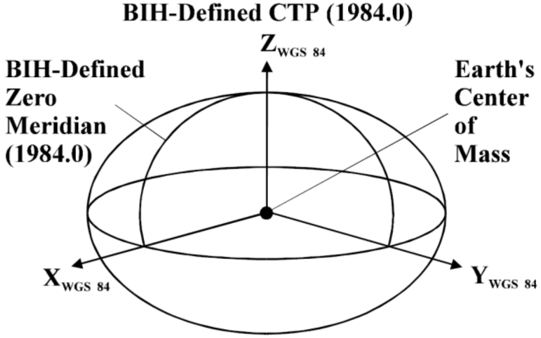
PPL/IR EUROPE

What is WGS84?

- Geodesy (or geodetics) is the science concerned with the study of the geometric shape and size of the earth. It defines the coordinate systems and references used in surveying, mapping, and navigation. Typically, such systems have 3 elements:
  - a "Cartesian" reference or datum, defining the origin as the centre of the earth's mass and the x,y,z axes in terms of polar, equatorial and prime meridian planes
  - an "Ellipsoidial" datum for latitude and longitude; based on the Cartesian datum and an ellipsoid model of the earth's surface
  - a "Geoid" datum for elevation, determined by local variations in the earth's gravity, which represents Mean Sea Level and differs from the idealised ellipsoid ("geoid undulation"). See later page on GPS and VNAV.
- Many different global, regional and national geodetic systems are used for different applications. National mapping coordinate systems tend to use a "local" ellipsoid model of the earth's surface, which is a more accurate mathematical approximation for a particularly country than any global ellipsoid.
- In 1960, the USA Department of Defense combined the different global reference systems used by the US Navy, Army and Air Force into a standard "World Geodetic System" known as WGS60. As terrestrial and space survey data improved, and working with scientists and institutions from other countries, the DoD published improved datums in 1966, 1972 and 1984 (WGS66, WGS72, WGS84).
- **WGS84 was selected as the Datum for the GPS system**, and is now a fixed standard; minor subsequent updates have had no practical impact
- Countries continue to use national coordinate systems, although some have changed theirs to conform more closely to WGS84. **However, there can be differences of hundreds of metres between WGS84 maps and other, relatively modern, national and regional maps**. For example, the UK's Ordnance Survey grid (OSGB36) meridian is 6m west of the historical meridian monument at Greenwich and the WGS84 meridian is 103m east of it

Definition of WGS84

- From the Eurocontrol WGS84 Implementation Manual:
- *The World Geodetic System - 1984 (WGS 84) coordinate system is a Conventional Terrestrial System (CTS), realised by modifying the Navy Navigation Satellite System (NNSS), or TRANSIT, Doppler Reference Frame (NSWC 9Z-2) in origin and scale, and rotating it to bring its reference meridian into coincidence with the Bureau International de l'Heure (BIH)-defined zero meridian.*
  - *Origin and axes of the WGS 84 coordinate system are defined as following:*
  - *Origin: Earth's centre of mass*
  - *Z axis: The direction of the Conventional Terrestrial Pole (CTP) for polar motion, as defined by BIH*
  - *X axis: Intersection of the WGS 84 reference meridian plane and the plane of the CTP's equator, the reference meridian being the zero meridian defined by the BIH*
  - *Y axis: Completes a right-handed, Earth Centred, Earth Fixed (ECEF) orthogonal coordinate system, measured in the plane of the CTP equator, 90° East of the x-axis*
- *WGS 84 is an earth-fixed global reference frame, including an earth model defined by the shape of an earth ellipsoid, its angular velocity, and the earth-mass which is included in the ellipsoid of reference.*



Appendix 2: How does GPS work?
10. Aviation charts and WGS84

Aviation charting datums

- Aviation charts use 3 types of position data
  - <u>Surveyed</u> positions for topographic and terrain features, navaid positions and physical references, like runway thresholds
  - <u>Declared</u> positions, defined by latitude and longitude (rather than any surveyed point) for airspace boundaries and oceanic entry/exit points
  - <u>Calculated</u> points, defined by a geometric relationship to a surveyed position (eg. a fix based on a VOR/DME radial and distance)
- RNAV waypoints are either <u>calculated</u> relative to navaids or at <u>declared</u> latitudes and longitudes (although, of course, charts will often show both the navaid reference and the lat/long of a waypoint)
- Historically, each country used its own geodetic datum for aviation charts. Navigating with ground-based aids, an aircraft could fly between countries that used datums hundreds of metres apart without any problem, since IFR terminal and approach charts used in the cockpit were published with the appropriate <u>local</u> datum
- However, work in Europe on radar and navaid trajectories in the 1970s demonstrated the inconsistency of national datums. For example, an aircraft could appear on one country's radar exactly at the declared longitude of an airspace boundary and 1km away from it on an adjacent country's radar

- **In 1989, ICAO adopted WGS84 as the standard aviation geodetic reference system**
- **This has been fully implemented in Europe and North America; so that GPS-derived WGS84 positions, approved electronic charts used in GPS receivers and approved paper-based aviation charts are self-consistent**

GPS Navigators and WGS84

- The source of approved aviation GPS navigation and map data are the ICAO-compliant charts published in national AIPs.
- These are encoded into electronic databases and maps using the ARINC 424 standard; proprietary standards may also be used for additional features like terrain and obstacle data and the electronic depiction of paper charts
- **Aviation GPS receivers establish the aircraft's position in terms of the WGS84 datum. The aircraft position is then used as the reference for the GPS navigation and map display**
- In "map display mode", objects such as waypoints, ground features and airspace boundaries are displayed on the map <u>relative</u> to the aircraft WGS84 position – based on the objects' stored WGS84 coordinates. Navigation data (eg. track and distance to waypoint, cross-track error) is also calculated from the relative WGS84 co-ordinates of the aircraft and the waypoint or flight plan track.

- **In most aviation GPS Receivers, the WGS84 datum can not be changed**
- In non-aviation GPS, the datum may be changeable (eg. to be consistent with maps used for hiking or marine navigation)

Example from Garmin GNS530 Pilot's Guide

The WGS 84 map datum is displayed (Fig 10-38), this field cannot be changed.

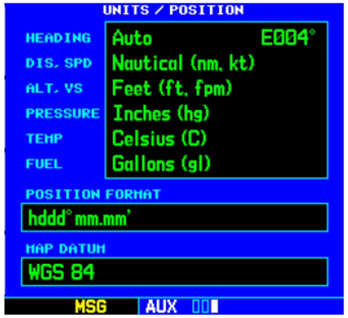
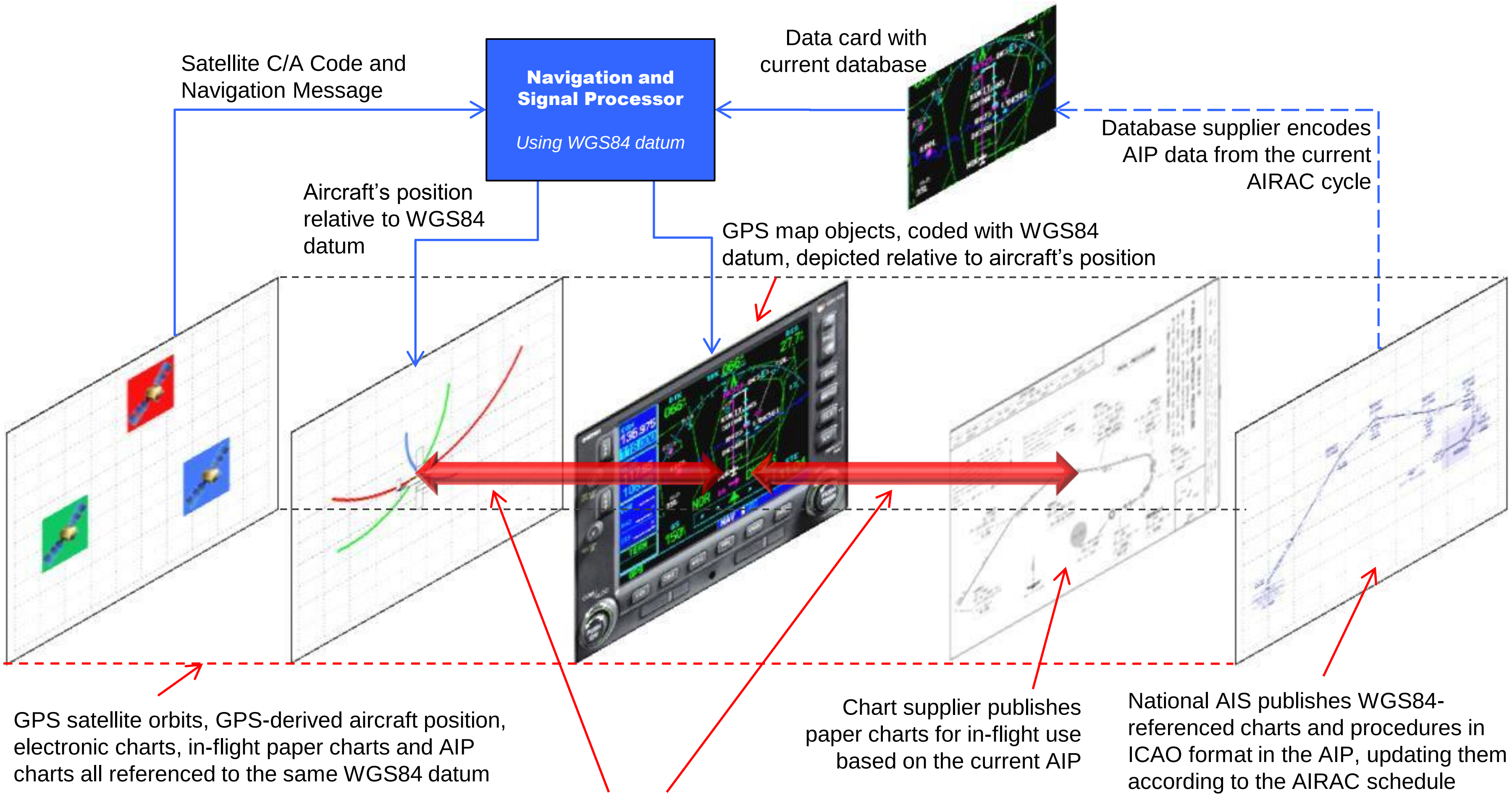


Figure 10-38 Units/Position Page

Appendix 2: How does GPS work?
11. GPS mapping illustration



- **The use of current, approved WGS84 charts and databases assures the consistency of GPS navigation with radio aids, paper charts and surveyed airport, terrain and obstacle positions**
- **If non-approved, non-WGS84 or outdated charts or data are used, inconsistencies may arise that could exceed the protection designed into IFR routes and procedures**

Definition of the "geoid" and Mean Sea Level

- The reference ellipsoid (global or local) for mapping datums is necessarily a geometric shape – so that latitude and longitude lines may be perfectly regular
- Measures of elevation (or, in aviation terminology, altitude) also need a datum; which, by convention, is Mean Sea Level (MSL). This is both a vertical reference *to measure from* and a (gravitationally defined) direction of up and down *to measure along*
- Climatic, tidal, weather, current and local topographic effects cause the sea level to fluctuate. At any given point, the actual sea level may be measured over time to determine its mean. However, measured mean sea levels do not fit well with any ellipsoid model of the earth - because of the gravitational effect of irregularities in the earth's shape and composition (eg. variations in the density of the earth's crust).
- In effect, where gravity is locally "stronger", MSL will be higher. Why?
  - water flows downhill under the influence of gravity. A still body of water will establish a surface which, at all points, is perpendicular to the "down" direction
  - in a perfect, ellipsoid planet of uniform density, "down" would always be towards its geometric centre. In the case of an irregular body like the earth, the gravitational "down" direction varies locally, rather than always pointing to the earth's centre of mass. Hence, the global MSL datum is an irregular *surface of gravitational "equipotential"*. At any point on this surface, a plumb line or spirit level (simple devices for identifying local, gravitationally "true" down) would indicate a down perpendicular to the surface.
- A "geoid" is the representation of the earth whose surface has the property of gravitational equipotential and is used as the reference for the Mean Sea Level datum
- The distinction between the geoid and the ellipsoid model of the earth is a significant one – MSL across the world can vary by 100m from the WGS84 ellipsoid.
- The geoid used in WGS84 is called EGM96 (Earth Geodetic Model 96), most aviation receivers use this model to transform the Ellipsoid height coordinate into an altitude above MSL

Aviation vertical navigation

- In aviation, *altitude* is measured from an MSL datum and *pressure altitude* is measured from the ISA pressure datum of 1013.25 hectopascals
- In an aircraft, a barometric altimeter is used to indicate
  - pressure altitude, directly, when set to 1013hp or 29.92" Hg
  - altitude, indirectly, by using a local pressure setting (QNH) that approximates to the MSL datum
- Under ICAO, the WGS84 datum is widely used as the standard for lateral navigation. There is no corresponding standard datum for Mean Sea Level in vertical navigation. Aviation charts and procedure designs tend to be based on a local MSL datum
- Using barometric altimetry, these variations in MSL datum are not observable to the pilot, because QNH is always referenced to the local MSL datum used for charts and procedures
- **Although modern aviation GPS receivers can display an altitude derived from GPS position data and referenced to EGM96 Mean Sea Level, this can vary significantly from the local MSL datum**

Thus, all enroute and terminal IFR vertical navigation uses barometric altimetry, not GPS altimetry

Example, from the Garmin GNS530W Pilot's Guide

> ***WARNING:*** *The altitude calculated by the 500W-series is geometric height above mean sea level and could vary significantly from altitude displayed by pressure altimeters in aircraft.*

- Terrain warning systems also use Radar and GPS altitude inputs to avoid depending on the manual setting of QNH

Appendix 3: Sources of Navigation Data
1. An overview of standards relevant to databases

ICAO Annex 15 states that *‘Contracting States shall ensure that the integrity of aeronautical data is maintained throughout the data process from survey/origination to the next intended user’*

	Originators →	AIS →	Commercial providers →	Users
Data standards how is data originated to a consistent standard? how is quality assured in data processing?	• **ICAO doc 8168 PANS OPS** • **FAA TERPS** • **ECAC Guidance Material** • **…etc** – standards for the design of IFR facilities and procedures, and the format of AIS data	• **RTCA Do 201A** • **EUROCAE ED 77** – quality assurance for the supply of AIS data used in databases	• **RTCA Do 200A** • **EUROCAE ED 76** – data processing quality assurance for commercial providers that create databases from AIS data	• **FAA TSOs** • **EASA ETSOs** – technical certification for IFR GNSS equipment • **FAA AC120-138,** • **EASA modification approval** – airworthiness approval for IFR GNSS units (or Type Certification for original equipment in newer aircraft) • **FAA: 14CFR Part 91 or 135** • **EASA: Part-NCO** • **Airplane Flight Manuals and AFM Supplements**
Coding standards how are databases created from AIS data?	• **The ARINC 424 standard** – standard for the structure of aviation navigation databases, including the type of data records (eg. Airports, VORs) and the coding of data fields (eg. runway elevation, VOR frequency) – includes standards for coding routes (airways) and procedures (terminal, approach) as well as individual facilities and waypoints			
Update standards how are databases kept current?	• **The AIRAC cycle** – ICAO standard for publishing additions and revisions to AIP data based on a schedule of calendar dates and a process associated with those dates to ensure all users receive timely and “synchronised” updates			

- **Navigation data management and quality assurance is a specialised topic, most of which is beyond the scope of this course**
- **The focus in this appendix is on the basics of the Do200A/ED76 standards and the AIRAC cycle, and details of ARINC 424 relevant to users of GNSS equipment**

Appendix 3: Sources of Navigation Data
2. The Do200A and ED76 standards

PPL/IR EUROPE

RTCA and Do200A, EUROCAE and ED76

- RTCA (Radio Technical Commission for Aeronautics) is a US non-profit organisation that develops standards for communications, navigation, surveillance, and air traffic management (CNS/ATM) with the participation of government, academic and industry stakeholders. RTCA recommendations are used by the FAA as a basis for policy and regulatory decisions

  RTCA http://www.rtca.org

- EUROCAE (the European Organisation for Civil Aviation Equipment) is a non-profit organisation, formed in Switzerland in 1963 to provide a European forum for developing standards for electronic airborne and ground systems. Its recommendations are used by EASA for policy-making

  EUROCAE communication http://www.eurocae.eu

- **RTCA Do200A and Eurocae ED76 are equivalent**, they were developed in the late 1990s to regulate the quality assurance of navigation databases supplied by commercial providers (such as Jeppesen, EAG, Lufthansa Systems) to airline, commercial and private users.
- **Do200A/ED76 were designed to meet the accuracy and integrity requirements of RNP applications**
- Airline and commercial operators are subject to quality management regulation (eg. JAR-OPS 1.035). The Do200A/ED76 standard may be used as a means of ensuring compliance for databases in Flight Management Systems (FMS)
- For non-commercial GA operators, the requirements for a database are specific to the airworthiness approval of an IFR installation and the limitations imposed by the Flight Manual (eg. a GNSS unit may only use an approved database and data card, they have part numbers like any other aviation component)
  - for RNP 5 above MSA, a current database is not required, but paper charts must be used to verify data in an expired database
  - **for RNP approaches, a current database will be a requirement specified in the AFM GNSS section or supplement**

References

- For the interested reader, a source of further detail on the methods of navigation data quality assurance is the Eurocontrol website, eg. the document "Integrity of Aeronautical Information - Data & Quality Management" (2003, AIM/AISD/DI/0007) http://www.ecacnav.com/downloads
- The full set of original sources for data standards are
  - ICAO Annex 4, International Standards and Recommended Practices : Aeronautical Charts
  - ICAO Annex 11, International Standards and Recommended Practices: Air Traffic Services
  - ICAO Annex 14, International Standards and Recommended Practices: Aerodromes and Heliports
  - ICAO Annex 15, International Standards and Recommended Practices: Aeronautical Information Services
  - ICAO Document 8126, Aeronautical Information Services Manual AN/872
  - ICAO Document 9613, Manual on Required Navigation Performance AN/937
  - EUROCAE document ED-76; Standards for Processing Aeronautical Data. RTCA Inc. document DO-200A is technically equivalent to ED-76. A reference to one document, at the same revision level, may be interpreted to mean either document
  - EUROCAE document ED-77/RTCA DO-201A, Standards for Aeronautical Information
  - EUROCAE document ED-75A/RTCA DO-236A, Minimum Aviation System Performance Standards: Required Navigation Performance for Area Navigation.

Appendix 3: Sources of Navigation Data

3. Database Supplier Approvals. Type 1 and Type 2 Letters of Acceptance (LoA)

- The Do200A/ED76 standard was published in 1998
- International agreements have been developed to reduce the burden of manual checks and to certify Database Suppliers as conforming to Do200A/ED76 and other defined conditions. There are 2 kinds of certification:
  - the Type 1 LoA applies to databases that are not specific to any particular avionics system or aircraft, one can think of it as a “wholesaler” approval. The Type 1 LoA holder can not release databases directly to end users
  - **the Type 2 LoA applies to databases compatible with specified avionics systems and may be released directly to end-users.** The GA owner/operator is thus concerned with Type 2 LoA suppliers
- Suppliers are certified by the regulatory agency in their home country (eg. the FAA for Jeppesen, EASA for EAG, Transport Canada for CAC) and mutual acceptance of this certification has been agreed
- **Honeywell, Garmin and Jeppesen hold Type 2 LoAs, but since these are equipment-specific, an operator must check that they apply to their particular model of receiver and database**
  - Garmin received a Type 2 LoA from the FAA for the G1000 and 400/500 series in April 2007
  - some modern IFR GPS units do not have a Type 2 LoA database available, but the Jeppesen data they use is Do200A/ED76 compliant, meeting the RNAV 1 requirement. The operator must check the status of their individual receiver model

Appendix 4: ARINC 424
1. Introduction

- ARINC was founded in 1929 as "Aeronautical Radio Inc", owned by the four major US airlines of the time and taking on responsibility for all ground-based, aeronautical radio stations. Since the 1930s, the company has developed various standards for aircraft electronics
  - eg. for the trays and boxes used in panel-mount radios, and the ARINC 429 standard for interfaces between different kinds of avionics
- The first RNAV systems, in the late 1960s, did not store any navigation data; they were basic VOR/DME "shifters"
- In the early 1970s, avionics manufacturers began to introduce Flight Management Systems (FMS) with a stored database of navigation facilities, each using a proprietary standard
- An industry committee was formed to standardise how FMS navigation data was formatted and coded, and this led to the adoption of ARINC Specification 424 in 1975
- The early versions only accommodated individual navaids and waypoints. ARINC 424-3, published in 1982, introduced the 'path-terminator' concept *(see Section 1b of this manual)* and allowed procedures and approaches to be coded
- ARINC 424 is updated as new navigation technology and RNAV applications emerge, the current version (as of March 2015) is 424-20

The rest of this section will cover two ARINC 424 topics relevant to GA pilots
- **the structure of navigation databases and records**
- **the conventions used for coding and naming database waypoints**

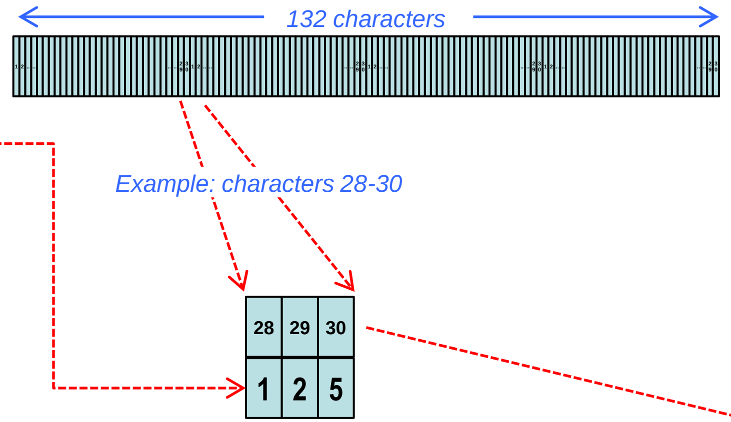
Appendix 4: ARINC 424
2. Database Structure

- The database consists of ~30 different types of "Record", each with 132 characters of data organised into a particular structure of "Fields" (several characters representing an item of information, eg. a frequency)

Record Types

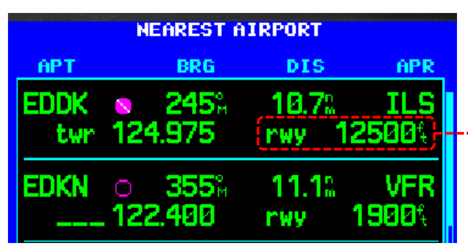
- VHF Navaid
- Waypoint
- Holding
- Airport
- Gate
- SID, STAR, Approach
- Runway
- NDB Navaids
- Localiser and Glide path
- Company Route
- Localiser Marker
- Path Points
- Airport Communications
- MSA
- Airways Marker
- Cruising Tables
- FIR/UIR
- GRID MORA
- Enroute Airways
- Enroute Airways Restrictive
- Enroute Communications
- Preferred Routes
- Controlled Airspace

132 characters per Record, organised into different Fields for each Record type



Example: characters 28-30

Example, characters 28-30 of the Airport Record are defined as the "Longest Runway" Field, the data content in this illustration "125" means the longest runway is 12,500 feet



Example: Airport data from Garmin 530 "NRST" page

Example: definition of Fields in an Airport Record

Column	Field Name (Length)	Ref
1	Record Type (1)	5.2
2 thru 4	Customer/Area Code (3)	5.3
5	Section Code (1)	5.4
6	Blank (spacing) (1)	
7 thru 10	Airport ICAO Identifier (4)	5.6
11 thru 12	ICAO Code (2)	5.14
13	Subsection Code (1)	5.5
14 thru 16	ATA/IATA Designator (3)	5.107
17 thru 18	Reserved (Expansion) (2)	
19 thru 21	Blank (spacing) (3)	
22	Continuation Record Number (1)	5.16
23 thru 27	Speed Limit Altitude (5)	5.73
28 thru 30	Longest Runway (3)	5.54
31	IFR Capability (1)	5.108
32	Longest Runway Surface Code (1)	5.249
33 thru 41	Airport Reference Pt. Latitude (9)	5.36
42 thru 51	Airport Reference Pt. Longitude (10)	5.37
52 thru 56	Magnetic Variation (5)	5.39
57 thru 61	Airport Elevation (5)	5.55
62 thru 64	Speed Limit (3)	5.72
65 thru 68	Recommended Navaid (4)	5.23
69 thru 70	ICAO Code (2)	5.14
71 thru 75	Transitions Altitude (5)	5.53
76 thru 80	Transition Level (5)	5.53
81	Public/Military Indicator (1)	5.177
82 thru 84	Time Zone (3)	5.178
85	Daylight Indicator (1)	5.179
86	Magnetic/True Indicator (1)	5.165
87 thru 89	Datum Code (3)	5.197
90 thru 93	Reserved (Expansion) (4)	
94 thru 123	Airport Name (30)	5.71
124 thru 128	File Record Number (5)	5.31
129 thru 132	Cycle Date (4)	5.32

Appendix 4: ARINC 424

3. There are Four Kinds of ARINC 424 Record

"Points"

Examples:

- VHF Navaid
- Waypoint
- Holding
- Airport
- Runway
- NDB Navaids

• Records of specific locations such as radio navaids, traditional fixes and intersections, RNAV waypoints and airports

• Some fields are common to all these types of record (eg. latitude & longitude, ICAO identifier), others are specific to the type of point

• **Most types of records are "independent" of each other, except for airports, which have a basic record plus several <u>associated</u> records for individual runways, gates, ILS facilities etc.**

Routes

- Company Route
- Enroute Airways
- Enroute Airways Restrictive
- Preferred Routes

• Simple routes which are a named sequence of fixed points

• Route data (eg. for an Airway) includes

- fix sequence number
- fix identifier
- route type
- RNP applicable
- max/min altitudes
- "Rho": distance in nm to next fix
- "Theta": magnetic bearing to next fix

Procedures

- SID, STAR, Approach

Example: waypoint record included in route & procedure sequences

• Complex routes coded as a named sequence of Path-Terminators *(see Section 1b)*

• May include Speed and Altitude limits associated with each fix

• **A fix or waypoint will have both its own "stand-alone" record, and its record repeated within any Route and Procedure sequences it is part of**

• **A waypoint may be designated as "Fly-Over" in one route and "Fly-By" in another**

Miscellaneous

Examples:

- MSA
- FIR/UIR
- GRID MORA
- Enroute Communications
- Controlled Airspace

• Other record types, mostly relating to communications and airspace

• Use is specific to individual receiver models eg. mapping function, airspace alerting, ATC frequency advisories, minimum IFR levels

IMPORTANT NOTE

• **Most GNSS maps <u>only</u> depict Class B, C and D airspace. For example, Class A is omitted because in the USA it is the entire airspace above FL180. However, this means that low-level Class A (and Class E & F) airspace in Europe is not displayed and airspace alerts are not provided**

Note: these four kinds of Record are not a formal ARINC distinction, only used here for descriptive purposes

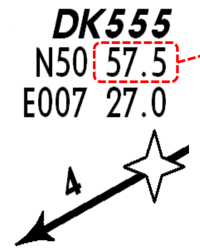
Appendix 4: ARINC 424
4. ARINC 424 Coding: Coordinates

Coordinate fields in ARINC 424

- The ARINC 424 latitude and longitude fields use the following convention:
  - Latitude is stored as nine alphanumeric characters in the form "N" or "S" plus degrees, minutes, seconds, and hundredths of seconds, eg. N50575196
  - Longitude is stored as ten alphanumeric characters in the form "W" or "E" plus degrees, minutes, seconds, and hundredths of seconds, eg. E007270361
- There are 60 seconds in a minute of arc
- Paper charts in the AIP or from commercial suppliers usually use degrees, minutes and **decimal tenths of a minute of arc**, not tens of seconds of arc
- GNSS units typically convert the ARINC format and display degrees, minutes and **decimal hundredths of a minute of arc,** not seconds of arc

Paper chart and database examples

Example: from Jeppesen paper chart



- **57.5 minutes of arc**

Decimal point indicates the last 5 is 0.5 minutes of arc, not 50 seconds

Example: from Garmin 530 database

- **57.51 minutes of arc**
- not 57 minutes of arc and 51 seconds

Note the decimal point, and the single apostrophe minute symbol after the group of 4 digits, both indicating minutes and a decimal fraction of minutes

This illustrates one of the many reasons manually-entered waypoints may not be used for RNP Approaches, and only with caution in other aviation applications

- confusing seconds of arc with decimal fractions of a minute of arc is easily done and can result in errors of up to 1/3 of a nautical mile

Appendix 4: ARINC 424

5. ARINC 424 Coding: Magnetic Variation

Coding of magnetic variation

- GNSS equipment normally displays directional guidance in terms of magnetic tracks and bearings
- Thus, ARINC 424 records always include the magnetic variation associated with fixed points
- There are three types of magnetic variation field
  - measured **Magnetic Variation**, used for physical location records, such as Airports
  - **Station Declination**, used for VORs, which is the tested difference between true north and the 360 radial of the VOR
  - **Dynamic Magnetic Variation**, used for RNAV waypoints, which is derived from a computer model rather than actual measurement
- Bearings along an Airway, and the headings and tracks in Path Terminators, are all coded with reference to magnetic north

GNSS calculation and display of magnetic tracks

- There are various magnetic north references available
  - local (at a given point) or regional
  - measured at a given time, or values valid for a period of time such as 1 year or 5 years
- Although ARINC databases do include the magnetic track or VOR radial along routes and procedures, these will typically not be used by GNSS navigation processors
- Instead, the receiver will calculate magnetic track based on the latitude and longitude of waypoints and the magnetic variation along the route segment. This calculated track (DTK) may ‘jump’ by 1 degree along relatively short route segments, as a result of rounding and changes in magnetic variation
- The magnetic variation may be sourced from the fields associated with waypoints in the database, or from the receiver’s internal magnetic variation model

- **Small differences of ~1 degree are common between charted magnetic tracks and receiver-calculated magnetic tracks**
- **If the waypoint cross-check of a GPS flight plan reveals no discrepancies, such small differences may be ignored and the GPS-derived magnetic track used**

Appendix 4: ARINC 424
6. Introduction to Names and Identifiers

- ICAO Annex 11 defines the international standard for the designators of navaids, waypoints, airways and procedures
- Where a waypoint is marked but not named in AIP charts, ARINC 424 provides standards for creating names
- Where a procedure does not include all the waypoints needed for RNAV guidance, the state can define additional "Computer Navigation Fixes" (CNF) or the database supplier will create CNFs and assign them database identifiers

Names	ICAO Identifiers	Database Identifiers
The full "prose" version of the name of a facility, waypoint or procedure	**A short letter or alphanumeric version of a name, corresponding to the ICAO Annex 11 standard. Published on paper charts, and transmitted as a Morse ident by radio facilities**	**The record name in a database. Generally the same as the ICAO identifier, but ARINC 424 may require some variation. CNFs may only have a database identifier and no published chart designator**
	Examples	
London Heathrow	**EGLL**	**E G L L**
Daventry	**DTY**	**D T Y**
waypoint name is the same as identifier ←	**KENET**	**K E N E T**
Lambourne Three Alpha	**LAM 3A**	**L A M 3 A**
a CNF created by the database supplier and not published in paper charts ←		**C I 2 7**

- Identifiers are not always unique, waypoint and procedure naming conventions change and databases are an inherently different format that can not perfectly "mirror" paper charts

7. Understanding Naming Conventions and Coding is Essential for PBN Operations

Example of an accident resulting in 160 fatalities

N651AA

Controlled flight into terrain accident near Cali, Colombia, December 20th 1995

American Airlines Flight 965, Boeing 757-223, N651AA

Names	ICAO Identifiers	Database Identifiers
Rozo NDB	R	ROZO
Romeo NDB	R	R

both in Colombia

ARINC 424 does not permit duplicate identifiers within the same country, hence full name used for Rozo

Extracts from the Accident Report of Colombia's Aeronautica Civil *(with emphasis added)*

Comment relating to non-unique identifiers: two NDBs in Colombia with different names but the same identifier "R"

*"The investigation determined that because of rules governing the structure of the FMS database, **Rozo, despite its prominent display as "R" on the approach chart, was not available for selection as "R" from the FMS, but only by its full name**. The evidence indicates that this information was not known by the flight crew of AA965."*

Comments that the crew did not cross-check the RNAV waypoint with published chart coordinates

*"Although the differences between the presentation of the same information could be confusing, and the selection of Romeo instead of Rozo can be understood according to the logic of the FMS, the fact remains that one of the pilots of AA965 **executed a direct heading to Romeo in violation of AA's policy of requiring flight crew members of FMS-equipped aircraft to verify coordinates** and to obtain approval of the other pilot before executing a change of track through the FMS"*

Comments relating to differences in ARINC 424 names from those in paper charts. Similar issues apply when CNFs are used that do not appear on paper charts

*"Furthermore, considerable additional differences existed in the presentation of identical navigation information between that on the approach charts and that in the FMS data base, despite the fact that the same company supplied the data to both. For example, **DME fixes for the Cali VOR DME runway 19 approach that were labelled on the charts as D-21 and D-16 were depicted on the FMS using a different nomenclature entirely, that is, CF19 and FF19**. The company explained that it presented data in the FMS according to a naming convention, ARINC 424, developed for electronic data, while data presented on approach charts met requirements of government civil aviation authorities"*

- **The single-pilot GA IFR operator can face GNSS challenges that have defeated experienced professional crews from the best airlines**
- **28 years after the Cali accident, these issues are still very relevant to GNSS database users**

This accident report is worth reading in full, see http://aviation-safety.net/database/record.php?id=19951220-1

Appendix 4: ARINC 424
8. Overview of Databases Identifiers

"Points"

Airports — a a a a
- 4 letter ICAO identifier eg. EGLL
- 'K' added to US 3 letter codes, eg. KLAX

VORs and VOR-DMEs — a a a
- Usually a 3 letter identifier eg. ABC
- Sometimes a 2 letter identifier, but no longer used for VORs in Europe

NDBs — a , a a , a a a
- 1, 2 or 3 letter identifier eg. A, AB, ABC

Enroute waypoints — a a a a a
- 5 character alphanumeric names; usually either 5 letters (the ICAO "5 letter name-code" or 5LNC) or 3 letters and 2 numbers representing a VOR reference and a DME distance in the form aaann

Other "point" records in databases
- Although encoded in ARINC 424 databases, other facilities (eg. ILSs, runways) are usually not directly accessible by the GPS user except as part of Airport or Procedure records

- **Published identifiers and database identifiers are generally identical**
- **Note that some identifiers are not unique, except within a country or geographic region (within Europe, mainly applies to NDBs)**

Routes and Procedures

Airways — a n .... a a n n n
- Alphanumeric identifiers of 2-5 characters. But, not supported in most panel-mount GPS units

Terminal procedure names — a a a n a
- ARINC 424 permits alphanumeric identifiers of up to 6 characters
- The leading letters usually refer to a fix at the start or end of a procedure. In the case of a 3 letter VOR identifier, the "aaana" format is used. If the fix is a 5LNC, the last letter of the 5LNC is dropped and the procedure name format is "aaaana"

Approach procedure names — a a a n n
- Alphanumeric identifiers of 3-6 characters are used
  - 3 characters might specify an approach not specific to a runway, eg. simply 'NDB'
  - 5-6 characters are typical, eg. 'ILS27' or 'ILS27R'
- They may be specified as starting from an approach transition waypoint or starting with vectors to intercept the final approach track

- **Terminal procedure database identifiers are published in [square brackets] on paper charts**
- **Approach procedure identifiers are usually the same as the charted procedure names, but see page 101 for potential ambiguities**

Procedure Waypoints

Terminal waypoint names

"Strategic" waypoints: — a a a a a
- Terminal waypoints of major significance to ATC, often designating the start and end or routes and major transitions
- Use the 5LNC or the 3 letter identifier of a navaid

"Tactical" waypoints: — a a x n n
- Terminal waypoints solely for use in the specific terminal area and not designated as strategic
- 'Tactical' RNAV terminal waypoints use a 5 character alphanumeric. The first two letters ('aa') are the last two letters of the airport ICAO code, the "x" is either a letter code (eg. orientation N,E,S or W) or a digit, and the last 2 characters ("nn") are digits from 00 to 99
- In older procedures, where a tactical waypoint does not have a suitable name, a CNF identifier will be created using a 5 character alphanumeric, in the form "Dnnna", based on the "bearing/distance" convention

Approach waypoint names
- May be named and published (eg. a navaid or 5LNC)
- May be published but with only a generic name (eg. the Outer Marker, or a Final Approach Fix) or no name, in which case a CNF identifier will be created using the Airport CNF convention

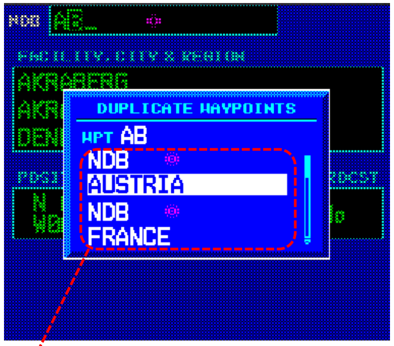
- **Procedure waypoint names are only unique within a terminal area or for a particular airport**
- **Note the similar format used for RNAV Tactical waypoint identifiers and the Bearing/Distance convention for CNFs**

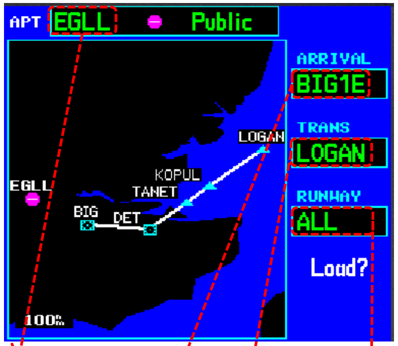
Appendix 4: ARINC 424

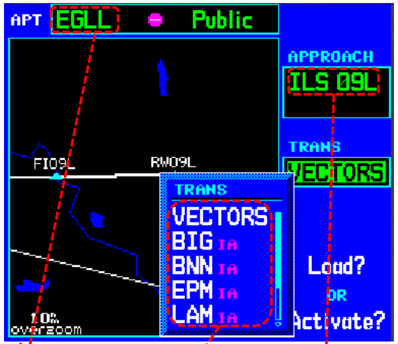
9. Since identifiers are not always unique, how is a specific record located?

	Airports	Radio Aids	Enroute Waypoints	Terminal Procedures	Approach Procedures
Is the Identifier unique?	• ICAO 4 letter airport codes are unique worldwide	• NDB and VOR identifiers are not unique	• 5LNCs are unique • ..but not all enroute intersections use 5LNC identifiers	• Procedures and procedure waypoints are unique to a particular TMA	• Approaches and final/missed approach waypoints are unique to a particular airport
How is the right record selected if duplicates exist?	• (n/a: no duplicates)	• Be familiar with how and when the GPS identifies that duplicate records exist for an identifier • Select the record with the correct name and geographic region		• Confirm correct airport • Select runway, transition and procedure identifier	• Confirm correct airport • Select runway, transition and approach type
How is a record identification confirmed?	• Check the airport name in the database to confirm ICAO code	• Gross error check of RNAV waypoint position with paper chart and radio instruments		• Check procedure waypoints with paper chart *terminal and approach waypoints should only be selected from within a loaded procedure* • Check the end waypoint of the STAR matches the transition at the start of the approach	

Garmin 530 examples







Example: select geographic region from GNS530W list of duplicated records available for a given identifier selection

Confirm facility name correct

data for gross error check and radio cross-check

1.Confirm airport correct
2.Select procedure identifier

3. Select transition
4. If applicable, select runway

1.Confirm airport correct

3.Select transition

2.Select procedure identifier – check list for multiple similar procedures

Appendix 4: ARINC 424

10. When are database waypoints different from those on paper charts?

1. When paper chart names are not suitable for ARINC 424	2. When waypoints are not named on paper charts, or where only a generic "label" is used	3. When a waypoint does not exist on paper charts, but is required for coding a procedure
• ARINC 424 limits waypoint database identifiers to 5 character, and duplicate identifiers are not permitted within a single country • When RNAV and the use of FMS databases were relatively new, paper charts in the USA and Europe would often have fix and intersection names not compatible with ARINC 424 • However, in Europe, AIP charts have been updated so that ARINC-compatible names are used in all enroute navigation	• Examples: - unnamed fixes or intersections - unnamed turning points in procedures (eg. simply defined by a time, lead radial) - points on procedures labelled only with a DME distance (eg. D4.5), which is not sufficiently unique to be used as a database identifier - points with generic labels such as FAF, IAF, OM; which, again, are not unique enough – a single airport may have numerous such points • Note that a "generic" name (eg. D4.5) may be used as a database identifier if it is unique within the procedures at a particular airport	• Procedures where the paper chart description is adequate but too "ambiguous" for the more deterministic coding needed in databases. Examples: - the localiser intercept after a base turn will often not have a published waypoint, but GNSS systems may require one to establish the track segment from the intercept to the FAF - the point at which a DME arc is intercepted will often not have a paper chart waypoint defined, but one may be needed for the path-terminator coding in a database

- ARINC 424 has coding rules for creating waypoint names when suitable names are lacking, and for creating Computer Navigation Fixes (CNFs) when suitable waypoints are lacking
- These coding rules can be summarised as 3 waypoint conventions:
  - **Enroute waypoint naming convention**
  - **Procedure CNF Bearing/Distance convention**
  - **Airport CNF convention**

Each of these conventions is described in the next pages

Appendix 4: ARINC 424
11. Enroute Waypoint Naming

If an __enroute__ fix has a published name which is not suitable for ARINC 424

- The method applied in ARINC 424 coding is as follows

A. If the name is greater than 5 letters, various rules are applied to shorten it to a "5LNC"
   eg. 'COTTON' becomes **COTON**
   eg. 'CLEAR LAKE' becomes **CLAKE**

B. If the 5LNC rule results in duplicate identifiers, a 4 letter name with a suffix number is used, eg. **CLAK1** **CLAK2**

C. Where more than one short identifier is published, ARINC 424 uses a long name for one of the duplicates eg. **R** and **ROM**

If an __enroute__ fix or intersection is published without a name

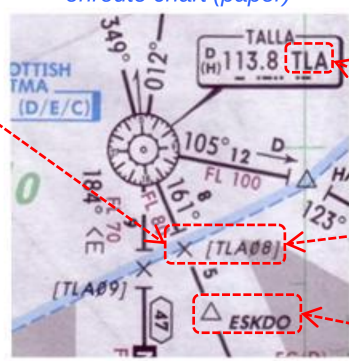
- The identifier is constructed from the identifier of, typically, the nearest airway VOR (which is the reference for the waypoint) and the distance from that VOR
- If the distance is less than 100nm, the identifier format is the three letters of the VOR ident followed by a two digit distance, eg a waypoint 35nm from "ABC" VOR: **ABC35**
- If the distance is 100-199nm, the identifier format is the three letters of the VOR ident preceded by the last two digits of the distance eg a waypoint 135nm from "ABC" VOR: **35ABC**
- If unnamed waypoint is collocated with a named waypoint on a __different route structure__ then the named waypoint's identifier is used

- **European enroute charts have been updated with airway waypoint identifiers that are always compatible with ARINC 424, hence the paper charts and databases should be highly consistent**
- **The three formats used are navaid identifiers, 5LNCs and the 'reference VOR plus 2 digit distance'**

Example of Airway waypoints

Jeppesen E(LO)2 low altitude enroute chart (paper)

Note square brackets and cross symbol indicating a __CNF database identifier__ which has no flight plan filing or ATC function, only aids pilot orientation.



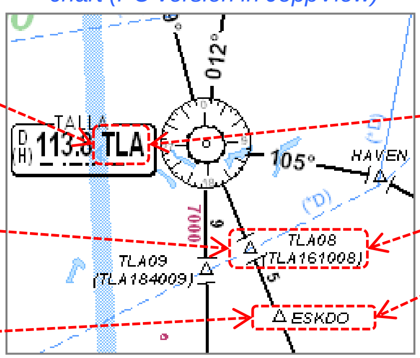
VOR identifier

Reference VOR and distance identifier

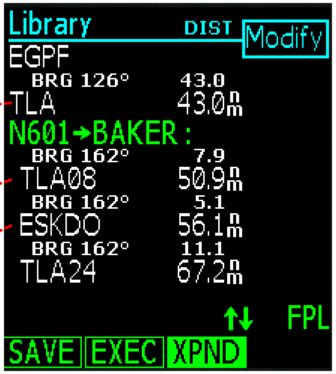
"5LNC" identifier

DO NOT USE FOR NAVIGATION

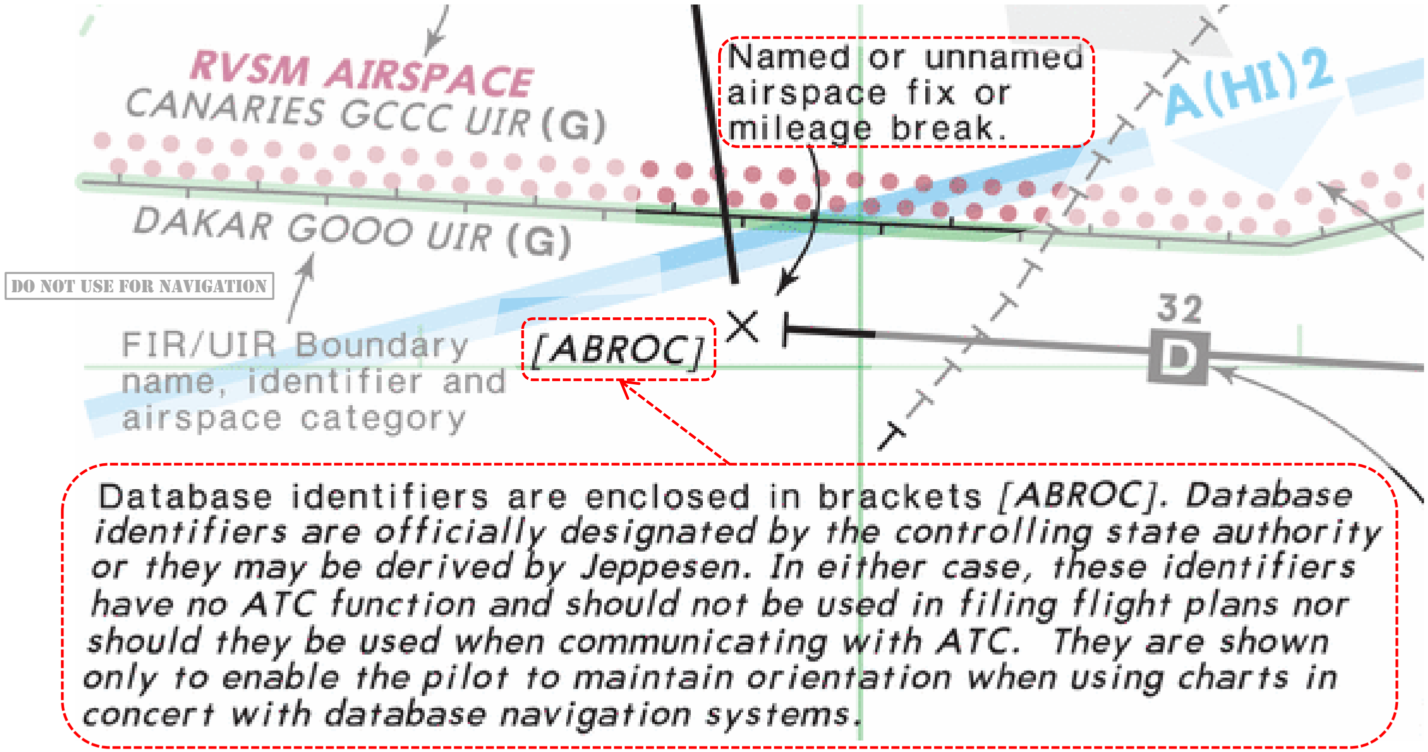
Jeppesen low altitude enroute chart (PC version in JeppView)



Garmin GNS480 airway route



12. Reference: Extract from Jeppesen Enroute Chart legend



- Note: the nomenclature of waypoint names is sometimes confusing.
- “Database identifier” can be a generic term for the ARINC 424 short, coded name of any navaid, fix, airport etc.
- In the context of the chart legend above, “database identifier” means a Computer Navigation Fix name which is not part of the normal published ATC route (although the underlying turning point is, in this case).
- When CNFs are published in state AIP sources, they will be included in paper charts [in square brackets]; if they are created by Jeppesen, they will only be found in the database

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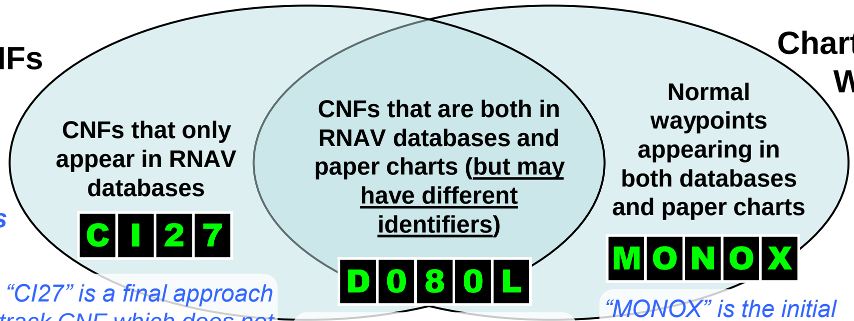
- CNFs are created when a waypoint required for coding Terminal or Approach Procedures is
  - <u>either</u> marked in paper charts without an identifier, or with an identifier too "generic" to meet ARINC 424 standards
  - <u>or</u> does not exist in paper procedure charts
- CNF identifiers defined by state AIS sources are included in paper charts [in square brackets], CNFs defined by Jeppesen appear only in the database

CNFs

Charted Waypoints

Examples



"CI27" is a final approach track CNF which does not appear on the paper chart.

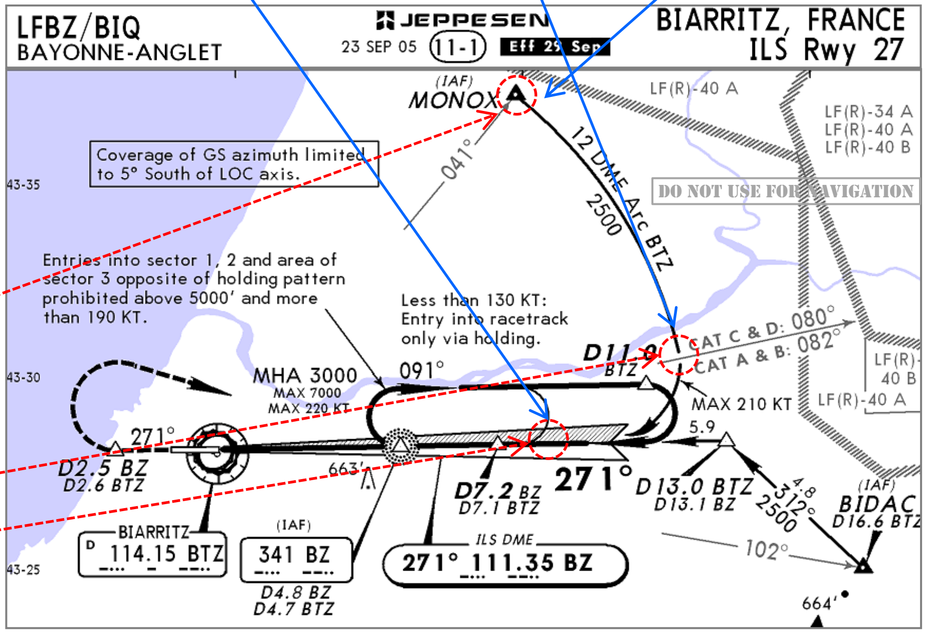
"D080L" is the CNF at the intersect of the DME arc and the lead-in radial which is not named on the chart

"MONOX" is the initial approach fix, published with a 5LNC and stored in the database with this identifier

LFBZ ILS 27 Procedure, MONOX transition: Garmin GNS530W display extracts

Other CNFs, see next pages

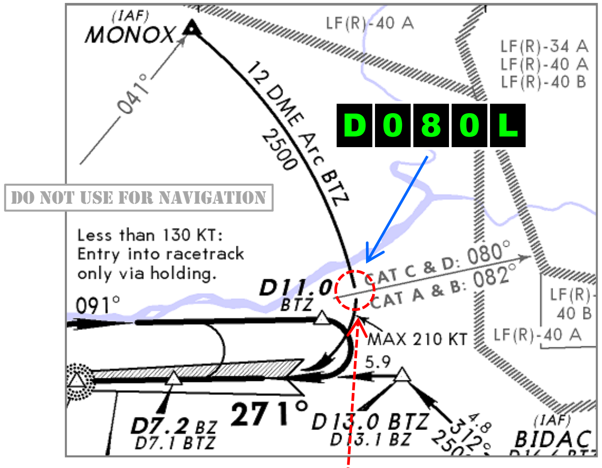
131º is the initial tangential track along the DME arc from MONOX

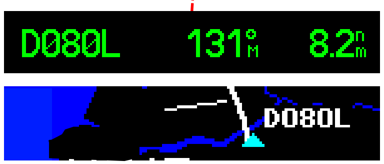


Appendix 4: ARINC 424

14. Procedure "bearing/distance" CNFs

- **In the previous example, why is the identifier "D080L" used for the CNF at the end of the DME arc?**





Garmin GNS530W display extracts

Procedure waypoint "bearing/distance" CNF convnetion

- In SIDs, STARs and Approaches, this convention is used to create an identifier for unnamed fixes or DME fixes
- The identifier is always a 5 character alphanumeric in the format:

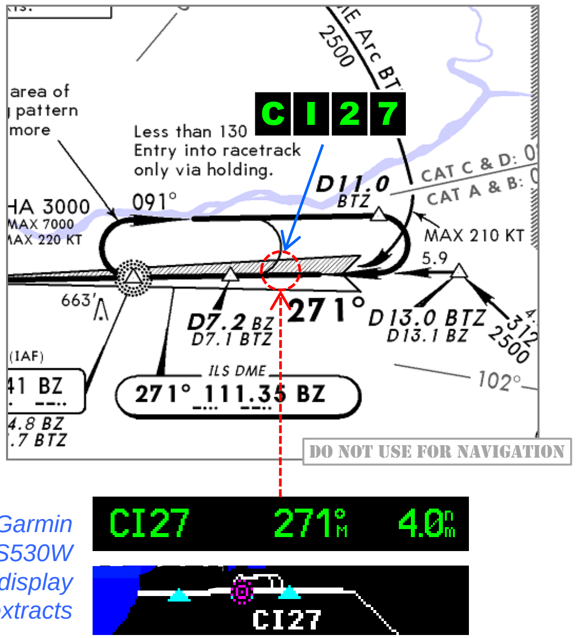
D n n n a

- **first character is <u>always</u> "D"**
- **middle 3 digits are the <u>radial</u> from the reference VOR (or other reference point)**
- **last character is a <u>letter code</u> for the <u>distance</u> from the reference point**

- The distance letter code is A=1nm, B=2nm….Z=26nm
- Distances are rounded to the nearest integer (i.e. A is used for 0.1nm to 1.4nm, B for 1.5nm to 2.4nm etc)
- If the distance is greater than 26nm, the Enroute waypoint convention is used (3 letters of the VOR ident plus 2 digit distance)
- The A-F letter codes are easy to remember as 1-6nm respectively. It is worth being familiar with G=7nm, H=8nm, I=9nm, J=10nm, K=11nm, L=12nm.

- **Hence, in the example above, the waypoint on the BTZ 080 radial and 12nm DME arc is given the identifier "D080L"**
- **Procedure "bearing/distance" CNFs are only unique <u>within</u> a TMA**

- **In the previous example, why is there a CNF called "CI27" on the final approach track prior to the FAF?**



Garmin GNS530W display extracts

Airport CNF convention

- This convention allows CNFs to be created for all the fixes GNSS equipment needs to provide guidance throughout an approach procedure, which may not be published or have an ARINC 424 compatible name
- The identifier is a 4 or 5 character alphanumeric in the format:

a a n n a

1st letter defines the waypoint type

2nd letter defines the approach type, <u>if there are multiple approaches to this runway</u>, otherwise it is the 2nd letter of the waypoint type code

2 digits are the runway identifier

If there are parallel runways, the 5th character is an L,C or R runway suffix

- The various codes for the waypoint type and approach type are detailed on the next page

- **In the "CI27" example above, the "C" indicates a final approach track fix, the "I" indicates an ILS procedure, and the "27" that the procedure is for runway 27**
- **Airport CNFs are unique to an <u>individual Airport</u> only. In the example above, there will only be a single instance of a CNF identifier "CI27" associated with LFBZ. Many other airports, including ones in the same TMA, can have an identically named CNF**

Appendix 4: ARINC 424
16. Airport CNF codes

A single approach procedure exists for a given runway	
First two characters of the CNF identifier are the Waypoint Type	
Initial Approach Fix	AF
Intermediate Approach Fix	IF
Final Approach Course Fix	CF
Final Approach Fix	FF
Missed Approach Point	MA
Step-Down Fix	SD
Runway Centreline Fix	RC
Touchdown point	TD
Runway Fix	RW
Outer Marker	OM
Middle Marker	MM
Inner Marker	IM
Back course Marker	BM

Rarely used (SD, RC, TD)

CNFs unique to a runway, so no need for a single letter code (RW, OM, MM, IM, BM)

If an approach marker has an identifier, that will be used in preference to this CNF convention

More than one procedure exists for a given runway	
First character of the CNF identifier is the Waypoint Type	
Initial Approach Fix	A_
Intermediate Approach Fix	I_
Final Approach Course Fix	C_
Final Approach Fix	F_
Missed Approach Point	M_
Step-Down Fix	S_
Runway Centreline Fix	R_
Touchdown point	T_

\+

Procedure type codes used	
Second character of the CNF identifier is the Procedure Type	
_I	**ILS Approach**
_L	**Localiser Approach**
_D	**VOR/DME Approach**
_V	**VOR Approach**
_N	**NDB Approach**
_Q	**NDB/DME Approach**
_R	**RNP APCH**
_P	**GNSS Approach**

These are 8 of the most common types, see next page for the full list of 25

- The only unfamiliar, but frequently used, waypoint type is the Final Approach Course (or Capture) fix, CF or C_
- Many older GNSS systems can only provide guidance from one waypoint to another. Without the CF/C_ fix, they could not provide track guidance along the final approach to the FAF following an intercept (eg. a base turn or radar vectors) that did not commence with a published waypoint
- **Hence, many approach procedures are coded with a CF/C_ fix after the intercept of the final approach track and before the FAF**

Source: www.jeppesen.com GPS NavData Services > Documentation and Support > see PDF download of NavData name conventions

Appendix 4: ARINC 424

17. Extract from Jeppesen NavData documentation

Full List of 25 Approach types

A. Approach Transition
B. LLZ Back course Approach
C. LORAN Approach
D. VOR/DME Approach
E. VOR Circle-To-Land Approach
F. FMS Approach
G. IGS (Instrument Guidance System) Approach
H. Helicopter Approach
I. ILS Approach
J. LLZ only Circle-To-Land Approach
K. LLZ Back course Circle-To-Land Approach
L. Localiser only Approach
M. MLS Approach
N. NDB Approach
P. GPS Approach
Q. NDB/DME Approach
R. RNP APCH
S. VOR Approach with DME Facility
T. TACAN Approach
U. NDB Circle-To-Land Approach
V. VOR Approach (Non-DME Facility)
W. MLS Type A Approach
X. LDA (Localiser Directional Aid) Approach
Y. MLS Type B and C Approach
Z. SDF (Simplified Directional Facility) Approach

Waypoint types	Matrix of Waypoint and Approach type combinations					
	ILS(I)	ILS(L)	ILS(B)	VOR(D)	VOR(V)	VOR(S)
IAF	AI	AL	AB	AD	AV	AS
IF	II	IL	IB	ID	IV	IS
FACF	CI	CL	CB	CD	CV	CS
FAF	FI	FF	FB	FD	FV	FS
MAP	MI	ML	MB	MD	MV	MS
TDP	TI	TL	TB	TD	TV	TS
RCI	RI	RL	RB	RD	RV	RS
Step-Down	SI	SL	SB	SD	SV	SS
	NDB(N)	NDB(Q)	MLS(M)	RNAV(R)	TACAN(T)	LORAN(C)
IAF	AN	AQ	AM	AR	AT	AC
IF	IN	IQ	IM	IR	IT	IC
FACF	CN	CQ	CM	CR	CT	CC
FAF	FN	FQ	FM	FR	FT	FC
MAP	MN	MQ	MM	MR	MT	MC
TDP	TN	TQ	TM	TR	TT	TC
RCI	RN	RQ	RM	RR	RT	RC
Step-Down	SN	SQ	SM	SR	ST	SC
	IGS(G)	LDA(X)	SDF(Z)	FMS (F)	GPS(P)	HEL(H)
IAF	AG	AX	AZ	1F	AP	AH
IF	IG	IX	IZ	2F	IP	IH
FACF	CG	CX	CZ	3F	CP	CH
FAF	FG	FX	FZ	4F	FP	FH
MAP	MG	MX	MZ	5F	MP	MH
TDP	TG	TX	TZ	6F	TP	TH
RCI	RG	RX	RZ	7F	RP	RH
Step-Down	SG	SX	SZ	8F	SP	SH
	VOR C-T-L(E)	NDB C-T-L(U)	LOC C-T-L(J)	BAC C-T-L(K)	MLS (W)	MSL (Y)
IAF	AE	AU	AJ	AK	AW	AY
IF	IE	IU	IJ	IK	IW	IY
FACF	CE	CU	CJ	CK	CW	CY
FAF	FE	FU	FJ	FK	FW	FY
MAP	ME	MU	MJ	MK	MW	MY
TDP	TE	TU	TJ	TK	TW	TY
RCI	RE	RU	RJ	RK	RW	RY
Step-Down	SE	SU	SJ	SK	SW	SY

18. Summary of “Point” Terminology

- The terminology around “types of point” can be confusing, because it is not always consistently defined and applied. The tables below provides some guidance on the use of various terms

Enroute and Terminal points

Term	Definition	On paper chart	In GNSS unit
Fix	<u>Specifically</u>, a geographical point defined by reference to radio aids, also, <u>in general</u>, includes any of the below	△ & name identifier	▲ & identifier *usually one symbol used for all fix and waypoint types, except radio aids*
Intersection	A fix defined by the intersection of two VOR radials	✕ & DME distance or unnamed	
RNAV Waypoint	A geographic point defined by coordinates rather than radio aids; the RNAV equivalent of a fix	✧ & identifier *(fly-by example)*	
Waypoint	<u>In general</u>, any of the above, also locations of a radio aid. Sometimes <u>specifically</u> an RNAV waypoint	Any of the above	
Computer Navigation Fix (CNF)	A fix or waypoint used in databases but not for ATC or flight plan filing purposes	Identifier, if shown and different from the published name, will be in [square brackets]	
Database Identifier	In <u>general</u>, the primary record name in a database for any of the above. Sometimes, <u>specifically</u> the name of a CNF		

Approach waypoints

Term	Definition	Traditional procedure	PBN procedure
IAF	Initial Approach Fix, Intermediate Fix and Missed Approach Point definitions are <u>exactly the same</u> in PBN procedures as in ‘traditional’ IFR approaches	△ & name ..or navaid symbol & name	✧ & name ..or navaid symbol & name
IF			
MAP (or MAPt)			
FAP	Final Approach Point – used only in a <u>precision</u> approach, the point at which the intermediate approach altitude or height intersects the glide path	In paper charts, <u>not defined as a fix</u>, but a DME distance may be marked at the FAP In databases, an “FF/F_“ CNF is defined at the FAP	
FAF	Final Approach Fix – used only in a <u>non-precision</u> approach (NPA), the fix which defines the start of the descent to MDA/MDAH	Fix and fix name depicted on paper charts and databases (may be a CNF identifier for a DME fix) *NPAs without a fix (eg. NDB approach based only on timing) will have a “FF/F_” CNF defined in the database*	

Note: in the late 1990s, it was proposed that the waypoints in RNP APCHs should be called “IAWP, IWP, FAWP, MAWP” (with “WP” for Waypoint replacing “F” for Fix). This new terminology was abandoned, but some older publications and charts still use the “-WP” notation

Appendix 5: Flight Training
1. Training course objectives and structure

PPL/IR EUROPE

• Here is a suggested PBN training course:

Theory Training objectives (key points)
General PBN theory - RNAV and RNP Concepts
PBN theory - changes to charting and documents to reflect PBN - required navigation equipment for enroute and approaches
Charting, database and avionics topics - Waypoint naming concepts - the 'TF' and 'CF' path terminators - fly-by and fly-over waypoints
Simulator and/or Flight Training objectives
Operational procedures and practices - Normal procedures - Contingency procedures
Use of GNSS Equipment - retrieving a procedure from the database - briefing the procedure, comparing it with the charted procedure - action to be taken if discrepancies are noted - tactically modifying the flight plan
Flying procedures - Horizontal tracking and turn anticipation - Approaches with Vertical Guidance and vertical control techniques, - Use of automatic pilot and flight director - Implications of system malfunctions not GNSS related

PART 1: GROUND THEORY
Self-study method:
A pilot may use this manual to self-study PBN theory. The Instructor could helpfully conduct an oral exam to ensure the pilot is fully proficient in the key knowledge items listed in the table on the left

or, **Classroom training method:**
The instructor or an ATO may conduct classroom training to cover the required PBN material in this manual. This may involve one or more 2-3hr classroom sessions, depending on how much preparation and reading the student has done

PART 2: PRE-FLIGHT BRIEFING
The pre-flight briefing sessions may require 1-2hrs, and should include:
Use of GNSS Equipment
Operational procedures
Particularly covering approach procedures, and using the actual aircraft or training device checklist/ops manual

PART 3: SIMULATOR OR FLIGHT TRAINING
The training syllabus we recommend is based on 2 "notional" lessons
1. Normal operations
2. Contingencies

The objective is for the pilot to demonstrate proficiency to the standards required of Instrument Rating holders and the specific requirements of GNSS. The minimum time this will require is probably 2-3hrs for a candidate who is current in IFR and RNAV operations.

Appendix 5: Flight Training
Lesson 1: Normal Operations

Element of Lesson	Content recommendations
1. Pre-flight preparation	• Briefing of route and procedure charts. Availability of non-RNAV procedures • RAIM check using AUGUR (requires internet access) and the GPS unit's built-in prediction tool, SBAS NOTAMs • Briefing on power, pitch and configuration for arrival • Other items in accordance with the checklist or ops manual
2. RNAV SID No.1 (manually flown)	• A normal IFR departure, flying the SID to its terminating point note the path-terminators at the start of the procedure which may not be supported by the receiver, and the transition to enroute guidance
3. Short cruise segment	• A cruise segment to the start of the arrival procedure, using an enroute flight plan a simulator should be slewed as required to reposition the aircraft, only 10mins in the cruise are needed to complete the pre-arrival checks
4. RNAV STAR No.1 (manually flown)	• A normal STAR, transitioning to a low approach and go-around practising the transition from the arrival to the approach should be included where practical
Repositioning as required	
5. RNAV SID No.2 (autopilot)	• A normal IFR departure, flown using the autopilot, to the SID airways terminating point note the point on the procedure at which autopilot may be engaged, and the use of available VNAV features
6. Short cruise segment	
7. RNAV STAR No.2 (autopilot) with continuous descent at required or maximum performance	• A RNAV STAR, transitioning to a low approach and go-around, flown using the autopilot in coupled modes • Subject to the type of aircraft flown/simulated, this procedure should be flown at highest arrival speed attainable up to the published chart maximum, and, if possible, at 160KIAS to 4 nm on the approach • The RNAV STAR should offer a continuous descent profile (most do, but some older procedures have a stepped arrival) A pilot's instrument training will have been conducted at the aircraft's normal arrival/approach speeds, and it useful for the RNAV 1 training to include faster arrivals that may be requested by ATC. The limiting speeds for gear and flap, good engine management and speed control in the transition to the glidepath should be briefed pre-flight.
Tactical changes	• The procedure training above should ideally include at least one each of an unplanned hold, a change of procedure, and a direct-to clearance to an intermediate waypoint

Appendix 5: Flight Training
Lesson 2: Contingencies

Element of Lesson	Content recommendations
1. Pre-flight preparation	• Briefing of route and procedure charts. • Review of RNAV and other contingency procedures in the check list or ops manual
2. Non-GNSS contingencies: RNAV SID (optional) Short cruise (optional)	• To include at least one RNAV STAR (flown manually or using the autopilot) in which GNSS performance is normal, but other simulated failures or contingencies are introduced which the pilot must manage whilst flying the full procedure • The failures may be specific to the aircraft type, but may include instrument, electrical, engine and fuel system problems; icing or storm avoidance; and, in a multiengine trainer or aircraft, an engine failure may be simulated during the arrival • The failures should permit the procedure to be flown in full, but the debriefing should emphasise circumstances in which an alternative course of action or declaring an emergency would be needed
RNAV STAR No.3	• This element of Lesson 2 should include at least one tactical change (unplanned hold, change of RNAV procedure, vectors)
Repositioning as required	
3. GNSS Contingencies: RNAV SID (optional) Short cruise (optional) **RNAV STAR No.4**	• This should include one RNAV terminal procedure in which a simulated loss of GNSS capability takes place (eg. a failure of the receiver or an SBAS/RAIM, Loss of Integrity) in which the pilot must follow the checklist contingency procedures and then fly a conventional or radar-vectored arrival • If a simulator is used which permits other GNSS failures, these may be included (eg. a discrepancy in a cross-check between GNSS position and radio aids)

RNAV 1 differences training or completion of training

If the aircraft or simulator used for Lessons 1 and 2 is not representative of the actual aircraft or specific model of receiver to be used for RNAV terminal operations, the course should be completed using an appropriate combination of representative PC RNAV simulator software, flight training device or aircraft

Element of Lesson	Content recommendations
1. Pre-flight preparation	• Briefing of route and procedure charts. Availability of non-RNAV procedures • RAIM check using the receiver unit's built-in prediction tool • Briefing on power, pitch and configuration for a high speed arrival • Review of RNAV normal and contingency procedures in the check list or ops manual
2. Normal RNAV Procedure	• To include at least one RNAV procedure (SID, STAR or RNP Approach) and at least one tactical change (unplanned hold, change of RNAV procedure, vectors)

Appendix 5: Flight Training

RNP Approach simulator and/or flight training

- The training and operating requirements for RNP Approaches are summarised in the table below. A training course could have the following three parts:

Theory Training objectives (key points)
General PBN theory
RNP Approach theory - PBN procedure designs and coding - RNP Approach procedure charts, limitations and minima - requirement for current database and database procedures - required navigation equipment for RNP 2D approaches
Charting, database and avionics topics - Waypoint naming concepts - the 'TF' and 'CF' path terminators - fly-by and fly-over waypoints
Simulator and/or Flight Training objectives
Operational procedures and practices - Normal procedures - Contingency procedures
Use of GNSS Equipment - retrieving a procedure from the database - briefing the procedure, comparing it with the charted procedure - action to be taken if discrepancies are noted - tactically modifying the flight plan
Flying PBN procedures - RNP Approaches with and without vertical guidance and associated control techniques - use of automatic pilot and flight director - missed approach and contingency procedures (eg. loss of RAIM/SBAS) - ATC procedures

PART 1: GROUND THEORY
Self-study method:
A pilot may use this manual to self-study PBN and GNSS theory. The Instructor could helpfully conduct an oral exam to ensure the pilot is fully proficient in the key knowledge items listed in the table on the left

or, **Classroom training method:**
The instructor or ATO may conduct classroom training to cover the key PBN material in this manual. This may require one or more 2-3hr classroom sessions, depending on how much preparation and reading the student has done

PART 2: PRE-FLIGHT BRIEFING
The pre-flight briefing sessions may require 1-2hrs, to include:
Use of GNSS Equipment
GNSS Operational procedures
Using the actual aircraft or training device checklist/ops manual

PART 3: SIMULATOR OR FLIGHT TRAINING
The training syllabus is based on 2 "notional" lessons
1. Normal GNSS operations
2. GNSS contingencies

The objective is for the pilot under training to demonstrate proficiency to the standards required of Instrument Rating holders and the specific requirements of RNP approaches. The minimum time this will require is probably 2hrs for a candidate who is current in IFR and RNAV operations.

Appendix 5: Flight Training
RNP Approaches Lesson 1: Normal Operations

Element of Lesson	Content recommendations
1. Pre-flight preparation	• Briefing of route and procedure charts. Availability of conventional approaches and alternates • If required, RAIM check using AUGUR (requires internet access) and the receiver's built-in prediction tool • Briefing of GNSS and 'normal' IFR checklist items • Entering a GNSS flight plan from departure to destination
2. IFR departure and short cruise segment (manually flown)	• A normal IFR departure and short cruise segment, using GNSS
3. RNP Non-Precision Approach (manually flown)	**Pre-Arrival** • Selecting and checking the Approach procedure • Determining the appropriate IAF • Activation of the procedure **Flying the PBN procedure** • Gross error check approaching the IAF, and check that the receiver is in TERM mode • GNSS and Navigation instrument mode selection • Check activation of APP/LNAV/LPV mode prior to the FAF • Flying CDFA, commencing MA to avoid flying below the MDA **Flying the Missed Approach** • Manually re-initiate waypoint sequencing and activation of the Missed Approach procedure • Mode selection and pilot actions in non-RNP missed approach segments
Repositioning as required	
4. LPV Approach (manually flown or using autopilot)	• As above, but flying the glidepath
5. RNP Approach with tactical changes (manually flown or using autopilot)	This procedure should include all of the "normal" items in Element 3 above, but it should be a scenario in which the instructor simulates a series of ATC tactical changes; for example: • An unplanned hold at the IAF • During the hold, a change of runway requiring a new procedure to be loaded • A direct-to clearance to the IAF • A missed approach, followed by Vectors to the FAF of the same procedure
SIDs and STARs	• Although not essential, the lesson may include, if possible, use of the GNSS with SID and STAR procedures prior to the approach.

Appendix 5: Flight Training

RNP Approaches Lesson 2: Contingencies

Element of Lesson	Content recommendations
1. Pre-flight preparation	• Briefing of route and procedure charts. • Review of GNSS and other contingency procedures in the checklist
2. Non-GNSS contingencies: **RNP Approach No.4**	• To include at least one RNP approach (flown manually or using the autopilot) in which GNSS performance is normal, but other simulated failures or contingencies are introduced which the pilot must manage whilst flying the approach • The failures may be specific to the aircraft type, but may include instrument, electrical, engine and fuel system problems • In a multiengine trainer or aircraft, an engine failure should be simulated during the arrival • The failures should permit the approach to be flown in full, but the debriefing should emphasise circumstances in which an alternative course of action is preferable • This element may also include tactical changes if appropriate (unplanned hold, change of PBN procedure, vectors)
Repositioning as required	
3. GNSS contingencies: **RNP Approach No.5**	• This could include at least one RNP APP in which a simulated loss of GNSS capability takes place (eg. failure of the receiver, SBAS/RAIM or LOI) during the procedure, such that the pilot must initiate the missed approach prior to the MAP. • The instructor should judge the training value of then flying to an alternate airport with a conventional procedure versus simulating a restoration of GNSS capability and completing the approach on a second attempt • If a simulator is used which permits other GNSS failures, these may be included (eg. a discrepancy in a cross-check between GNSS position and radio aids)

RNP Approaches differences training or completion of training

If the aircraft or simulator used for Lessons 1 and 2 is not representative of the actual aircraft or specific model of receiver to be used, the course should be completed using an appropriate combination of representative PC simulator software, flight training device or aircraft

Element of Lesson	Content recommendations
1. Pre-flight preparation	• Briefing of route and procedure charts. • RAIM check, if applicable, using the receiver's built-in prediction tool, as required • Review of GNSS normal and contingency checklist procedures
2. Normal PBN procedure	• To include at least one approach procedure (RNP, or conventional approach using the receiver for supplementary guidance) and including at least one tactical change (unplanned hold, change of procedure, vectors)

Glossary of Abbreviations

Below is a list of the abbreviations used in the book. Where an explanation is included in the text, a page number is given.

2D	Two Dimensional	102
3D	Three Dimensional	102
5LNC	Five-Letter Name-Codes	182
ADF	Automatic Direction Finder	
AF	Arc to a Fix	37
AFM	Aircraft Flight Manual	
AIM	Aeronautical Information Manual (FAA)	
AIRAC	Aeronautical Information Regulation And Control	72
AIS	Aeronautical Information Service	
AOPA	Aircraft Owners and Pilots Association	
APCH	Approach	24
APR	Approach	24
APV	Approach with Vertical Guidance	104
ARINC	Aeronautical Radio Inc	175
A-RNP	Advanced RNP	158
ATC	Air Traffic Control	
ATS	Air Traffic Services	
BIH	Bureau International de l'Heure	
BIPM	Bureau International des Poids et Mesures	
BPSK	Binary Phase Shift Keying	
C/A	Coarse/Acquisition	160
CA	Course to Altitude	37
CAA	Civil Aviation Authority	
CD	Course to DME Distance	37
CDA/CDFA	Constant Descent (Final) Approach	
CDI	Course Deviation Indicator	
CF	Course to Fix	36
CFR	Code of Federal Regulations (FAA)	
CI	Course to an Intercept	37
CNF	Computer Navigation Fix	77

CR	Course to Radial	37
CRC	Cyclic Redundancy Check	
CS	Control Segment	
CTP	Conventional Terrestrial Pole	
DA	Decision Altitude	
DF	Direct to Fix	36
DIS	Distance (to next waypoint)	
DME	Distance Measuring Equipment	
DP	Departure Procedure	
DTK	Desired Track	
EASA	European Aviation Safety Agency	
EGM96	Earth Geodetic Model 96	168
EGNOS	European Geostationary Navigation Overlay Service	58
EHSI	Electronic HSI (ie Glass)	
ENR	Enroute	
ETA	Estimated Time of Arrival	
ETSO	European Technical Standard Order	
EU	European Union	
FA	Fix to an Altitude	36
FAA	Federal Aviation Authority (USA)	
FAF	Final Approach Fix	
FAS	Final Approach Segment	
FC	Fix to a Distance	34
FD	Fix to a DME Distance	34
FD	Fault Detection	55
FDE	Fault Detection and Exclusion	55
FM	Fix to Manual termination	35
FMS	Flight Management System	
FRT	Fixed Radius Transition	154
G/S	Glideslope	
GA	General Aviation	
GA	Go-Around	
GAGAN	GPS Aided GEO Augmented Navigation	57

GBAS	Ground-based Augmentation System	57
GDOP	Geometric Dilution of Precision	51
GLONASS	Global Navigation Satellite System	57
GLS	GBAS Landing System	57
GNSS	Global Navigation Satellite System	47
GPS	Global Positioning System	47
GPSS	GPS Steering	
GS	Groundspeed	
HA	Racetrack to Altitude	38
HAL	Horizontal Alert Level	67
HDOP	Horizontal Dilution of Precision	51
HF	Racetrack to Fix	38
HM	Racetrack to Manual	38
HPL	Horizontal Protection Level	67
IAF	Initial Approach Fix	
ICAO	International Civil Aviation Organization	
IDF	Initial Departure Fix	145
IF	Initial Fix	36
IF	Intermediate Fix	88
IF	Intermediate Frequency	
IFR	Instrument Flight Rules	
ILS	Instrument Landing System	
IMC	Instrument Meteorological Conditions	
INS	Inertial Navigation System	
IRU	Inertial Reference Unit	
JAA	Joint Aviation Authorities	
KIAS	Indicated Air Speed in Knots	
L of A	Letter of Authorization	
LDA	Localiser type Directional Aid	
LNAV	Lateral Navigation	7
LNAV+V	Lateral Navigation + Advisory Glidepath	7
LOI	Loss of Integrity	52

Glossary of Abbreviations

Below is a list of the abbreviations used in the book. Where the definition is included in the text, a page number is given.

LPV	Localiser Performance with Vertical Guidance	118
MA	Missed Approach	
MAP or MAPt	Missed Approach Point	124
MCA	Minimum Crossing Altitude	151
MDA/H	Minimum Descent Altitude (Height)	104
MEA	Minimum Enroute Altitude	
MNPS	Minimum Navigation Performance Specification	13
MOC	Minimum Obstacle Clearance	43
MSA	Minimum Sector Altitude	80
MSAS	MTSAT Satellite Augmentation System	57
MSL	Mean Sea Level	
NOTAM	Notice to Airmen	
NPA	Non Precision Approach	100
NSE	Navigation System Error	33
PA	Precision Approach	104
PANS-OPS	Procedures for Air Navigation Services – Aircraft Operations	
PAR	Precision Approach Radar	104
PBN	Performance Based Navigation	14
PDE	Path Definition Error	33
PDOP	Position Dilution of Precision	51
PI	Procedure Turn	38
PinS	Point in Space	151
POH	Pilot Operating Handbook	
PRN	Pseudorandom Number	156
PSE	Path Steering Error	33
PSK	Phase Shift Keying	156
QNH	Atmospheric Pressure at MSL	
RAIM	Receiver Autonomous Integrity Monitoring	54
RF	Radius to Fix	36
RF	Radio Frequency	
RIMS	Ranging and Integrity Monitoring Station	58
RNAV	Area Navigation	12
RNP	Required Navigation Performance	20
RNP AR APCH	RNP Authorisation Required Approach	159
RWY	Runway	
SBAS	Satellite based Augmentation System	56
SID	Standard Instrument Departure	
SPS	Standard Positioning Service	160
SRA	Surveillance Radar Approach	108
SS	Space Segment	49
STAR	Standard Arrival	
STC	Supplemental Type Certificate	
SV	Satellite Vehicle	48
TC	Type Certificate	
TDOP	Time Dilution of Precision	51
TERM	Terminal	128
TERPS	Terminal Instrument Procedures	172
TF	Track to Fix	36
TAI	International Atomic Time	163
TMA	Terminal Manoeuvring Area	
TOA	Time of Arrival	
TOAC	Time Of Arrival Control	27
TSE	Total System Error	33
TSO	Technical Standard Orders	
US	User Segment	48
UT1	Earth Time	163
UTC	Universal Co-ordinated Time	
VA	Heading to Altitude	37
VAL	Vertical Alert Level	67
VD	Heading to DME termination	35
VDOP	Vertical Dilution of Precision	51
VFR	Visual Flight Rules	
VI	Heading to Intercept Leg	38
VLOC	VOR/Locator	
VM	Heading to Manual Termination	36
VMC	Visual Meteorological Conditions	
VNAV	Vertical Navigation	17
VOR	VHF Omnidirectional Range	
VPL	Vertical Protection Level	67
VR	Heading to Radial	38
WAAS	Wide Area Augmentation System	58
WGS84	World Geodetic System datum 1984	168
WIDN	What's it doing now?	21

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