PBN Manual

Including RNAV and GNSS

A complete reference to PBN and GNSS for General Aviation non-commercial fixed wing pilots using GNSS for IFR







PPL/IR Europe

PBN Manual

(including RNAV and GNSS)

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Introduction



- This manual covers the PBN theoretical knowledge and ground training for a Europe based Instrument Rated pilot operating single-pilot general aviation aircraft under IFR in Europe
- The manual also has a recommended syllabus to meet flight training requirements for RNAV enroute and approach procedures
- It is intended to be used in a classroom training seminar or for self-study
- Some of the detailed content and reference material is beyond the scope of what is required for pilot training, but may be of interest.
- The learning objectives to meet EASA PBN training requirements shown in Appendix 2 refer to the
 applicable text which meets those objectives. Some of these learning objectives are outside the scope
 of what a GA fixed wing pilot needs to know, but are included, as they could appear in an exam. In
 those cases we have kept detail to an absolute minimum.
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- PPL/IR Europe welcomes feedback and questions via its website forum (www.pplir.org). Any person interested in operating light aircraft under IFR in Europe is welcome to join.

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- Edition 1 was written by Vasa Babic. This edition has been heavily revised by John Shannon,
 Timothy Nathan, David Chambers and Ed Bellamy to take account of the many changes that have occurred since.
- We would like to thank Julian Scarfe, Vasa Babic and Damian Walker for reviewing this document in detail and for their very knowledgeable feedback. Errors and omissions are entirely the editors' 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 (<u>www.pplir.org</u>). 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 join and support 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

Course contents



- 1. PBN & RNP theory
 - a. Introduction to PBN
 - b. The Path-Terminator
 - c. PBN procedure design
- 2. GNSS
 - a. GNSS and the GPS system
 - b. RAIM
 - c. SBAS
 - d. Databases
 - e. Procedures
 - f. Error detection and warnings

- 3. RNP Approach Procedures
 - Classifications
 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
- Avionics training
- Simulator and/or Flight training

Appendices

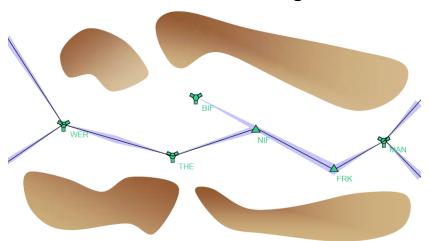
- 1. Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

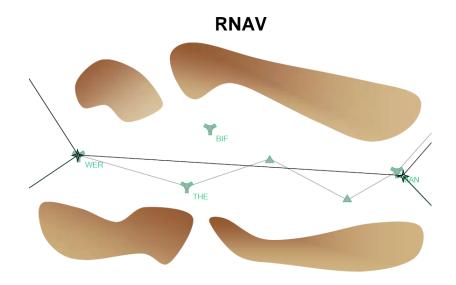
Glossary of Abbreviations

What is the basic concept of RNAV?









- "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
- 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
 - Initially, in the 1970s, based on VOR-DME "shifting" or systems like Loran C; limited by station range and coverage. Large jets also used Inertial Navigation Systems.
 - Modern RNAV in general aviation aircraft is based on panelmounted GPS. Transport aircraft also use Inertial Reference and DME-DME in multi-sensor Flight Management Systems (FMS)

How is RNAV implemented?



- Traditional IFR has 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. Non-standard applications are relatively rare and specialised (eg. CAT 2 ILS operations)
- 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 fuelefficient descent management
- However, until recently, no homogenous way of providing the standards and safeguards needed for accurate and consistent RNAV has emerged, and thus there are a variety of RNAV applications in different regional and national airspace and for different phases of flight (enroute, terminal, approach)
 - eg. RNAV 1 (formerly P-RNAV), RNAV 5 (formerly B-RNAV) in Europe; MNPS (RNP 4) in the North Atlantic.

Objectives of the PBN concept



Traditional procedure design

RNAV procedures pre-PBN



- Standard infrastructure of ground radio aids
- Aircraft carry a standardised suite of navigation receivers and instruments
- Procedure tolerances designed around these standards

- Proliferation of different RNAV navigations systems
- Even within one type of aircraft and one make of avionics, a variation in the FMS or GPS software release installed can make an important difference to the system's capabilities for executing a particular procedure
- Procedure design increasingly complex and restricted

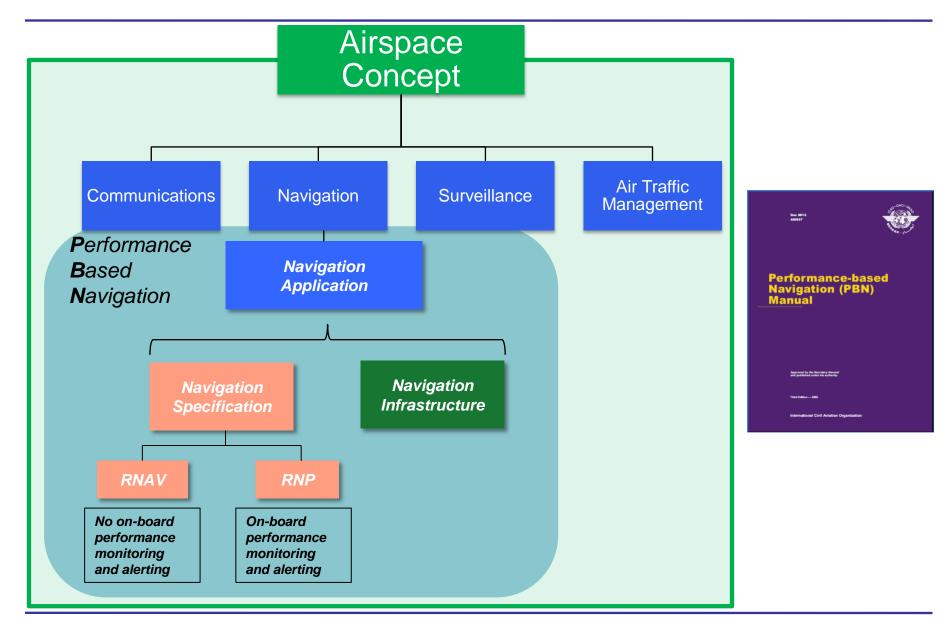
- Standard performance specifications established: "RNP X"
- Procedure tolerances designed around these RNP X standards
- Navigation and autopilot systems certified to RNP X criteria
- Crew & database PBN requirements



• PBN is a 'standard interface' between the complex worlds of IFR airspace and procedure design, avionics and autopilot design/certification and the development of flight training and operating procedures

How PBN fits into the overall ICAO Airspace Concept





What is PBN (Performance Based Navigation)?



- '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.
- 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.
- 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).

What is PBN (Performance Based Navigation)?



- 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.
- See page 20 for an example of the components of navaid infrastructure, navigation specification and navigation application.

What is PBN (Performance Based Navigation)?



- 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 1nm either side of the desired flight path.
 - 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.

Current PBN applications in Europe: an overview



Under the EASA Aircrew Regulation, from August 2018 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.

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 2D or 3D (ie without or with vertical guidance). Requirements for the IR(R) are yet to be formulated by the UK CAA.

Provided this is completed, there are no operational approval requirements for normal GA PBN operations. The three main PBN specifications likely to be encountered are:

Enroute/Terminal



Mandatory on almost all ATS routes.

Terminal



RNAV 1

- Most SIDs and STARs require RNAV 1
- Conventional SIDs and STARS are still in place, but are gradually being replaced.

Approach



RNP APCH

- RNP APCH is the standard PBN specification used for instrument approach procedures.
- RNP approaches may be 2D or 3D, but EASA and ICAO intends that all instrument runway ends have vertical guidance in place by 2024.

Navigation Capability (as 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	RNAV 5	RNAV 5	RNP APCH
B ased N avigation	RNAV 2	RNAV 1	
		RNP 1	

Navigation Capability – Complete list



- Below is a complete list of PBN navigation specifications, flight phases and RNP accuracy limits.
- The GA pilot will normally only encounter those on the previous slide, but they are all included below for completeness (see Learning Objectives in Appendix 2).

	Flight Phase							
Navigation Specification	Enroute	Enrollta		Approach				
Specification	Oceanic Remote	Continental	ARR	Initial	Intermediate	Final	Missed	DEP
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

Navigation Capability – Additional Functionalities



Navigation	Additional Functionalities (Required or Optional)					
Specification	RF	FRT	TOAC	Baro VNAV		
RNAV10 (RNP10)						
RNAV 5						
RNAV 2						
RNAV 1				0		
RNP 4		0				
RNP 2		0				
RNP1	0			0		
Advanced RNP	R	0	0	0		
RNP APCH	0			0		
RNP AR APCH	Specific Requirements for RF & VNAV					
RNP 0.3	0 0					

- 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 3)
- (RNP AR APCH See Appendix 3)

R Required
O Optional

Further notes on Navigation Specifications



- Note that RNAV specifications have no (or in some way limited) on-board monitoring and alerting.
- 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.

Oceanic and remote 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.

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 course 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 VOR/DME RNAV systems and INS are acceptable as long as they can achieve the required accuracy.

Enroute and Terminal navigation applications



• 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.
- The RNP 1 specification is based upon 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.

An example of the components of a PBN Specification in terms of a navaid infrastructure, navigation specification and a navigation application:-

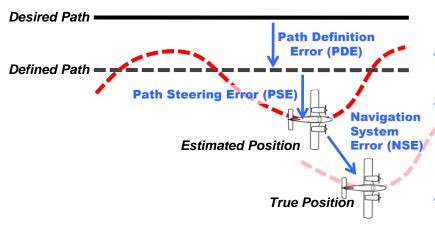
RNAV 1 and 2

- 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, 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.

Definition of RNP accuracy requirement



- There are four main navigation performance criteria:
 - 1. **Accuracy** is the as 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.
 - 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 vector sum of

- Path Definition Error (PDE)
- Path Steering Error (PSE)
- Navigation System Error (NSE)
- Path Definition Error is 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 is 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 <u>not</u> include human "conceptual" errors eg.
 selecting the wrong procedure, waypoint or autopilot mode, or simply turning in
 the wrong direction
- Navigation System Error is 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 ANP (EPE) with the 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

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 - b. Approach types
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Appendices

- 1. Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

What is a Path-Terminator?



- IFR routes and procedures are designed using standardised specifications and criteria
 - ICAO PANS-OPS Doc 8168 in Europe
 - TERPS (United States Standard Terminal Instrument Procedures) in the USA
- 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
- 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
- Note: 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. When a Departure, Arrival or Approach procedure is loaded, the flight plan will include each of the pathterminators that make up the procedure. Some receivers do not support all the leg types used at the start and end of RNAV procedures, or in an unpublished GNSS "overlay"

ARINC 424 Path-Terminator leg types (1 of 3)



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

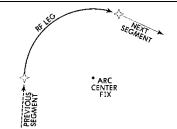
- Track to a Fix defines a great circle track over ground between two known databases fixes
- Preferred type for straight legs

TF LEG



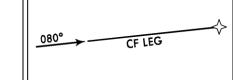
RF leg type

- 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



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



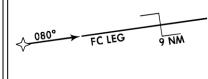
FA leg type

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



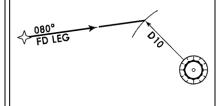
FC leg type

 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



ARINC 424 Path-Terminator leg types (2 of 3)



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

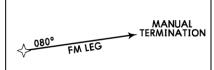
 Course to an Altitude Leg defines a specified course to a specific altitude at an unspecified position

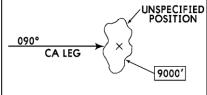
CD leg type

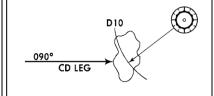
 Course to a DME Distance Leg defines a specified course to a specific DME Distance which is from a specific database DME Navaid

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

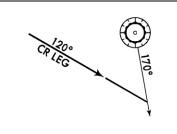
AF leg type

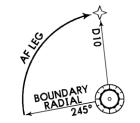
 Arc to a Fix or defines a track over ground at specified constant distance from a database DME Navaid

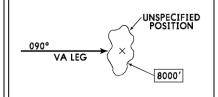
VA leg type

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

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







ARINC 424 Path-Terminator leg types (3 of 3)



VI leg type

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

VM leg type

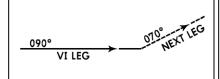
 Heading to a Manual termination Leg defines a specified heading until a Manual termination

VR leg type

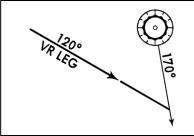
 Heading to a Radial termination Leg defines a specified heading to a specified radial from a specific database VOR Navaid

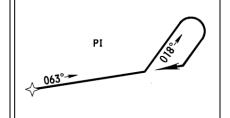
PI leg type

 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

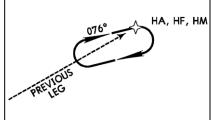
 HA leg defines racetrack pattern or course reversals at a specified database fix terminating at an altitude

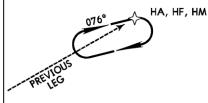
HF leg type

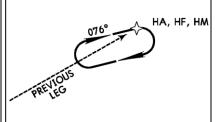
 HF leg defines racetrack pattern or course reversals at a specified database fix terminating at the fix after a single pattern

HM leg type

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









Terminators

Paths

	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		НМ		
Distance		FC						
DME Distance		FD	CD	VD .		leg type has a t		
Intercept			CI	VI		based on the p minator combin		
Radial			CR	VR				
Procedure Turn	PI							

Fly-By and Fly-Over RNAV waypoints



- 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

Jeppesen symbol Note: Jeppesen sometimes depict the curved fly-by track, sometimes the two straight tracks are joined under the fly-by symbol Fly-Over waypoint Jeppesen symbol Jeppesen symbol Jeppesen symbol Note: radio aid or other symbols may be overlaid on waypoint symbol

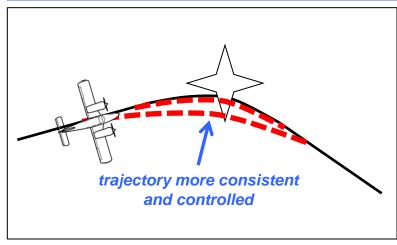
- A waypoint which requires turn anticipation (start of turn before the waypoint) to allow tangential interception of the next segment of a route or procedure
- The aircraft navigation system calculates the start of the turn onto the next route leg before the waypoint
- This is the preferred type of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

- 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

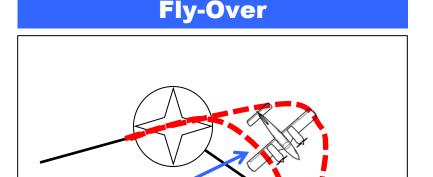
Aircraft trajectory in Fly-By and Fly-Over waypoints







 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

trajectory less consistent

and controlled

- 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

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 - a. GNSS and the GPS system
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 - c. SBAS
 - d. Databases
 - e. Procedures
 - f. Error detection and warnings

- 3. RNP Approach Procedures
 - Classifications
 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
- Avionics training
- Simulator and/or Flight training

Appendices

- 1. Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

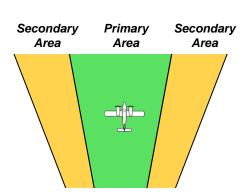
Glossary of Abbreviations

Principles of 'traditional' Instrument Procedure design 1. The Protected Area



 Instrument procedures in Europe are designed using the specifications and criteria in ICAO PANS-OPS Doc 8168. The US equivalent standard is "TERPS" (United States Standard Terminal Instrument Procedures)

Full width of Protected Area Full width of Protected Area // width // wid



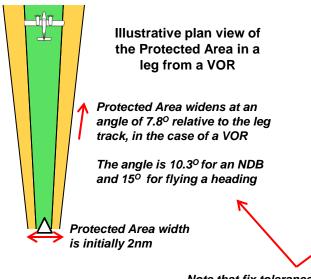
Plan View of Protected Area

- 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)

Principles of 'traditional' Instrument Procedure design 2. Track and Fix tolerances, and MOC



- The horizontal width of the Protected Area is determined by various tolerances relating to where an aircraft could be located whilst flying the procedure
- The key tolerance is based on the type of radio aid being tracked and distance from it. An angular splay is used that widens the protected area as the aircraft travels further from the fix



 Protection in a descent or a turn initiated at a fix is also provided by including a Fix Tolerance

Examples	VOR	NDB	DME	LOC
System Tolerance	4.5 [°]	6.2 ^o	0.25nm	1.4 ^O
Flight Technical Tolerance	0.70	0.70	plus 1.25% of the DME	1.0 ^o
Total Fix Tolerance	5.2 ^o	6.9 ^O	distance	2.40

Note that fix tolerances are different from path tracking tolerances

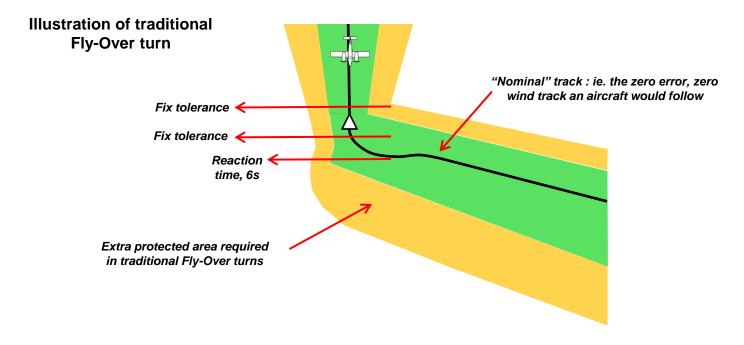
Note: FTT excluded when fix is based on an intersect. These are illustrative examples, the full definition of fix tolerances (eg. overhead a beacon, radar fixes) is beyond the scope of this course

• The Minimum Obstacle Clearance (MOC) is 984' or 300m up to the Initial Approach Fix, and declines during the Approach and Missed Approach (down to a minimum of 98' or 30m on the missed)

Principles of 'traditional' Instrument Procedure design 3. Fly-Over Turns



- The protected area around a turn is necessarily greater than the "sum" of the track protection required to and from a fix: it must take into account
 - the fix tolerance
 - the time it takes a pilot to react to crossing the fix and establish the turn
 - the effect of worst-case wind pushing the aircraft to the outside of the turn
 - the turning radius of different aircraft types



Source: Jens Gerlev, "Instrument Flight Procedures"

Principles of 'traditional' Instrument Procedure design 4. 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
В	91-120	120-180	85-130	135
С	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 Vat is as
 certified but the approach speeds are as flown.
 - Note that databases sometimes <u>only</u> include the Category C&D procedures
 - 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)

How are PBN procedures different?



1. Definition of Protected Area based on RNAV system performance or RNP

Based on RNAV system type

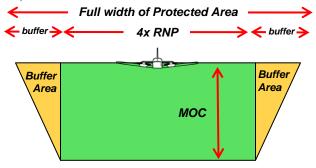
- PBN procedures designated for specific navigation systems, eg
 - RNAV_(GNSS)

 ie. FMS GNSS only, not panel mount GNSS

 RNAV_(EXCEPT CLASS A GNSS)
- Each procedure type has a systemspecific "semi area width", which is the lateral protection either side of the nominal track, eg. 3nm for GNSS STARs
- Modern approach is to define procedures based on PBN, not on specific navigation systems
- Fix Tolerance is based on systemspecific linear Along Track (ATT) and Cross-Track (XTT) tolerances, rather than angular splays

Based on PBN

- PANS OPS protected area width on either side is 2x RNP + a buffer
- The buffer is 2nm for arrival, 1nm for initial and intermediate approach and 0.5nm for final, missed approach and departure



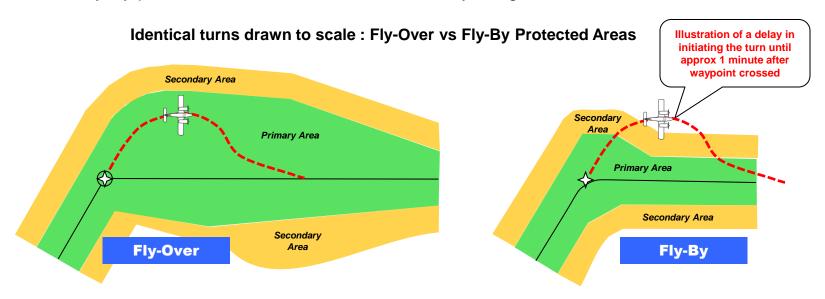
 Fix Tolerance is simply a 1x RNP radius around the waypoint

How are PBN procedures different?



2. Fly-By turn Protected Area is smaller than that of conventional turns

- 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

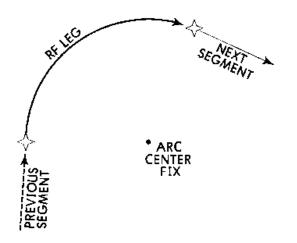




3. A Radius to Fix ensures that aircraft speed does not affect turn radius

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
- At present RF legs require either approved roll steering autopilots or flight director, but the requirements are likely to be reduced in the future.
- RF legs can only be flown by more recent GNSS receivers and their use has not yet been approved by EASA. However EASA approval is pending.
- RF legs are used in circumstances where navigational precision is vital (eg due to terrain) so it is important to follow flight director guidance and the speed constraints associated with the procedure.



3. Procedures use only a few of the most "predictable" Path-Terminators

Paths

	Fix to	Track from fix to	Course to	Heading to	Direct to	Racetrack	DME Arc to	Radius from fix
Fix	IF Initial Fix	TF Track to Fix	CF Course to Fix		DF Direct to Fix	HF Racetrack to Fix	AF	RF Radius to Fix
Altitude		FA Fix to Altitude	CA Course to Altitude	VA Heading to Altitude		HA Racetrack to Altitude	Red: '	'best practi
Manual Termination		FM Fix to man. term.		VM Heading to man. term.		HM Racetrack to man. term.	RNAV	leg types
Distance		FC						
DME Distance		FD	CD	VD	Orange: RNAV leg types used			
Intercept			CI	VI Course to Intercept	mainly at the start and end of procedures when required (eg. VA as the first leg of a SID)			
Radial			CR	VR -	Blue:	non-RNAV	leg types	
Procedure Turn	PI							

Terminators

4. There is a distinct PBN procedure "style"



"Style" features typical of PBN procedures:

"traditional"
Entry Fix

- RNAV STARs start with a conventional Fix, which the pilot should use to cross-check with radio aid raw data to avoid gross errors
- RNAV SIDs require a nav accuracy check on the runway
- RNAV(GNSS) approaches may require a user-defined check for gross error, since they often start with a 'pure' RNAV waypoint

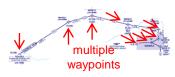
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Conventional initial fix

Use of many Waypoints

- After the initial Fix, all subsequent leg terminators are RNAV waypoints, rather than radio-referenced fixes
- 6-10 waypoints are common in an RNAV arrival procedure, compared to 3-6 fixes in a traditional one



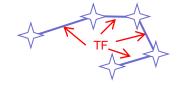
Turns are Fly-by

- · Generally, all turns will be Fly-By, with Fly-Over waypoints avoided
- Turns may also use the "Fix to Fix via a Constant Radius" (RF) leg
- Waypoints are spaced far enough apart to allow stable track capture between turns

Fly-By

Legs are TF, except at the start/end of procedures

- TF (and, in the future, RF) legs are used to provide the most predictable flight paths and the most FMS/GNSS-"friendly" coding, sequencing and guidance
- By necessity, procedures may start or end with non-TF legs, eg. a SID may begin with VA (Heading to Altitude) then CF (Course to Fix), followed by a TF sequence



Many altitude and speed constraints

 RNAV arrivals, in particular, include more specific altitude and speed constraints than a typical conventional procedure. This is designed to allow efficient traffic flows and descent profiles and reduced radio communications Examples:

3000 "or above"

4000 2000 "between"

3000 "at"

Max IAS **220KT**

000 ^{"ol} belo

IAS I **80KT**

speed target

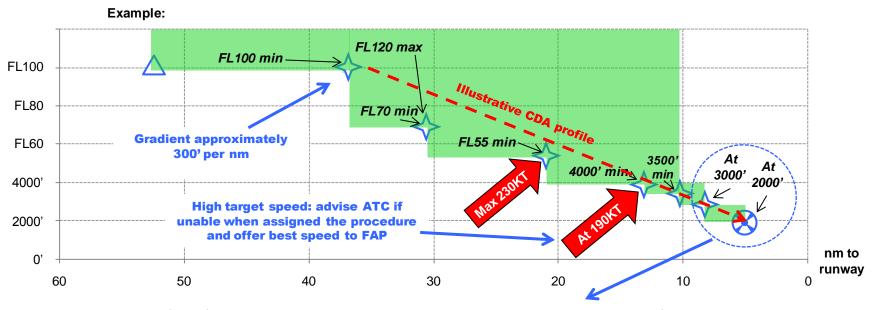
speed

limit



5. Arrival vertical profile often optimised for jet aircraft "continuous descent"

- Unlike most conventional procedures, RNAV STARs are often "closed", terminating at the final approach point, rather than an initial or intermediate one ("open")
- The vertical profile is usually designed to allow jet aircraft to commence descent late and then descend
 continuously, at 220KIAS and flight idle power, from the start of the procedure until the final approach
 waypoint and speed. This corresponds to a gradient of approximately 300' per nm.
 - -this is the most efficient and environmentally friendly method, known as CDA (Continuous Descent Approach). Otherwise, for jet aircraft, the earlier descent and power/configuration changes in a "step-down" arrival involve unnecessary fuel burn and a greater noise footprint



- Note the aircraft performance and pilot workload required during the transition to the final approach
 - descending at ~300' per nm whilst decelerating from 190KIAS (or speed attainable) to approach speed
 - no distinct level-off available for slowing down
 - cockpit transition of CDI, GNSS course guidance and autopilot mode from RNAV to ILS/DME

How are PBN procedures different? Summary



Traditional Procedures

- <u>Execution</u> 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

- <u>Execution</u> 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 the following sections of this course is on the proficient and safe management of RNAV flight

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Glossary of Abbreviations

The Global Satellite Navigation System (GNSS)



The general term for the global navigation satellite and ground station infrastructure



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



GPS

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

GLONASS

- Russian "<u>Glo</u>bal <u>Na</u>vigation <u>Satellite</u> 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
- Certified for Maritime but not Aviation use as yet, but expected shortly.



ialileo

- The European Union's GNSS project
- After some controversy, formally approved in Nov 2007
- Should be fully operational by 2020
- USA/EU agreement that Galileo and GPS will be "interoperable"
- Will use 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 US GPS system and GNSS includes all the above systems.

1. Overview of the system's three "segments"





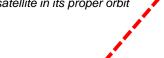
Space Segment (SS)

- 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

- Each satellite broadcasts a "ranging code", used to establish distance from the GPS 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)



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



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



2. 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 <u>ranging</u> 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.

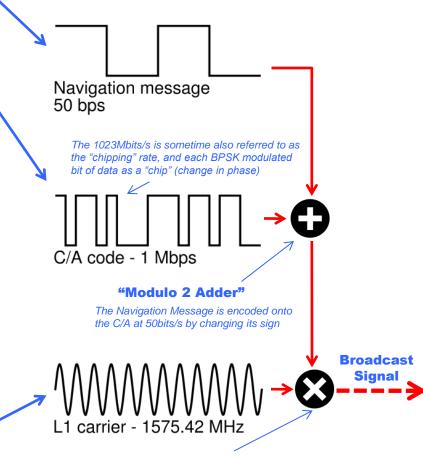
The PRN is unique to each satellite, and all the PRNs are stored in GPS Receiver memory. Because they are long pseudorandom numbers designed to be "orthogonal", any two different PRNs will "correlate" poorly (ie. when multiplied together, give a value near zero).

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. $L1 = Fo \times 154$. All radio frequencies and codes generated in the satellite are from the same 10.23MHz crystal, controlled by an atomic clock



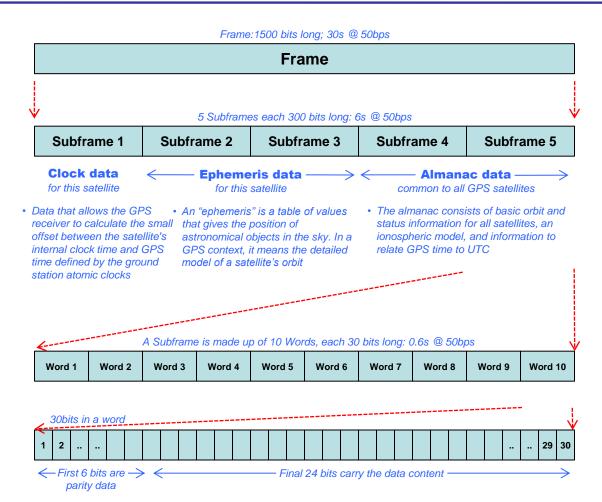
"BPSK" Modulation

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° out of phase

3. 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



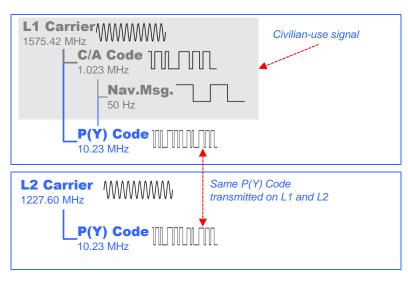


 The Navigation Message is the 'real-time reference manual' for the GPS receiver, which helps it calculate an accurate position based on the C/A Code ranging signals

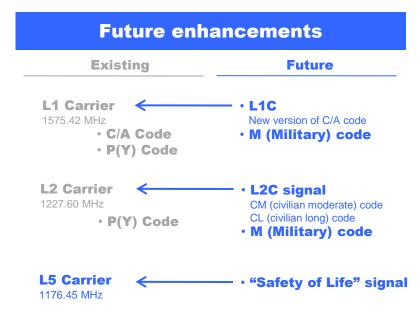


4. Other (non-civilian) signals and future enhancements to the system

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.



- 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

5. International time and the GPS time system



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



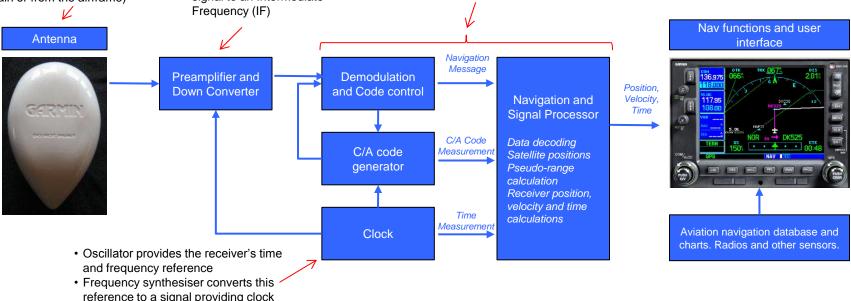
• Time measurement is the basis for GPS navigation, because the range from a satellite to a receiver can be determined by the time delay in receiving a signal, and with multiple range fixes, a position can be calculated

6. 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 degrees 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)





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.

7. The GPS Receiver: Calculation of time and position



Stage 1: The "pseudorange"



Stage 2: The accurate fix

- 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

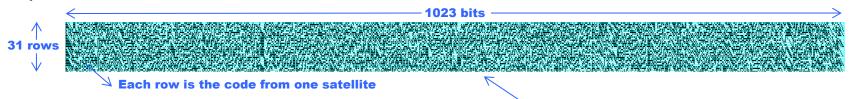
- The Receiver then uses the ephemeris (orbital) data in each satellite's Navigation Message to establish the satellite's position in space at the time of the Pseudorange calculation
- It requires a minimum of 4 satellite pseudoranges to determine a 3D navigational fix for the Receiver.
- The GPS system specification is that 5 satellites should always be available above a mask (elevation) angle of 7.5 degrees (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 later pages 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



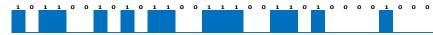
Stage 1: The "pseudorange"



Sample of the C/A PRN codes

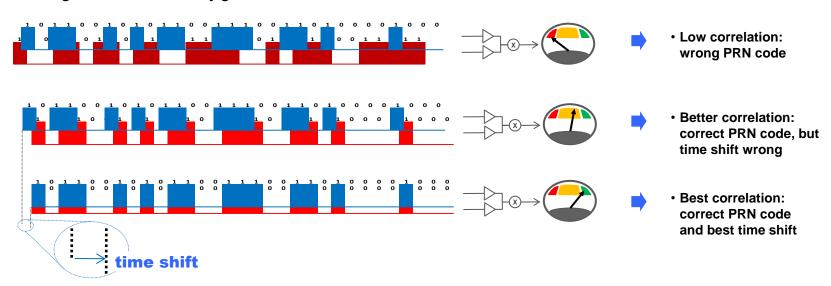


The Receiver generates the C/A PRN code for the satellite it is trying to lock on to....



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

- 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





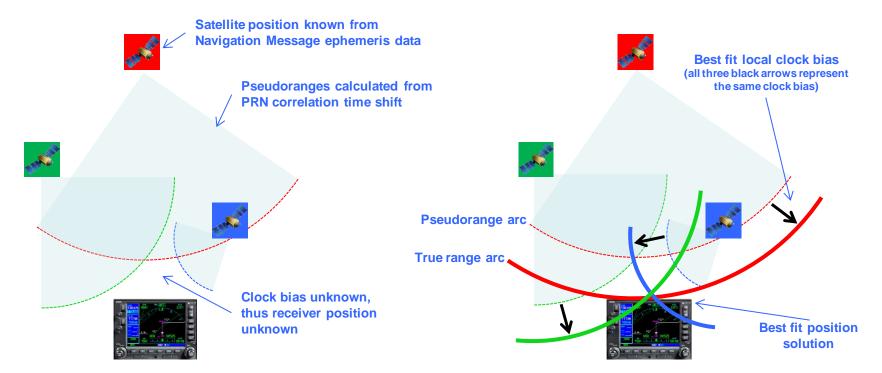
9. Illustration of the GPS navigation calculation

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

10. The WGS84 map datum



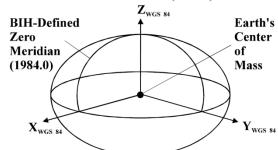
What is WGS84?

- 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 ellispoid ("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 US 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.

BIH-Defined CTP (1984.0)



11. Aviation charts and WGS84



Aviation charting datums

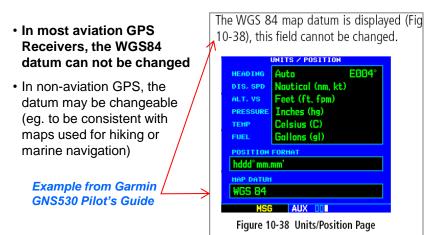
- Aviation charts use 3 types of position data
 - Surveyed positions for topographic and terrain features, navaid positions and physical references, like runway thresholds
 - Declared positions, defined by latitude and longitude (rather than any surveyed point) for airspace boundaries and oceanic entry/exit 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 county'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

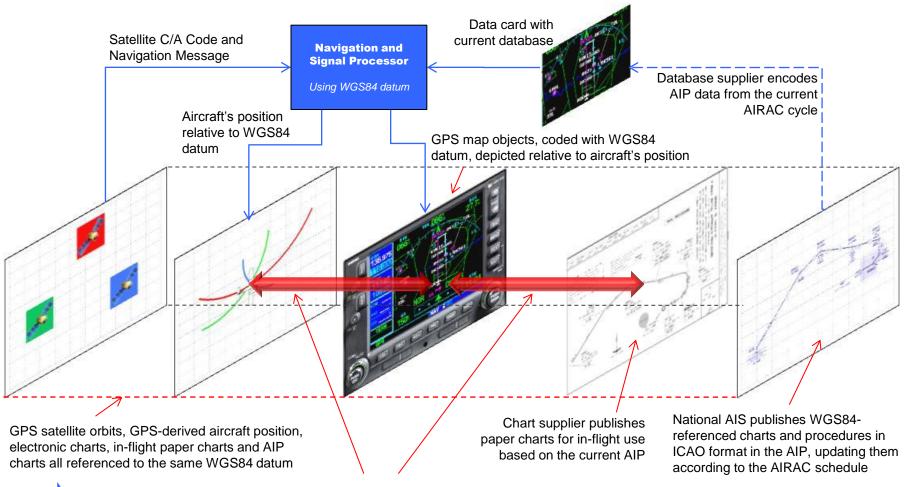
GPS Navigators and WGS84

- 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 relative 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 coordinates of the aircraft and the waypoint or flight plan track.



12. 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

GPS and Vertical Navigation



Definition of the "geoid" and Mean Sea Level

- The reference ellipsoid (global or local) for mapping datums is necessarily a <u>geometric</u> 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
- Climactic, 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, <u>measured</u> mean sea levels do not fit well with any ellipsoid model of the earth - because of the <u>gravitational</u> 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 <u>no</u> corresponding standard datum for Mean Sea Level in vertical navigation. Aviation charts and procedure designs tend to be based on a <u>local</u> 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



GPS System Performance1. A model of GPS performance measures and factors affecting them

	Accuracy	Integrity	Continuity	Vulnerability	
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	susceptibility to unintentional or deliberate interference	
GPS 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	Satellite coverage Satellite reliability Terrain masking (situation where terrain creates a mask angle greater than the 7.5 degrees the GPS constellation model is designed to provide coverage for) System is unaffected by number of users	Spoofing potential Civilian GPS is vulnerable to fake' transmissions from 'spoofing' equipment	
GPS Receiver	Receiver noise Receiver processing error Receiver display error	 Receiver RAIM prediction and monitoring (see Section 2b on RAIM and FDE) Other receiver alarms and alerts 	 Reliability of receiver hardware, software and antenna Quality of installation and power supply Receiver FDE Reliability of receiver hardware, software and antenna Quality of installation and power supply Dynamic masking 	Installation vulnerability to RF interference	
GPS Database	Coding error	Quality assurance by database supplier	Completeness of database Delivery method for updates	Masking or attenuation of a satellite signal through aircraft motion (eg. wing blocks the signal path in a bank)	
Pilot input and interpretation	Flight Technical Error User "conceptual" error	Use of RAIM tools	Database updatingInadvertent mis-operation		

GPS System Performance

PPL/IR EUROPE

2. Sources of accuracy error in GPS

	Accuracy	Nature of error	Size of error
	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
CDS	lonospheric error	 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 GPS 	5m
GPS System and Satellite Signal	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, GPS 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
	Receiver noise	The result of noise in the receiver further compromising the accuracy of the decoded PRN	1m
GPS Receiver	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, GPS is continuously updated and does not suffer from systematic "map shift" error 	-



• The "User Equivalent Range Error" (UERE) in civilian GPS is better than 35m horizontally and 75m vertically 95% of the time. In practice, the accuracy is significantly better almost all of the time.

GPS System Performance



3. GPS performance model: a practical risk assessment from a pilot's perspective

(applies only to IFR-approved aircraft installations)

	Accuracy	Integrity	Availability	Continuity	Vulnerability	
GPS System and Satellite Signal	Very low risk of system that are not identified or Loss of Ir	by a Receiver RAIM	predicted by RAII time (annually) du At the <u>local</u> level, part of the PBN p	At the <u>system</u> level, very low risk of a loss of service not predicted by RAIM tools. <u>Availability</u> is the percentage of me (annually) during which the system is available for use. At the <u>local</u> 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		
GPS Receiver	Very low risk of des TSO/ETSO certified ha	•	Approved installations have proven highly reliable in millions of hours of service. Of course, like all radio aids, they depend on aircraft power			
GPS Database	Generally highly reliable. However, in the current phase of rapid deployment of RNAV (both new procedures and approaches and new designs of procedure and approach) some extra caution is warranted in checking GPS nav data against paper charts. Use of unapproved or expired databases presents a distinct risk				Note: these "green" risks a not zero, and regulations thus require alternative procedures and facilities be available for many GP applications	
Pilot input and interpretation	▶ The major risk is pilot error in operating and interpreting GPS navigation equipment					



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

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- 1. PBN & RNP theory
 - Introduction to PBN
 - b. The Path-Terminator
 - c. PBN procedure design
- 2. GNSS
 - a. GNSS and the GPS system
 - b. RAIM
 - c. SBAS
 - d. Databases
 - e. Procedures
 - f. Error detection and warnings

- 3. RNP Approach Procedures
 - a. Classifications
 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
- Avionics training
- Simulator and/or Flight training

Appendices

- 1. Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

Principles of RAIM (Receiver Autonomous Integrity Monitoring)

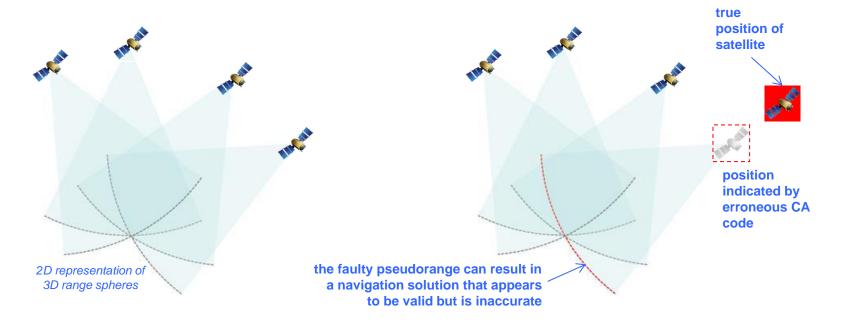


1. The requirement for integrity monitoring

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



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





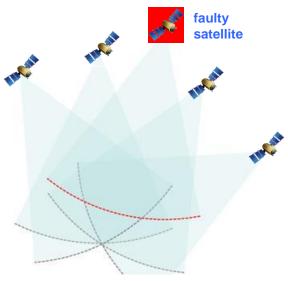
- The GPS Control Segment ground stations monitor satellites and detect faults
- However, the system may take <u>up to 2hrs</u> to detect a fault and then update the Navigation Message to declare that a particular satellite signal is erroneous
- This potential delay means that IFR GNSS receivers need an "autonomous" way of assuring the integrity of the navigation solution

Principles of RAIM

2. Fault detection and fault exclusion



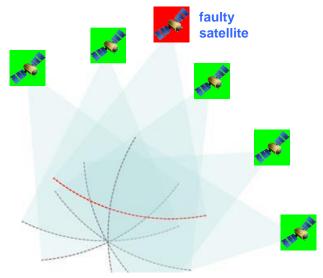
A 5th satellite provides a GNSS receiver with the capability for <u>Fault Detection</u> (FD)



- The receiver can recognise that a satellite is faulty, because the 5 range spheres don't <u>all</u> intersect at a consistent point; but, because any combination of 4 satellites might provide a valid solution, it can not always identify <u>which</u> 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 selfconsistent and valid navigation solution, and excluding the 6th
- Many TSO C129 receivers (eg. Garmin 430/530 with software version 3.0 or higher) and all TSO C146 receivers (eg. Garmin 430W/530W and 480) also feature RAIM with Fault Detection and Exclusion (FDE), which requires 6 visible satellites



•If RAIM is available, the GNSS receiver can assure the integrity of its calculated position within a specified protection limit: 4 nm for oceanic, 2 nm for enroute, 1 nm for terminal and 0.3 nm for RNP approaches.

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Glossary of Abbreviations

Systems used to improve upon GPS accuracy and integrity



Ground-based Augmentation Systems (GBAS)

- The principle of GBAS is also called "Differential" GPS
- Many of the most significant errors in basic civilian GPS are common to 2 receivers in the same geographical area (eg. Ephemeris, SV clock & Atmospheric errors, Signal noise and GDOP)
- A reference GBAS ground station, whose position is very accurately surveyed, can calculate a correction for such errors which can be broadcast to nearby stand-alone GPS receivers.
- 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
- Rarely used directly by GA aircraft

Satellite-based Augmentation Systems (SBAS)

- SBAS uses the same principle as GBAS (differential corrections derived from ground-based stations) to achieve ~2m accuracy
- 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
- 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 and India.



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



Not yet available

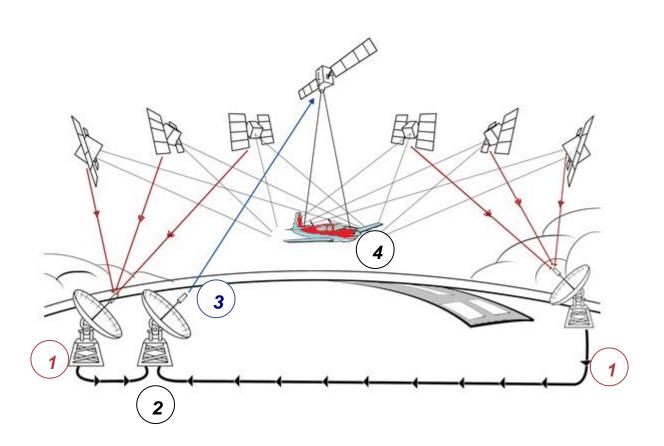


GAGAN (India)

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

SBAS Architecture (EGNOS)





How SBAS works (EGNOS)

- GNSS signals are received at 34 RIMS (Ranging and Integrity Monitoring Stations)
- 2. Differential correction signals are calculated centrally, to cater for the entire region
- Correction signals are sent via three geostationary satellites which broadcast using GPS L1 frequency but different PRN channels
- Onboard SBAS receiver combines the corrections to achieve very high accuracy of typically 1m horizontally and 2m vertically

GNSS errors and SBAS



- 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

Panel-mount GNSS units are either non-SBAS or SBAS capable



TSO-C129A (Non-SBAS)	TSO-C146A (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, 530, G1000 •Bendix/King KLN89, 94, 90 and all other Bendix/King IFR panel mounts • All older GPS units from other makes (eg. Trimble, Northstar)	Examples: • Garmin GNS430W, 530W, G1000W, GTN650, 750, GNS480 • Avidyne FMS900W and other WAAS



Typical features



- · Suitable for enroute IFR, but not as primary nav source
- · Most units also support overlay and non-precision RNAV IAPs
- Typically a slow moving map refresh rate (1/sec)
- · Require RAIM prediction
- Do not support RNAV SIDs and STARs (except Garmin units)
- Do not provide guidance or roll-steer commands for holds, procedure turns etc

- · Suitable for enroute IFR as primary nav source
- · Support overlay, non-precision RNAV and LPV approaches
- Fast moving map refresh rate (5/sec)
- RAIM not required in SBAS coverage area
- Support RNAV SIDs and STARs, and RNP 1 capable
- Provide guidance or roll-steer commands for holds, procedure turns etc
- The basic functional requirements of PBN, most 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.



• The ETSO (EASA) or TSO (FAA) certification of a GPS unit may be found in the approved flight manual or flight manual supplement for a particular installation

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- 3. RNP Approach Procedures
 - a. Classifications
 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
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- Simulator and/or Flight training

Appendices

- 1. Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

What is the AIRAC cycle?



Introduction to AIRAC

 From the Aeronautical Information Management section of the Eurocontrol website: http://www.eurocontrol.int/aim

Aviation data is constantly changing; airspace structures and routes are revised, navigation aids change, SIDs and STARs are amended, runway and taxiway information changes. It is essential, for both efficiency and safety, that Pilots, Air Traffic Controllers, Air Traffic Flow Managers, Flight Management Systems and Aviation Charts all have the same data set. How can this be achieved? The answer is AIRAC

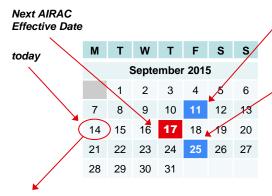
AIRAC stands for Aeronautical Information Regulation And Control and stems from the ICAO Annex 15 - Aeronautical Information Services (AIS) document. AIRAC defines a series of common dates and an associated standard aeronautical information publication procedure for States

All information provided under the AIRAC system is published in paper form and distributed by national AIS units at least 42 days in advance of the effective date, with the objective of reaching recipients at least 28 days in advance of the effective date

- A commercial supplier like Jeppesen thus receives AIS updates at least 28 days before the Effective Date of a new cycle and uses that time to code the changes into its electronic and paper products, and to distribute updates to customers
- AIRAC thus 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 break down the distribution of paper and electronic charts into 2 batches per AIRAC cycle, delivered at 14 day intervals. GPS 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: Jeppesen example

- AIRAC cycle Effective Dates are available from AIPs or the Eurocontrol website, for several years in advance, and from the preface of the Jeppesen Airway Manual
- Example: imagine today is 14 September 2015, the next AIRAC Effective Date is 17 September 2015:



Jeppesen "Issue Date" for their "01-2008" cycle for Airway Manuals and JeppView – changes become Effective on 25 Jan

Jeppesen "Issue Date" for the "02-2008" cycle; changes Effective on 14 Feb

Note: these Jeppesen products have 26 Issue cycles per year but they become effective only on the 13 AIRAC effective dates

- The customer should have received paper chart and JeppView disc updates by today
- NavData GPS updates should be available online from "JSUM", the update management software, about 1 week prior to the 17 Jan Effective Date
- If the prior database was loaded in December, and the new database has now been loaded, the illustration below is an example of how a GPS Database Validity page should read:

Database now "loaded" for use in navigation is current and will expire on 16 January 2008

Next cycle database has been stored, and will become current on 17 January 2008, when the GPS unit will automatically load it DB Effective Dates

*Database A:
Starts: 12/20/2007
Ends: 1/16/2008

Database B:
Starts: 1/17/2008
Ends: 2/13/2008

*- Database Loaded

Summary: three tasks a GA pilot must perform before using an approved RNAV database





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
- Note: GNSS databases usually do not include Category A and B approaches



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 at present, because of the rate at which new procedures are being introduced as many European countries begin to implement RNAV-1 and RNP approaches
- It is not legal or practical to try and enter these as user waypoints. An approved, current database is essential
- 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 arise quite regularly between AIP charts, commercial service provider charts and GNSS databases
- In addition, <u>RNAV databases are an inherently different format from published charts</u> and some waypoints will not be identical in both (see ARINC 424 pages later in this section)
- Flying an PBN procedure is <u>not</u> 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 legal, necessity for RNAV operations

If my GNSS database is approved and current, do I really need to cross-check it 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)
- Databases do not show minima
- Terminal Arrival Altitudes are not shown
- etc



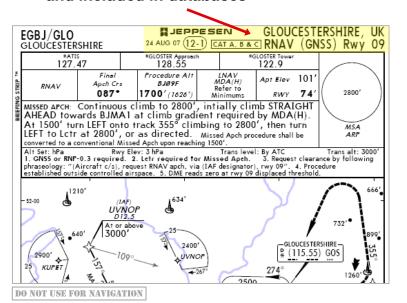
If my GNSS database is approved and current, do I really need to check NOTAMs for navigation facilities and procedures?



Example: EGBJ Gloucestershire

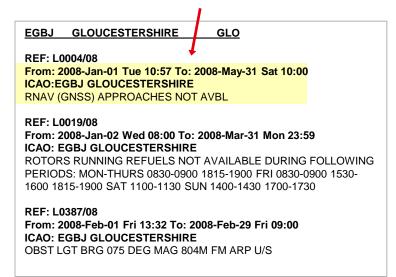
EGBJ: RNAV (GNSS) approach plate current in AIRAC cycle to 14 Feb 08

GNSS Approach published, current and included in databases



EGBJ: Airfield NOTAMs 3 Feb 08

...but RNAV Approaches NOTAMed not available





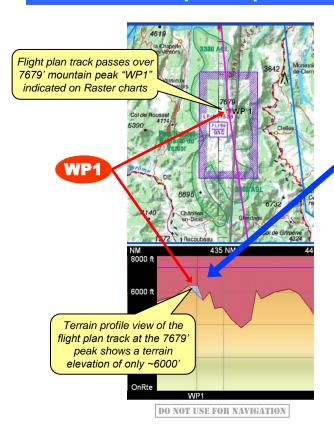
If am using reputable aviation products, does it matter if the data is not approved for IFR navigation?



Example: non-approved terrain data in popular IFR flight planning software

Comparison of Raster Chart with vertical profile depiction

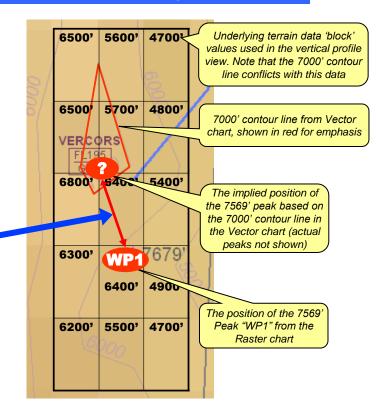
Comparison of Vector chart with Raster chart position data and vertical profile data



At this sample point, in the French Alps:

Terrain profile view understates actual terrain by ~1500'

Map shift between Vector and Raster chart of ~1nm





Computer Navigation Fix (CNF)



- 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 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
- 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.
- CNFs are random five letter identifiers, not pronounceable like waypoints, 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.

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Glossary of Abbreviations

Important note



- This section of the manual is intended as a guide, not a complete rule book
- 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.
- Databases that have expired by no more than 28 days may be used, but only if the relevant waypoints and procedures to be used are checked and found to conform with current published charts.
- In the event of any discrepancy between this document'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
- Also, self-evidently, none of the Jeppesen charts or Garmin screen shots in this manual may be used for navigation purposes
- The manual entry, or creation of new waypoints by manual entry, of latitude and longitude or place/bearing/distance values is not permitted 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.





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	Departures	Arrivals	Approaches
procedure 7	collectively known a		
Paper chart procedure "titles"	 "SID" "Departure", FAA charts also use "Departure Procedure" and "DP"	 "STAR" "Arrival" "Transition" "Initial Approach" Continuation charts between a STAR and an approach 	 Many types of approach: ILS, VOR, SRA, RNAV 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 procedure identifier and transition identifier
- If the ICAO and database identifiers are not the same, the database identifier will be included on the paper chart in [square brackets]

GNSS databases encode both RNAV and "traditional" procedures



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

procedure:			
	1. "Database Overlays"	2. "Published Overlays"	3. GNSS Procedures
	Traditional, non-RNAV procedures coded in the database using all the ARINC 424 path- terminators and CNFs as required	"Hybrid" procedures, where the published charts denote that radio navigation <u>or</u> GNSS guidance may be used	Procedures designed and published for use only with GNSS.
Terminal Procedures	 In Europe, many terminal procedures are still 'traditional' These are coded as database overlays 	There are a small number of published overlay terminal procedures. They typically appear on separate chart pages that depict the overlaid RNAV waypoints, but use the same.icao.ncedure.identifiers as the conventional SID or STAR chart	 RNAV 5 or 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 final approach and missed approach procedures 	 A small number of non-precision approach procedures in Europe are published overlays, with a title that includes either method of navigation (eg. "VOR DME or RNAV Rwy 27") 	 A variety of names are used (RNAV, RNP, GNSS) – however for a GNSS approach the title must include either GNSS or GPS. All the CNFs required are usually published on the paper charts (including Airport CNFs)
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 optional, if approval requirements are met	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 RNAV and overlay procedures
- GNSS units will generally provide a message alert when "advisory only" guidance is activated for a overlay procedure



2. Background on terminal procedure titles

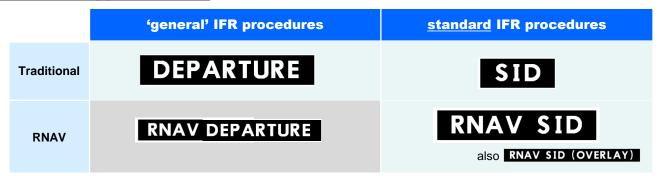
- Terminal procedures always serve to provide safe obstacle and terrain clearance for flight in IMC

 –"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 <u>also</u> 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





Departure titles in Jeppesen charts:



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

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)

Often the code letter for 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, ea. Lambourne Three Alpha vs. LAM 3A)

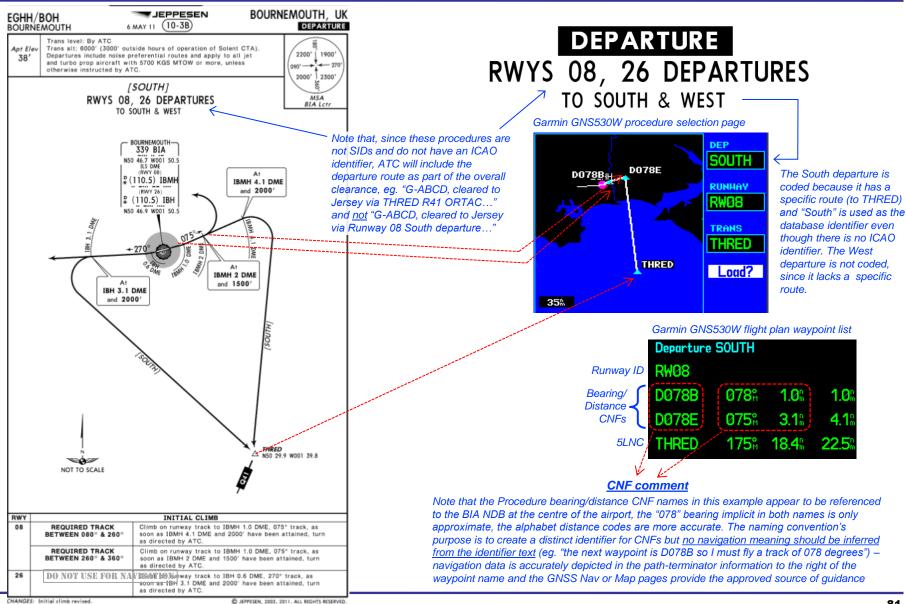
The ARINC 424 procedure name is limited to 6 characters. If the name of the final fix is a 3 letter VOR ident, the ICAO procedure identifier will be 5 characters (3+1+1) and used as the database identifier. If the final waypoint name is a 5LNC (as in the example above), the database identifier will drop 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

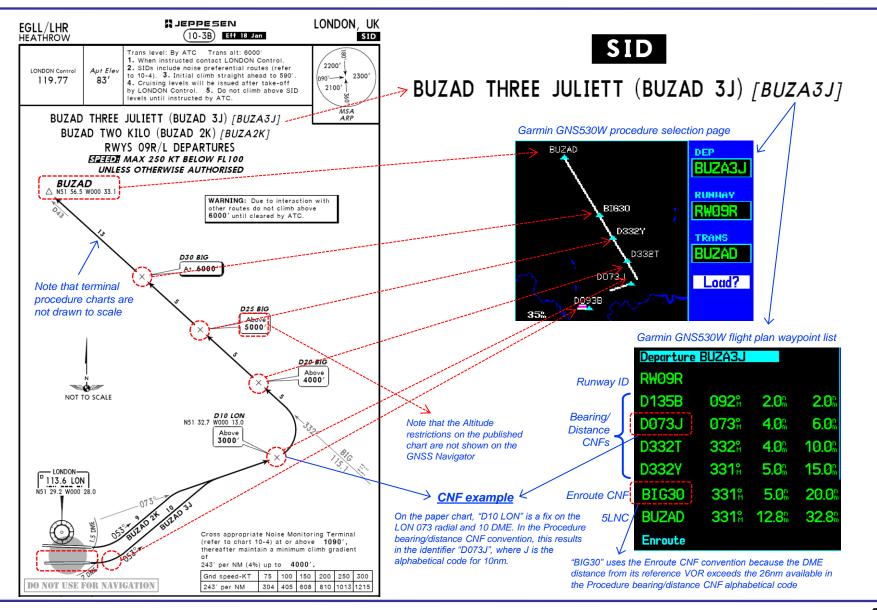
Example of a (non-SID) Departure





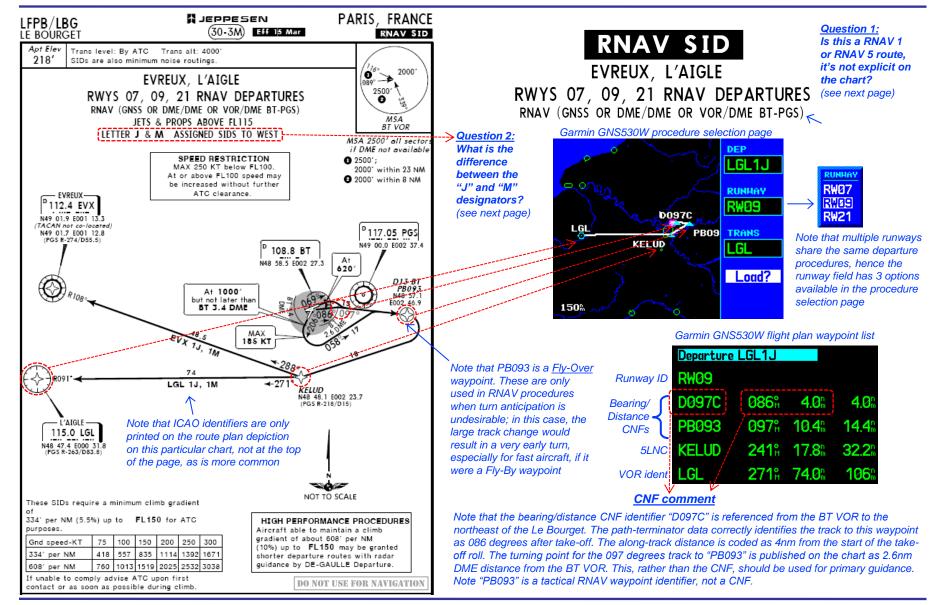
Example of a conventional SID





Example of an RNAV SID





Example of an RNAV SID (..continued from previous page)

SID



 Page 30-3 of the LFPB charts has departure instructions that are helpful for interpreting the individual SID pages

JEPPESEN PARIS, FRANCE LFPB/LBG 30-3B) LE BOURGE

DEPARTURE INSTRUCTIONS

OPERATING PROCEDURES

If unable to fly the RNAV junction phase report 'Unable RNAV 1' upon requesting start-up clearance on PREFLIGHT frequency

2. RNAV DEPARTURES

2.1. Protection

Initial departures are only protected in conventional navigation RNAV departures are protected only for RNAV 1 navigation based on GNSS and/or DME/DME sensors.

2.2. Equipment

The equipment must be approved for RNAV operations within Terminal Area (including SIDs) based on the following sensors: GNSS and/or DME/DME.

ATC provides permanent RADAR services

3. PARTICULAR RULES FOR DEPARTURES (CONVENTIONAL SID OR DIRECT PLAN)

3.1. Non RNAV equipped aircraft below FL115

Specify FPL item 15:

- to north sector: DCT MTD then DCT first point joining the en-route network
- to east sector: DCT NIPOR or DCT ALIMO. - to south sector . SID PTV MONOT or DORDI
- to west sector: DCT EVX or DCT LGL

After initial departure, depending on which runway has been used for take-off

- to north sector: RADAR guidance to MTD.
- to east sector: RADAR guidance to CGN R-085 to proceed NIPOR or
- RADAR guidance to CLM R-103 to proceed ALIMO.

 to south sector : RADAR guidance to proceed SID PTV, MONOT or DORDI.
- to west sector: RADAR guidance to proceed EVX or LGL.

Only south sector is provided with conventional SIDs PROP aircraft destination UIR must indicate:

- after PTV: DCT AGOPA or DCT ERIXU.
- after MONOT: DCT LATRA, DCT OKASI or DCT PILUL

VFR traffic unknown to ATC may occur below the requested FL115

3.2. Departures RWY 07

The crews attention is drawn to the proximity of the final approach course RWY 08R at Charles-De-Gaulle.

3.3. Departures RWY 09

The crews attention is drawn to the proximity of the final approach course to RWY 08L/R at Charles-De-Gaulle. Due to risk of confusion between RWY 07 and RWY 09 crews are requested to

check their magnetic track after lining up and before take-off.

4. SID DESIGNATION

Letter C & P assigned when westerly take-offs/landings (same direction) in use at Orly and Charles-De-Gaulle.

Letter F & P assigned when easterly take-offs/landings (reverse direction) in use at Orly and westerly take-offs/landings (same direction) in use at Charles-De-Gaulle Letter J & Q assigned when easterly take-offs/landings (same direction) in use at Orly and Charles-De-Gaulle

Letter M & Q assigned when westerly take-offs/landings (reverse direction) in use at Orly and easterly take-offs/landings (same direction) in use at Charles-De-Gaulle

Question 1: (referring to previous page)

Is this a RNAV 1 or RNAV 5 route, it's not explicit on the chart?

2. RNAV DEPARTURES

2.1. Protection

Initial departures are only protected in conventional navigation. RNAV departures are protected only for RNAV 1 havigation based on GNSS and/or DME/DME sensors.

2.2. Equipment

The equipment must be approved for RNAV operations within Terminal Area (including SIDs) based on the following sensors: GNSS and/or DME/DME.

ATC provides permanent RADAR services.

Paragraph 1.1 describes how the procedures are designed to protection criteria suitable for RNAV 5 GNSS, however 1.2 specifies that AIC/AIP sources must be checked for the minimum requirements; which are RNAV 5 approval in this case. A RNAV 1 requirement would normally be specified here and on the individual RNAV chart pages - see Section 3.

Question 2: (referring to previous page)

What is the difference between the "J" and "M" designators?

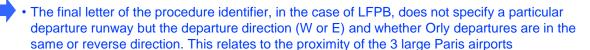
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Letter F & P assigned when easterly take-offs/landings (reverse direction) in use at Orly and westerly take-offs/landings (same direction) in use at Charles-De-Gaulle.

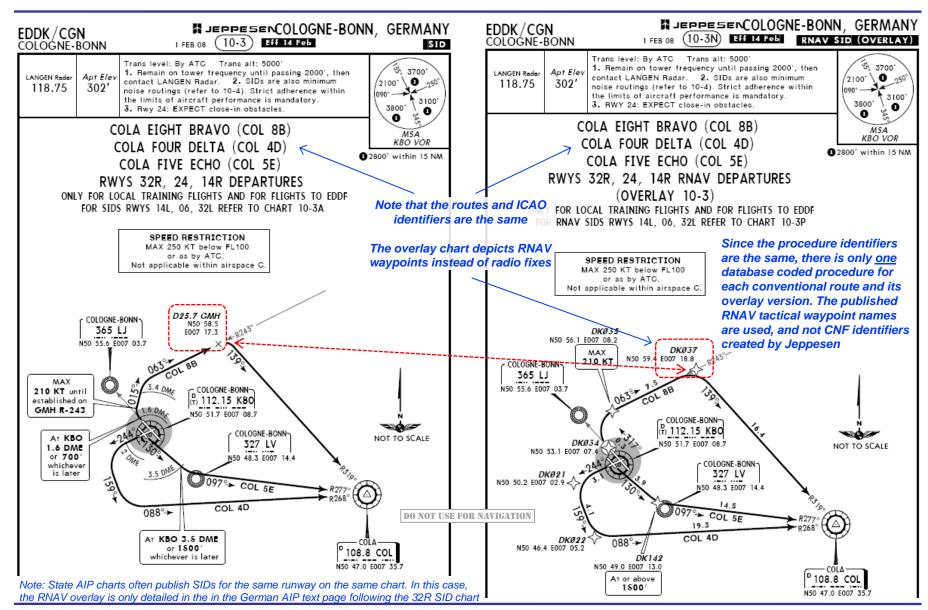
Letter J & Q assigned when easterly take-offs/landings (same direction) in use at Orly and Charles-De-Gaulle.

Letter M & Q assigned when westerly take-offs/landings (reverse direction) in use at Orly and easterly take-offs/landings (same direction) in use at Charles-De-Gaulle.



Example of a SID with a published RNAV Overlay



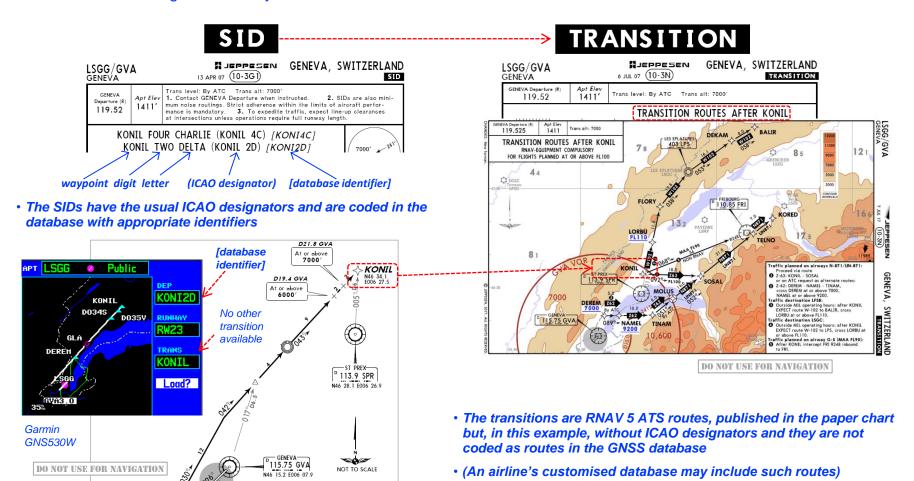


Example of a SID followed by Transition routes



LSGG Geneva

 Geneva is an example (relatively rare in Europe) where some SIDs are followed by a number of different Transition routes connecting to the airways around the TMA



Example of a SID which is not coded in RNAV databases



EICK Cork

TRANS LEVEL: BY ATC

↓ JEPPESEN 29 SEP 00 10-3 Eff 5 Oct

CORK, IRELAND

CORK

TRANS ALT: 5000'

OMNIDIRECTIONAL DEPARTURES

(RWYS 07, 17, 25, 35) CAT A & B NON JET

DO NOT USE FOR NAVIGATION

MAX IAS 250 KT below FL100. Departures are also minimum noise routings and require a minimum climb gradient of 273' per nm (4.5%).

Gnd speed-Kts	75	100	150	200	250	300
273' per nm	342	456	684	911	1139	1367

If unable to comply inform ATC as soon as possible. CAT A & B aircraft may be assigned an omnidirectional departure appropriate to CAT C & D aircraft at the discretion of ATC.

RWY	ROUTING		
07	Climb on 069° track to	1000', then depart as directed by ATC.	
17	Climb on 167° track to	1000', then depart as directed by ATC.	
25	Climb on 249° track to	1000', then depart as directed by ATC.	
35	Climb on 347° track to	1000' then depart as directed by ATC	

OMNIDIRECTIONAL DEPARTURES

(RWYS 17, 35) CAT C & D JET

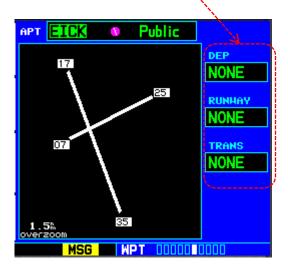
MAX IAS 250 KT below FL100. Departures are also minimum noise routings and require a minimum climb gradient of 553' per nm (9.1%).

Gnd speed-Kts	75	100	150	200	250	300	l
553' per nm	691	922	1382	1843	2304	2765	
If unable to comply inform ATC as soon as possible							

RWY	ROUTING		
17	Climb on 167° track to	2000', then depart as directed by ATC.	
35	Climb on 347° track to	2000', then depart as directed by ATC.	

SID

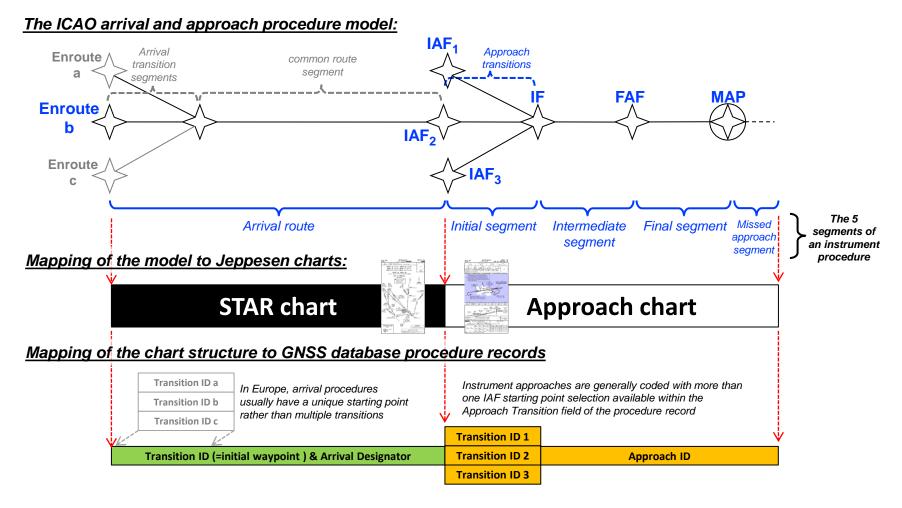
- Although this chart has a SID title, the omnidirectional departures do not have a route structure, so they are not coded as a departure procedures in the database.
- Route based SIDs are also available at EICK



Structure of Arrival and Approach procedures



1. The ICAO model



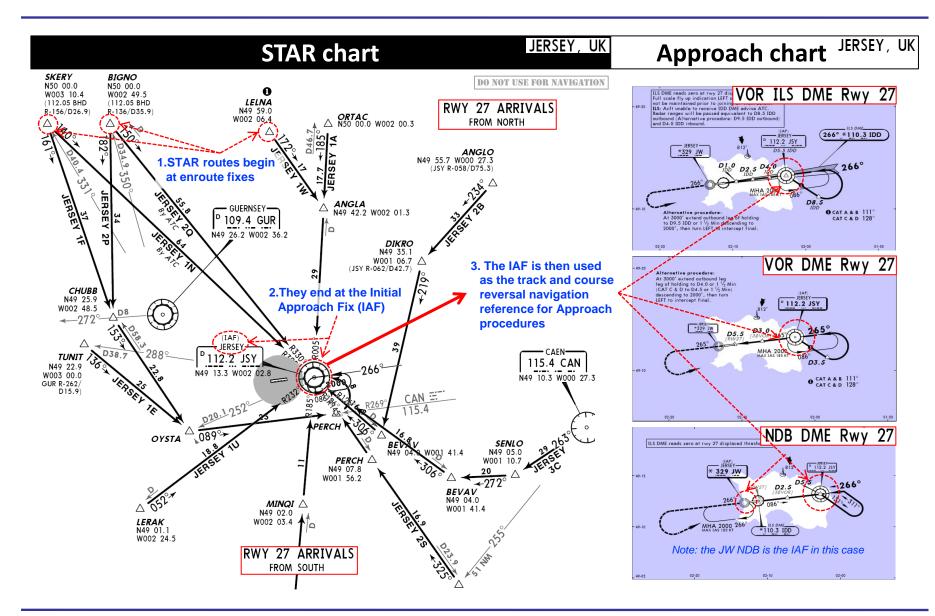


• The typical arrival structure involves STAR routes beginning at enroute waypoints and ending at the IAF and Instrument Approach procedures starting at the IAF

Structure of Arrival and Approach procedures



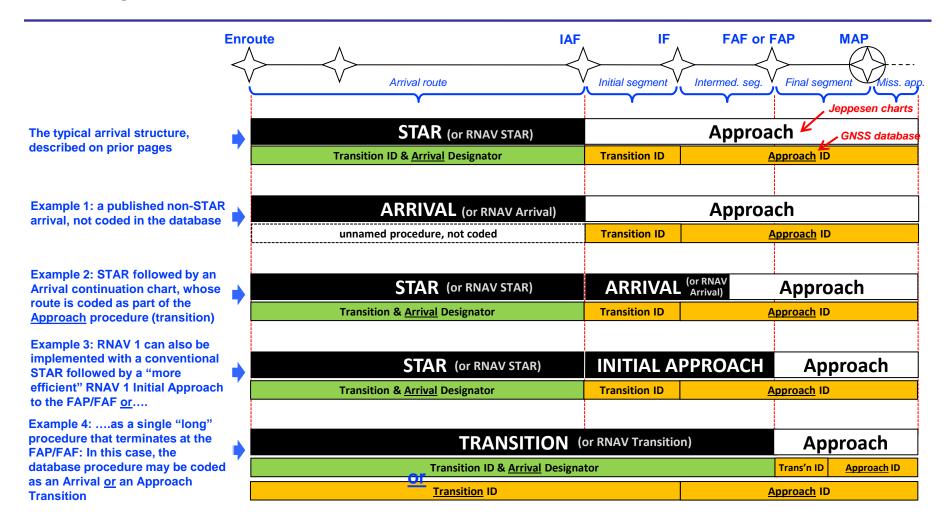
2. Example of conventional STAR and Approach structure



Structure of Arrival and Approach procedures



3. Examples of other structures





RNAV can avoid the inefficient requirement, in many conventional procedures, for arrivals to reach the IAF, track outbound, perform a course reversal and then establish on final approach. Hence, many RNAV arrivals provide an "efficient" route terminating at the FAP/FAF





Summary of Arrival procedure titles in Jeppesen charts:

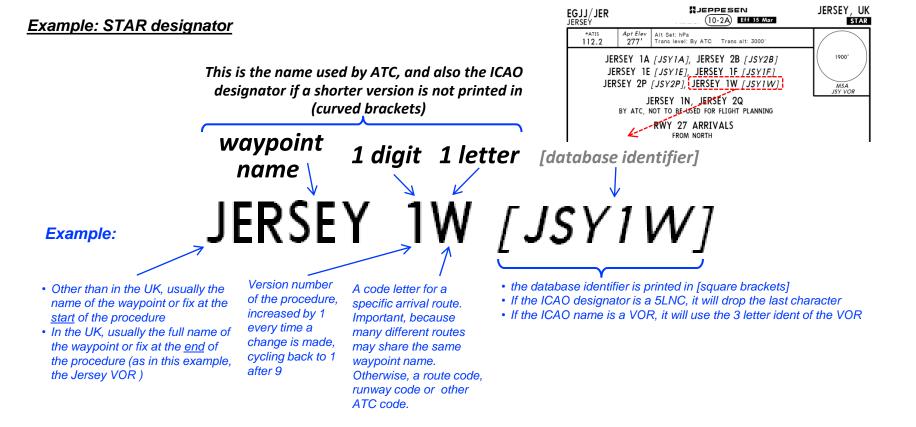
	'general' IFR procedures	<u>standard</u> IFR procedures
Traditional	ARRIVAL	STAR ARRIVAL TRANSITION INITIAL APPROACH
RNAV	RNAV ARRIVAL	RNAV STAR RNAV ARRIVAL RNAV TRANSITION RNAV INITIAL APPROACH



- Note that an "Arrival" chart may be a 'general' route (not coded in the RNAV database),
 or a continuation route coded within the transition selections for an approach
- The examples that follow illustrate each of the procedure types





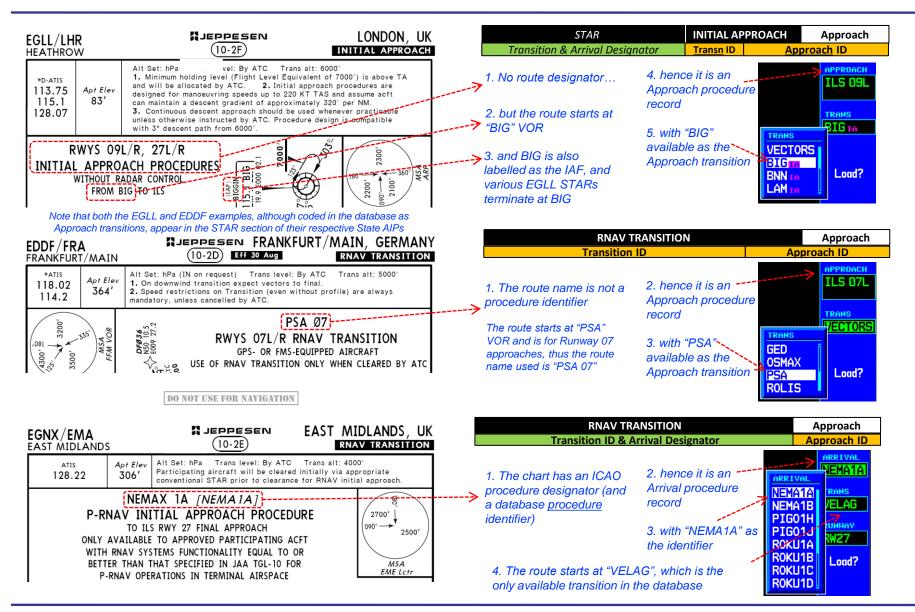




- No other record uses this format. Other identifiers at the top of a "Transition" or "Initial Approach" arrival chart will denote a fix, waypoint or other kind of route name which, usually, means that the route is coded as a transition that is part of an <u>Approach</u> <u>procedure record</u>

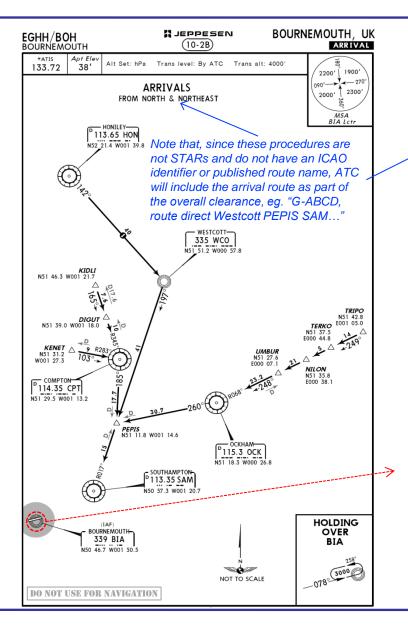
6. Transition and Initial Approach examples





Example of a 'general' Arrival





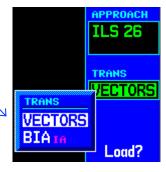
ARRIVAL ARRIVALS FROM NORTH & NORTHEAST

The Arrival record selection includes all of the published STARs for EGHH, which are coded in the normal way, but not any routes called "North" or "Northeast" - they are not coded in the database



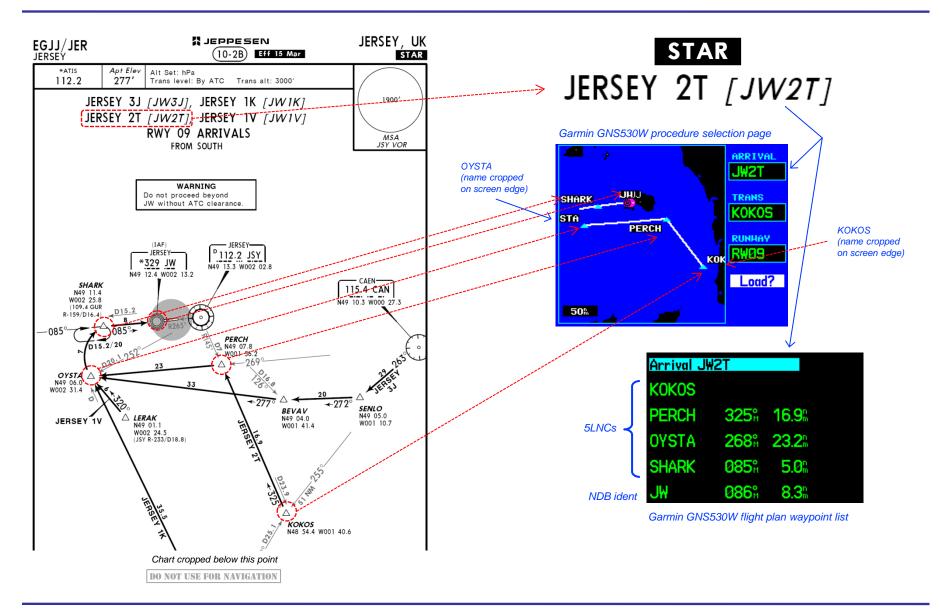
Garmin GNS530W procedure selection pages

The approach procedures at EGHH have only one transition available, the "BIA" NDB on the airport, plus Vectors to Final. In this example, at the end of the arrival route, an aircraft would be cleared to the BIA for a procedural approach or be given radar vectors to the localiser



Example of a conventional STAR

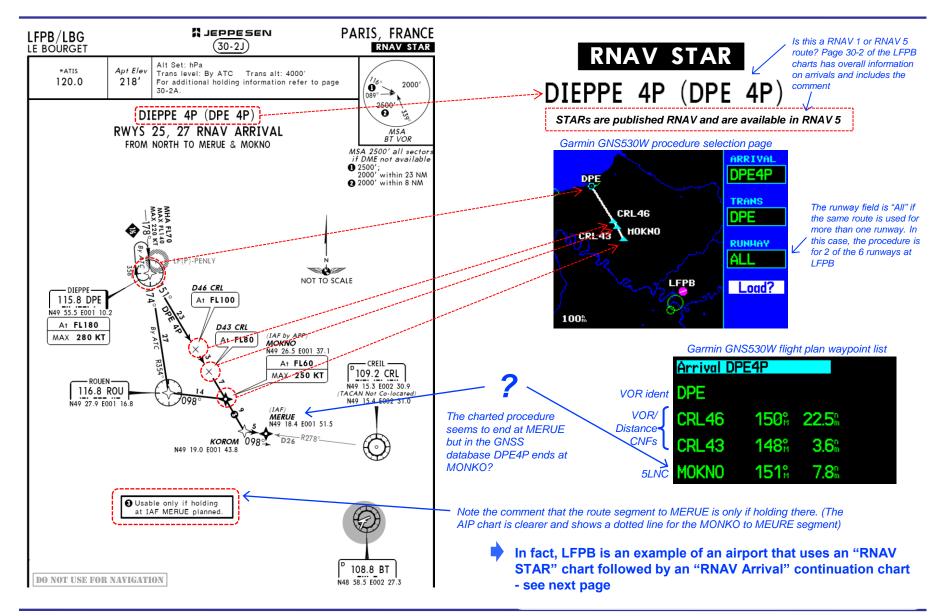




Example of an RNAV STAR to the IAF



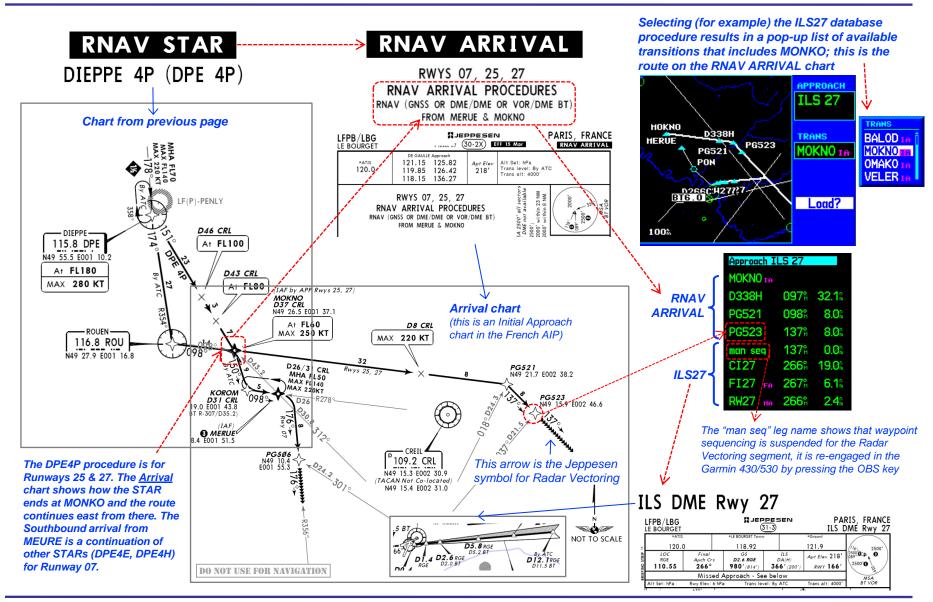
(but see next page) (For illustrative purposes: this procedure no longer exists)



This RNAV STAR is followed by an RNAV Arrival 'continuation' chart from the IAF, which is coded as an Approach transition



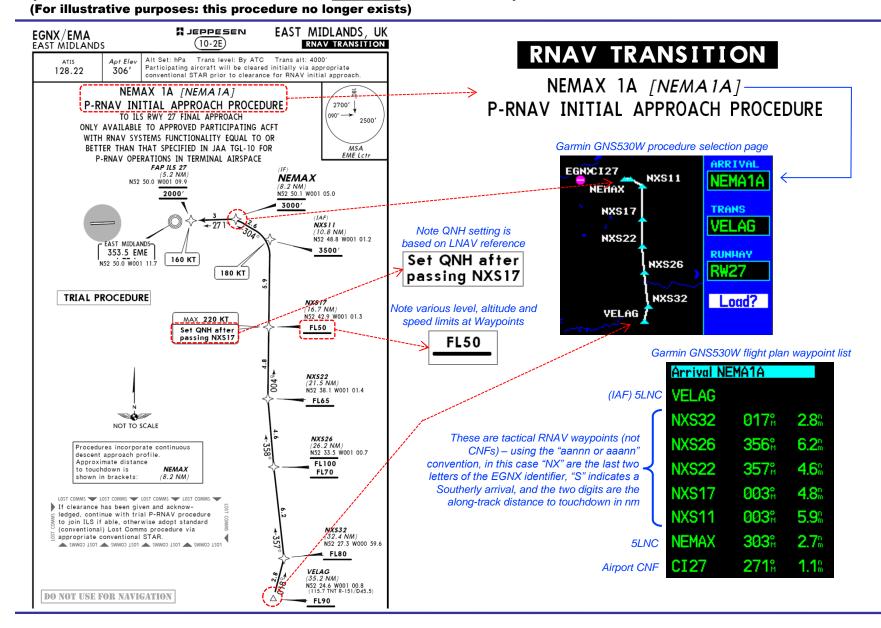
(For illustrative purposes: this procedure no longer exists)



Example of an RNAV transition to the final approach

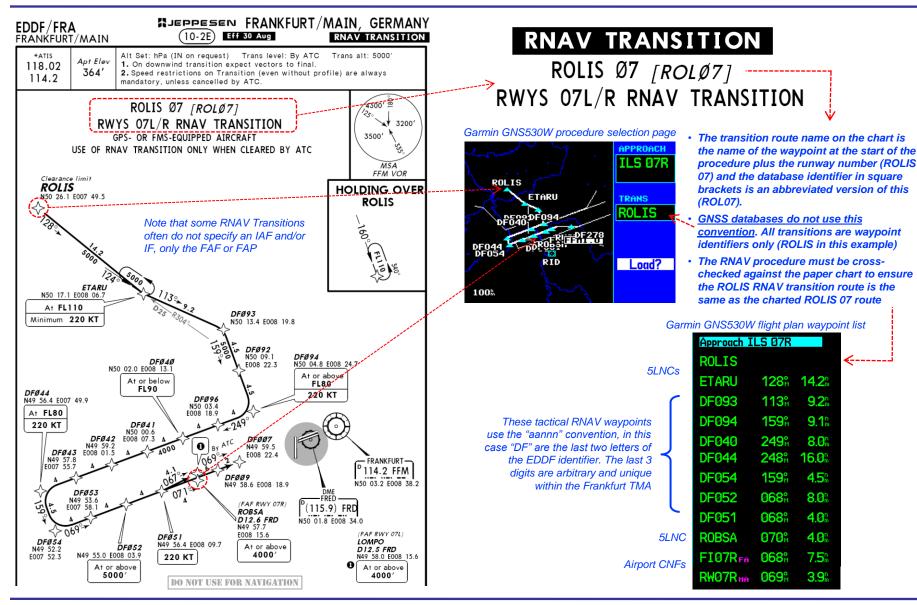


(coded in the database as an Arrival Procedure)



Example of an RNAV transition to the final approach (coded in the database as an Approach Transition)

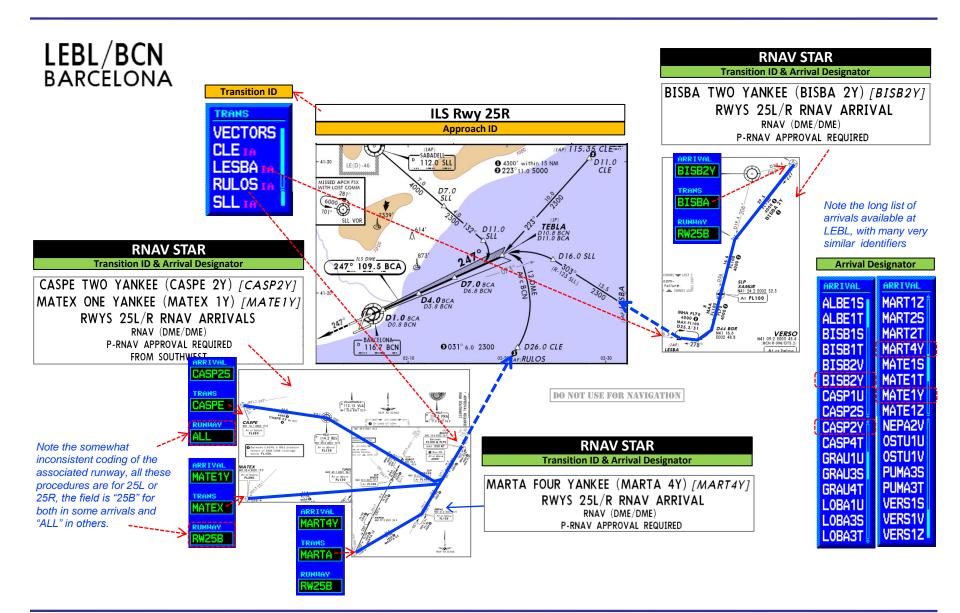




Example of RNAV STAR arrival structure to the IAF



(compare with the "long" RNAV transitions on the two prior pages)



Altitude and Speed restriction coding in ARINC 424 database procedures



- ARINC 424 provides for the encoding of altitude and speed restrictions published in IFR procedure charts and this
 feature is implemented in modern Flight Management Systems
- Speed and 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 course.

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 degrees 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

Approach Procedures: Introduction



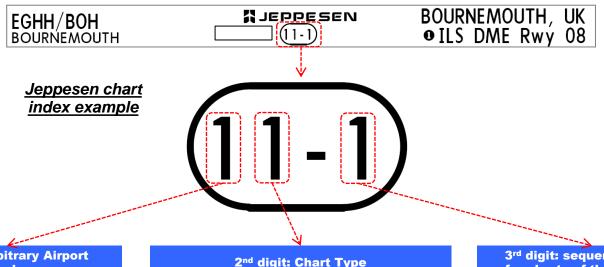
	Database Overlays	Published Overlays	RNP APCHs
Approved flight procedure	• No	• Yes	• Yes
Precision Approach	All ILS approaches are coded as database overlays		GLS approaches (not used by GA)LPV approaches with 200' DH
Approach with Vertical Guidance			LPV approaches with higher DHLNAV/VNAV approaches
Non-Precision Approach	 Most published conventional non- precision approach procedures (VOR,NDB) are coded as database overlays Radar approaches are not coded 	 A small number of non-precision approach procedures in Europe are published overlays, with a title that includes an RNAV method of navigation (eg. "VOR DME or RNAV Rwy 27") 	LNAV approachesLNAV+V (Garmin – Advisory GS only)



- 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
- Note that important topics not specific to RNP APCH (eg. approach minima, circle-to-land procedures, obstacle clearance and MSAs) are not considered
- The detailed description of Database Overlays does not imply that GNSS can be used as primary guidance for conventional approaches.
- 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

5. Jeppesen chart index number convention





- 1st digit: arbitrary Airport number
- Usually 1, but higher numbers are used to distinguish airports under the same city name
- For example, for LONDON UK,
 1 is used for Heathrow, 2 for
 Gatwick, 3 for Stansted, 4 for
 London City, etc
- 0 terminal procedure and airport charts
- 1 ILS, LOC, LDA (also MLS, SDF, KRM)
- 2 GPS (sole use of GPS, not "or GPS")
- 3 VOR
- 4 TACAN
- 5 Reserved, not currently used
- 6 NDB
- 7 DF (radio direction finding, QDM approach)
- 8 Radar approaches (eg. SRA, PAR)
- 9 Vicinity chart, Visual chart

3rd digit: sequence number for charts of the same type

- For example, in the illustration above, further ILS approach charts at EGHH would have a chart index of 11-2, 11-3 etc
- Note that the "0" chart type can have many pages of SIDs and STARs, hence the sequence number may be in the format 1digit+1letter or 1digit+1letter+ 1digit if required

for example: (10-3Q7)

Note on AIP chart naming conventions

There is not a consistent standard for AIP chart names. For example, the UK uses 2:Aerodrome, 4:Airspace, 5:MVA, 6:SID, 7:STAR, 8:Approach. In Germany, it is 2:Aerodrome, 3: STAR, 4:Approach, 5:SID. Other states don't use a numbered convention, but titles such as IAC, SID, STAR, VAC and sort the charts in that order

Source: Jeppesen airway manual chart legend section

6. Approach chart name conventions



- Until a few years ago, the ICAO standard for approaches was that the procedure title should include the navaids to be used. This convention led to a significant amount of variation from state to state, and the requirements for navigation equipment were not always explicit.
- The present convention is more highly standardised, but some current European charts still use the former ICAO standards
- The current convention is summarised in the form of the 7 rules below:

Rule 1: Basic name

- The chart title is the primary navaid for the procedure plus "Rwy" and the runway identifier
- eg. ILS Rwy 27, NDB Rwy 09L
- "ILS" means that <u>both</u> the localiser and glideslope are required
- "LOC" is used instead of "LLZ" as the Localiser abbreviation

Rule 2: "or"

- If more than one type of procedure is published on the same page, then "or" is used
- eg. ILS or LOC Rwy 27
 VOR or NDB Rwy 09L

Rule 3: Secondary navaid

- If navaids other than the primary one are required, this is noted on the chart rather than included in the title; eg. "ILS Rwy 27" with a chart note if DME is required
- Some countries continue to include DME in the chart title

Rule 4: Chart notes

 The chart notes may include other important requirements eg. other navaids, communications equipment, crew training or authorisations, ATC radar availability etc

Rule 5: Multiple procedures

- When there are multiple procedure charts of the same type for the same runway, their titles are differentiated by adding a single letter, (starting at "Z" and sequenced in reverse alphabetical order) after the navaid type and before "Rwy"
- The multiple procedures may relate to different final approach transition routes published on different pages, requirements for navigation equipment, charts for different aircraft categories or variations on an approach design for other operational reasons
- eg. 'VOR Z Rwy 09L' followed by 'VOR Y Rwy 09L'

Rule 6: Offset final approach

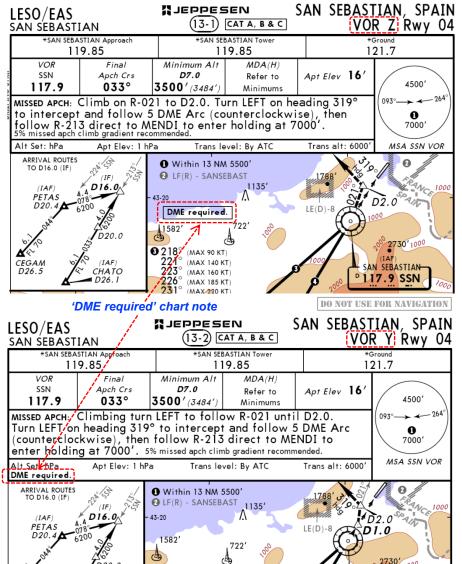
- When a procedure does not meet straight-in landing minima, the navaid is followed by "A".
 Subsequent such procedures at the same airport will use "B", "C" etc
- eg. NDB A Rwy 09

Rule 7: RNAV

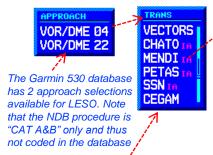
- The current standard is to use the more generic 'RNAV' instead of GNSS, but GNSS still appears on a few current charts
- RNP APCHs may specify the equipment type to be used or an RNP value required
- · The standard is changing to RNP



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



- Example where there are two VOR approach charts to Runway 04, hence the procedure titles 'VOR X' and 'VOR Y'
- The difference between them is that the 'VOR Y' approach has a later missed approach point (1d inbound from SSN, rather than at SSN) and correspondingly lower minima
- Only the 'Z' variant is coded in the GNSS database, and the procedure identifier does not include the 'Z' character



The VOR/DME 04 procedure has several transition (starting) waypoints available, as per the main chart and the small 'Arrival Routes' inset, but not a "Z" or "Y" selection

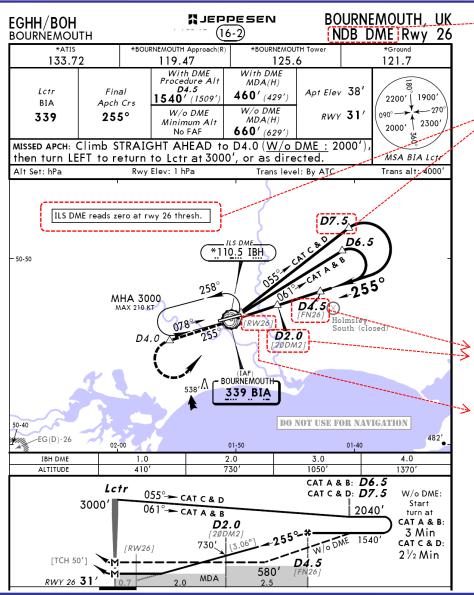
MENDI 16		
D227Q	213°	4.0m
D213P	033 °	1.0 ⁿ
MENDI	033 °	4.0m
FD04 FA	033 °	5.0 ⁿ
SSN _ HA	033°	7.0 ⁿ
7\		

The coded version of the procedure has the MAP at SSN, not 1d inbound from it as in the 'Y' variant. (the small pink letters 'IA', 'FA' and 'MA' denote the IAF, FAF and MAP respectively. Note that the missed approach waypoints are not shown above)

- In this example, there is only a very small difference between the "Z" and "Y" procedure, but some alternatives of this kind may have wholly different routes. In either case, an ARINC database includes only one procedure of a given type (eg. VOR) per runway and does not store the "Z", "Y", "X" procedures as individual records: there is not always a systematic mapping between paper charts and database procedure selections
- It is doubly important to cross-check the database with the procedure chart in such cases

Example of an NDB approach





Note: title with secondary navaid (DME) included. This convention is often used in Europe instead of the alternative of noting the DME requirement in the chart text

Garmin GNS530W procedure selection page

Note that the paper chart depicts distances from the DME, which reads zero at the 26 threshold. The database overlay uses along-track distance between waypoints. Hence "D7.5" on the chart becomes "D8.2" in the database, because its preceding waypoint, the BIA NDB, is 0.7nm SSW of the 26 threshold



Garmin GNS530W flight plan waypoint list

This chart has CNF identifiers printed in faint grey [square brackets] under the DME fix names and a CNF waypoint for the 26 threshold called 'RW26'. These identifiers are used in the database procedure record

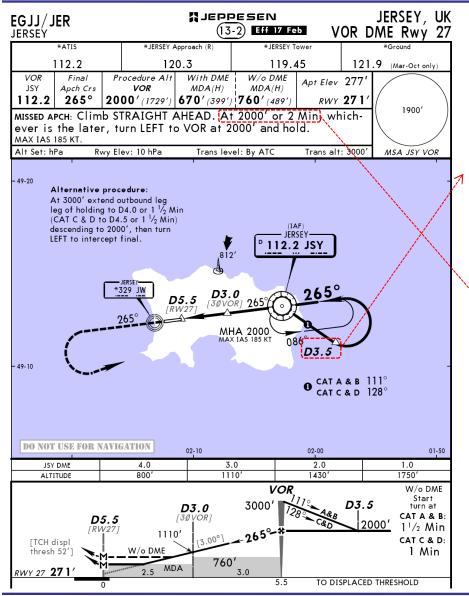
The database also uses 'RW26' as the missed approach point, rather than BIA; this is the normal convention if the charted MAP is <u>after</u> the runway threshold.

On the missed approach procedure, the distance to the D4.0 fix (called '2000ft' in the database to recognise the non-DME turning condition) is 3.1nm, again because of the displacement of the BIA from the DME

Approach N	IDB 26	
BIA IA		
D8.2	055 %	8.2 ⁿ
FN26 FA	255 [°] _м	3.0m
20DM2	254°	2.5 ⁿ
RW26 HA	257 [°] ₁	2.0 ⁿ
BIA	246°	$0.7^{\rm n}_{\rm m}$
≥ 2000€	254 [°] €	3.1%
BIA		

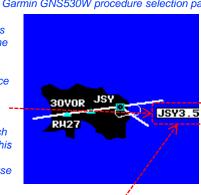
Example of a VOR approach





Garmin GNS530W procedure selection page

Note the discrepancy that this waypoint has a different name on the map display and the database waypoint list. Both variants are examples of a database identifier for a charted fix name where the bearing/distance convention is not used (which would have been "D128D" in this case). This occurs when an identifier like "D3.5" may be used because it is unique. Jersey has 6 approach charts, and "D3.5" appears only once, on this one. "D3.0" is not unique at Jersey, so it is given a CNF [30VOR], which happens to use a non-standard name



Garmin GNS530W flight plan waypoint list

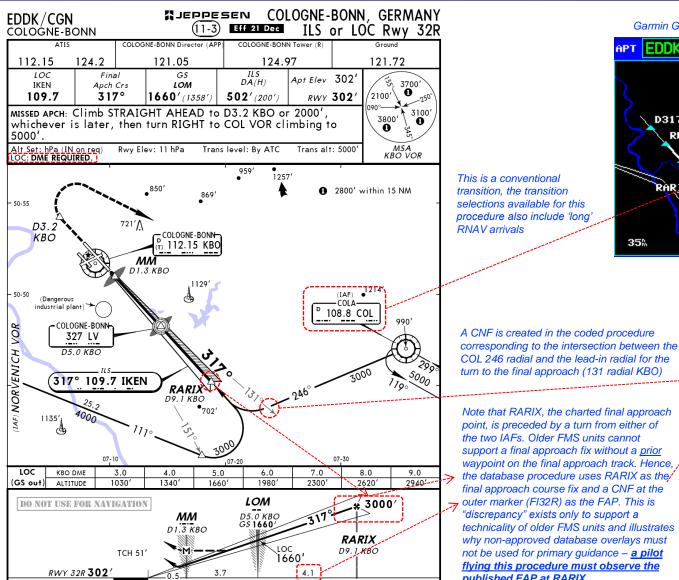
This missed approach procedure leg has a conditional terminator for the turning point, "2000' or 2mins. whichever is later". It is coded as a notional fixed point in the procedure record, and will appear as such on the map display. The distance from the MAP is a notional 3.4nm, corresponding to approximately 100kts or a climb of 600, per nm. However, the GNSS unit will not sequence automatically when this waypoint is reached - it is a manual termination leg, so the pilot must press the OBS kev (in the Garmin 430/530; varies in other GPS units) to start guidance to the JSY when the 2000/2min condition has been met. In an SBAS receiver SUSP can be cancelled immediately after the MAP, as the receiver will only indicate the track to the next leg once the aircraft is above the first turn

altitude restriction.

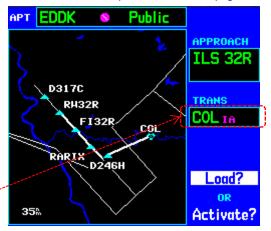
Approach VOR/DME 27					
JSY IA					
D3.5	128°	3.5 _m			
JSY FA	265 [°] €	4.5m			
30V0R	265 [°] €	3.0m			
RW27 MA	265 [°] €	2.5 ⁿ			
20001	265 _n °	3.4			
JSY _{HH}					
hold	266° 0	1:00			

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

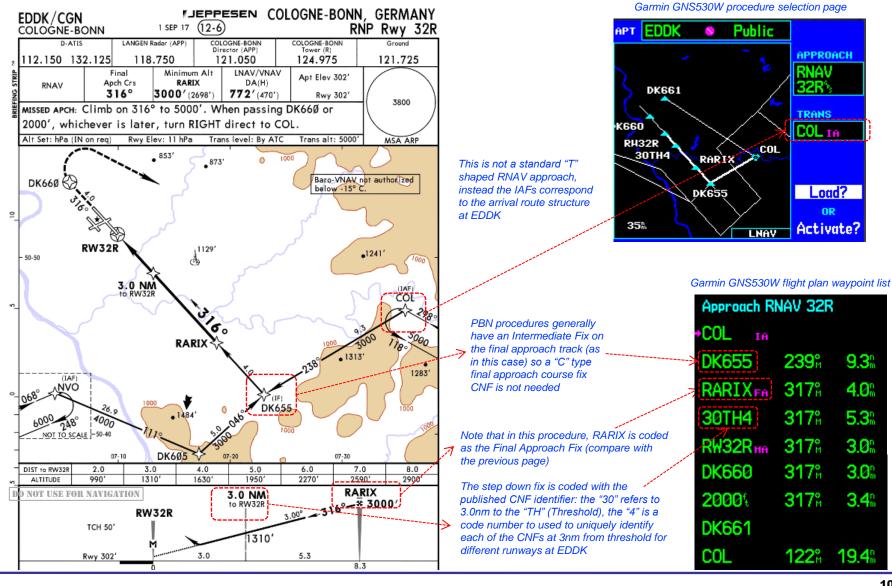
Garmin GNS530W flight plan waypoint list

Note that RARIX, the charted final approach point, is preceded by a turn from either of the two IAFs. Older FMS units cannot support a final approach fix without a prior wavpoint on the final approach track. Hence, the database procedure uses RARIX as the final approach course fix and a CNF at the outer marker (FI32R) as the FAP. 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 FAP at RARIX

Approach ILS 32R		
COL IA		
D246H	246°	8.5 ⁿ
RARIX	317 _m	3.0m
FI32R _{FA}	318 ⁸	4.1m
RW32R _{HA}	318 ⁸	4.2 ⁿ
D317C	317 _m	3.5m
2000 £	317 _m	3.4 ⁿ
COL		

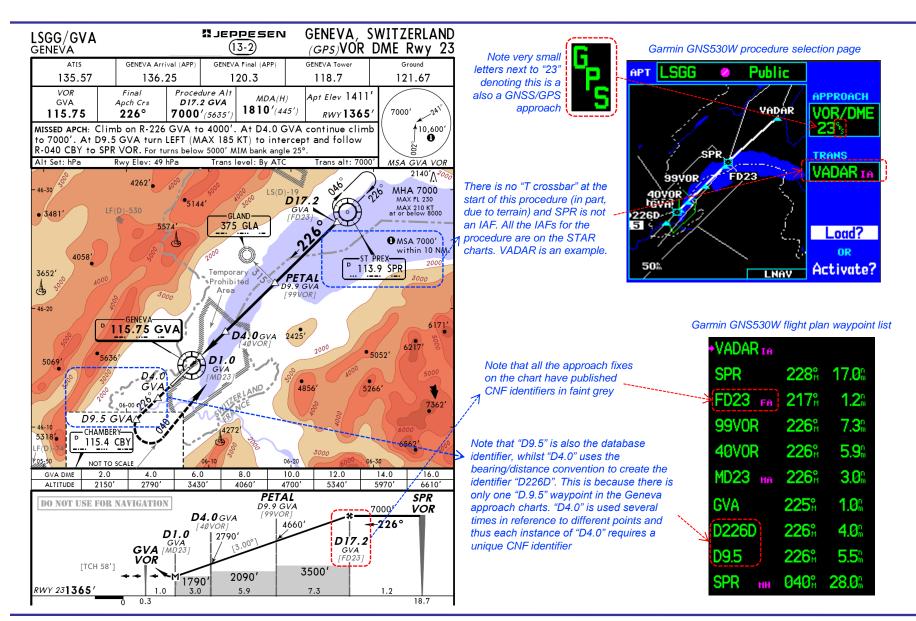
Example of an RNP approach





Example of a GNSS 'published overlay' approach





Course contents



- 1. PBN & RNP theory
 - Introduction to PBN
 - b. The Path-Terminator
 - c. PBN procedure design
- 2. GNSS
 - a. GNSS and the GPS system
 - b. RAIM
 - c. SBAS
 - d. Databases
 - e. Procedures
 - f. Error detection and warnings

- 3. RNAV Approach Procedures
 - Classifications
 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
- 4. Avionics training
- Simulator and/or Flight training

Appendices

- Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

Onboard Performance Monitoring and Alerting



- 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?)

SBAS Available

- The pilot is not required to check RAIM.
- SBAS provides a more accurate method of error checking.

SBAS Not Available

· RAIM checks required in-flight

Onboard Performance Monitoring and Alerting



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 <u>predicted</u>, 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 <u>predicted</u> 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 <u>integrity</u> of the position is not
 assured (ie. one of the 4 signals could be erroneous)
- Where the receiver determines that it cannot provide accuracy within limits, such as due to lack of SBAS, then the guidance mode will fallback. For example, LPV would revert to LNAV.

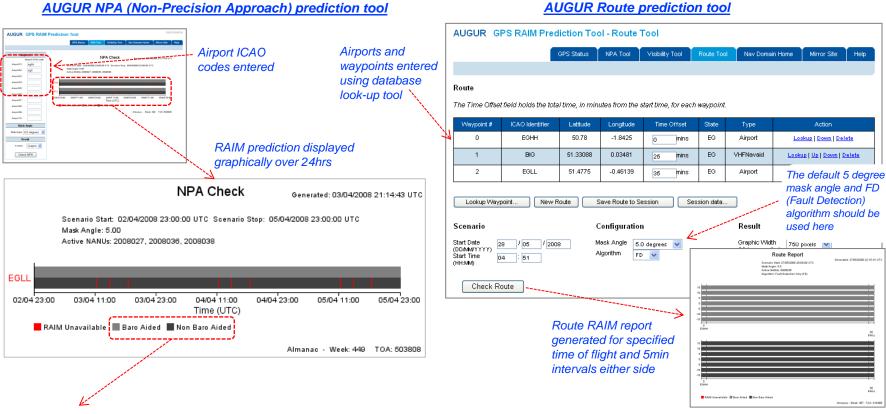
	Pre-flight Prediction	In-flight Integrity
Non- SBAS	Not required, but recommended for RNAV 5. RAIM prediction must be conducted before a RNAV 1/ flight, or SIDs/STARs and approaches. If there is a predicted lack of availability, the flight must either use alternative procedures or reschedule for a time 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.)

Methods of RAIM prediction



1. Eurocontrol's AUGUR internet site: http://augur.ecacnav.com/

- AUGUR is the approved RAIM prediction tool for flight in European airspace
- Use of this website complies with JAA TGL 10 Sub-section 10.2.1.3: "If a stand-alone GNSS is to be used for RNAV 1, the availability of RAIM must be confirmed with account taken of the latest information from the US Coastguard giving details of satellite non-availability"



- "Baro Aiding" in this context means a GNSS unit which can use a barometric altitude input as a substitute for a 4th satellite in determining a 3D position fix. Most IFR GNSS installations will have such an altitude input as part of their certification requirements, allowing the less demanding (by 1 satellite) "baro-aided" prediction result to be used.
- Note that this is completely different from the concept of baro-aiding in turbine aircraft FMS/GNSS units that may use barometric input to provide a synthetic glidepath for baro-aided VNAV approaches.

Methods of RAIM prediction

2. GNSS receiver software



 All IFR GNSS receivers can use the Almanac data in the Navigation Message to predict whether there will be adequate satellite coverage to enable RAIM for a given time and route of flight

Example: Garmin 530 Pilot's Guide Section 10.3

Predicting RAIM availability:

- Select 'RAIM Prediction' from the Utility Page, using the steps described at the beginning of this section.
- The flashing cursor highlights the waypoint field. Use the small and large **right** knobs to enter the identifier of the waypoint at which the pilot wants to determine RAIM availability. Press the **ENT** Key when finished. (To determine RAIM availability for the present position, press the **CLR** Key, followed by the **ENT** Kev.)
- 3) The flashing cursor moves to the arrival date field. Use the small and large **right** knobs to enter the date for which the pilot wants to determine RAIM availability. Press the **ENT** Key when finished.
- 4) The flashing cursor moves to the arrival time field. Use the small and large **right** knobs to enter the time for which the pilot wants to determine RAIM availability. Press the **ENT** Key when finished.

5) The flashing cursor moves to 'Compute RAIM?' (Figure 10-24). Press the **ENT** Key to begin RAIM prediction. Once calculations are complete, the GNS 530 displays one of the following in the RAIM status field:



Figure 10-24 'Compute RAIM?' Highlighted

RAIM Not Available - Satellite coverage is predicted to NOT be sufficient for reliable operation during non-precision approaches

RAIM Available - Satellite coverage is predicted to be sufficient for reliable operation during all flight phases, including non-precision approaches

Methods of RAIM prediction

3. Note on use of GNSS receiver software



- 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.
- Note that 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)
- Note that 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 RNAV 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

GNSS position warnings

1. The Loss of Integrity alert



- 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 <u>not</u> 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) 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 LOI 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 LOI are very brief. However, if an en-route LOI 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 subsumes 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 position warnings

2. Garmin 530 examples



- IFR GNSS receivers always display the LOI alert prominently. In the Garmin 430/530 series, it is a black on yellow "INTEG" annunciator on the bottom left of the screen:
- In addition to the prominent LOI 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 unit, and how they are annunciated and accessed



Example: Garmin GNSS receiver status messages

Searching Sky	The GPS receiver is searching the sky for ANY visible satellites. The pilot is informed of this status with a 'Searching the Sky' message.
Acquiring Sat	The GPS receiver is acquiring satellites for navigation. In this mode, the receiver uses satellite orbital data (collected continuously from the satellites) and last known position to determine which satellites should be in view.
2D Navigation	The GPS receiver is in 2D navigation mode. Altitude data is provided by an altitude serializer.
3D Navigation	The GPS receiver is in 3D navigation mode and computes altitude using satellite data.
Poor Coverg	The GPS receiver cannot acquire sufficient satellites for navigation.
Rcvr Not Usbl	The GPS receiver is unusable due to incorrect initialization or abnormal satellite conditions. Turn the unit off and on again.
AutoLocate	The GPS receiver is looking for any available satellite. This process can take up to five minutes to determine a position.

Example: Garmin RAIM messages

RAIM is not available - Receiver Autonomous Integrity Monitoring (RAIM) has determined that sufficient GPS satellite coverage does not exist for the current phase of flight. (The CDI/HSI NAV flag also appears.) Select an alternate source for navigation guidance, such as the GNS 530's VLOC receiver.

RAIM position warning - Although sufficient GPS satellite coverage may exist, Receiver Autonomous Integrity Monitoring (RAIM) has determined the information from one or more GPS satellites may be in error. The resulting GPS position may be in error beyond the limits allowed for the current phase of flight. Crosscheck the position with an alternate navigation source.

Degraded accuracy - GPS position accuracy has been degraded and RAIM is not available. Poor satellite geometry (or coverage) has resulted in a horizontal DOP greater than 4.0. Additional cross-checking using another navigation source is required to verify the integrity of the GPS position.

RAIM not available from FAF to MAP waypoints - When performing an instrument approach, Receiver Autonomous Integrity Monitoring (RAIM) has determined that sufficient GPS satellite coverage does not exist to meet the required protection limits. Select an alternate source for navigation guidance, such as the GNS 530's VLOC receiver

Garmin information on SBAS RAIM prediction requirements (WAAS RAIM Fault Detection & Exclusion, WFDE)



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.

Reference: UK CAA CAP773



4.1.3 Integrity, accuracy & RAIM prediction

Before the availability of Wide Area Augmentation Systems (WAAS) (such as the EGNOS SBAS signal in Europe) flight crew were required to perform a check on the availability of the RAIM function for the GPS signal prior to flight when planning to use a GNSS receiver certified in accordance with TSO/ETSO C129 for any RNAV approach.

Even today, when using these "C129 standard" receivers, during the pre-flight planning phase, the availability of RAIM (or equivalent monitor) at the destination must be verified as closely as possible before departure, and in any event, not more than 24 hours before takeoff. (RAIM should be confirmed as available from 15 min before Estimated Time of Arrival (ETA) until 15 min after ETA).

This may be established either by an internal function of the receiver (see Note 5) or an air navigation service provider may offer an approved RAIM availability service to users (for example: http://augur.ecacnav.com/augur/app/npa?number=02&icao [see Note 6])

Note 5: Receiver-based RAIM prediction programmes are not able to predict short notice 'outages' and failures, and will not take account of scheduled disruptions to the satellite signals. Consequently, a receiver-based RAIM prediction may appear sound when the actual availability proves insufficient to provide the RAIM function. RAIM predictions also do not normally take account of terrain above the horizon. Where terrain interrupts the 'view' of a satellite from the receiver as the aircraft descends on approach, availability may be affected.

Note 6: Research has shown that such independently available RAIM prediction tools may not have the latest accurate availability data and are also unable to predict short notice outages and failures. A RAIM prediction from these service providers is also not guaranteed.

4.1.4 Using SBAS

With SBAS receivers certified in accordance with TSO/ETSO C146 a RAIM check is no longer required unless the SBAS signal either fails or is lost for any reason. In the event of loss of SBAS, RNP approaches with vertical guidance (other than Baro-LNAV/VNAV) will not be available. The GNSS receiver will automatically make a RAIM check one mile outside the Final Approach Fix and, if satisfactory, will allow an LNAV (non SBAS) approach.

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- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

New Approach Classifications ICAO Annex 6



- ICAO has introduced a new method of classifying instrument approach operations, set out on the
 following page. This new method is intended to simplify and more accurately describe the various types
 of approach and landing operations, 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 type of underlying instrument approach procedure ("the system performance procedure")
- Approach operations are divided into
 - 3D approach operations, in which a continuous indication of vertical deviation 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 ILS precision approach procedure may be designed to a non-instrument runway. It would be flown an 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 procedure 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)

New Approach Classifications ICAO Annex 6



	Classification	Type A		Type B		
Approach		(>=250')		CAT I (>=200')	CAT II (>=100')	CAT III (<100')
Operations (Annex 6)	Method	2D	3D			
(Alliex 0)	Minima	MDA/H	DA/H			
	M(DA/H)>=VMC	Non-Instrum	nent Runway			
	M(DA/H)>=250' Visibility=1000m		on Approach way			
Approach Runways	DA/H>=200' Visibility>=800m or RVR>=550m	Precision A	Approach Runw	ay, Category I		
(Annex 14)	DA/H>=100' RVR>=300m	F	Precision Appro	ach Runway, Cate	egory II	
	DA/H>=0' RVR>=0m	Precision Approach Runway, Category III (A, B & C)		C)		
System	NPA		OR, Azimuth, ISS			
Performance Procedures	APV		GNSS/Baro /SBAS			
(Annex 10)	PA			ILS, ML	S,SBAS GBAS	

Glossary: 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	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)	ILS, MLS, 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 larger turbine aircraft RNP approach procedures to LPV 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	GLS approach GNSS Landing System: precision approach based on GNSS with GBAS (eg. LAAS) Currently, CAT I procedures have been deployed in limited numbers. CAT II and III applications are being developed. GBAS and GLS are not supported at present in GA aircraft and will not be discussed further in this manual

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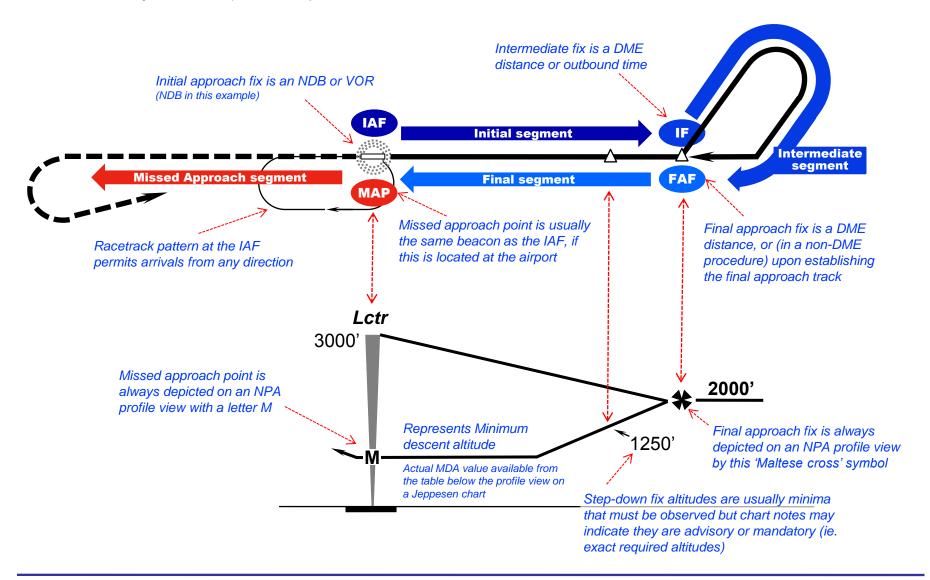
- 1. Database Coding and Naming Conventions
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Glossary of Abbreviations

Typical structure of a conventional NPA



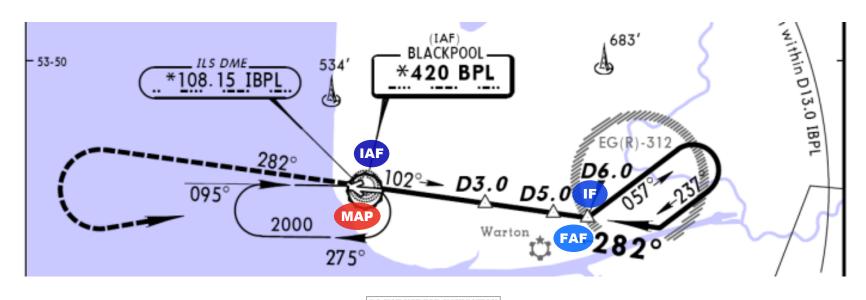
Note: this is an illustrative generalisation of a procedure. Always refer to actual charts and chart notes

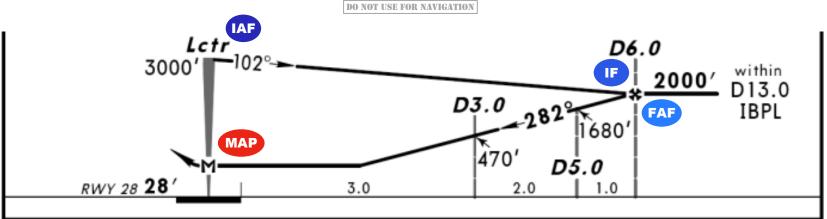


Example of a conventional NPA





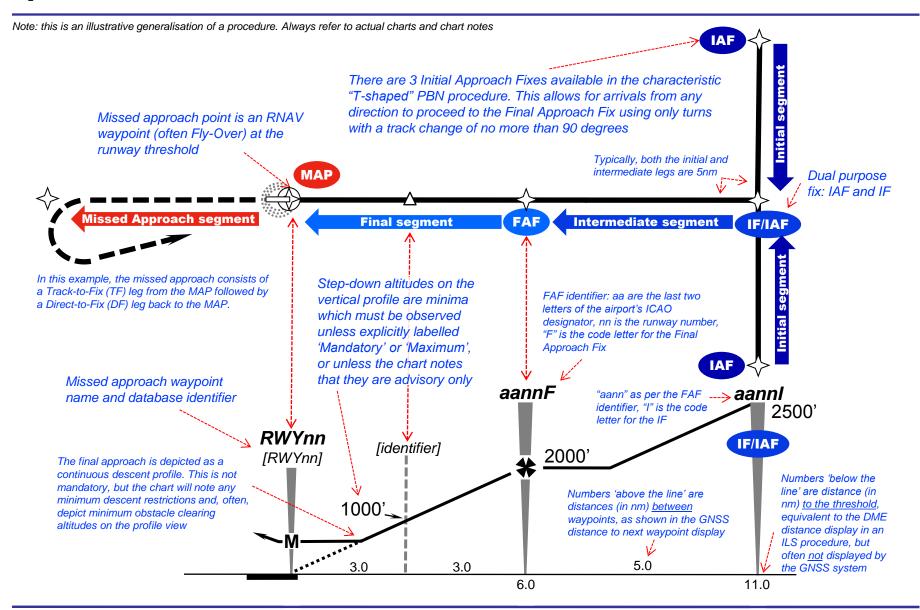




Source: Jeppesen

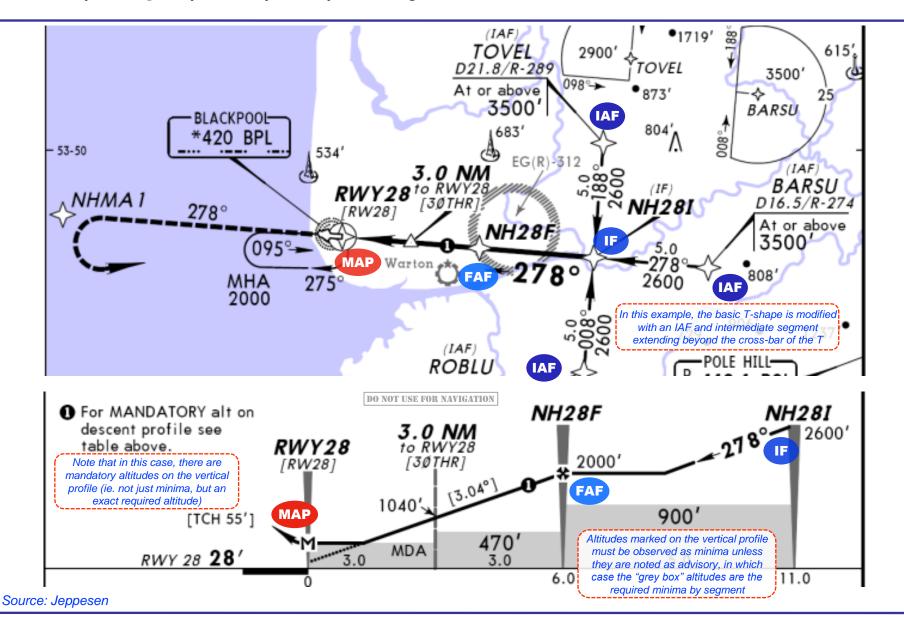
Typical structure of an RNAV NPA: the "T-shaped" procedure





Example of an RNP Approach EGNH (Blackpool) RNAV(GNSS) Runway 28

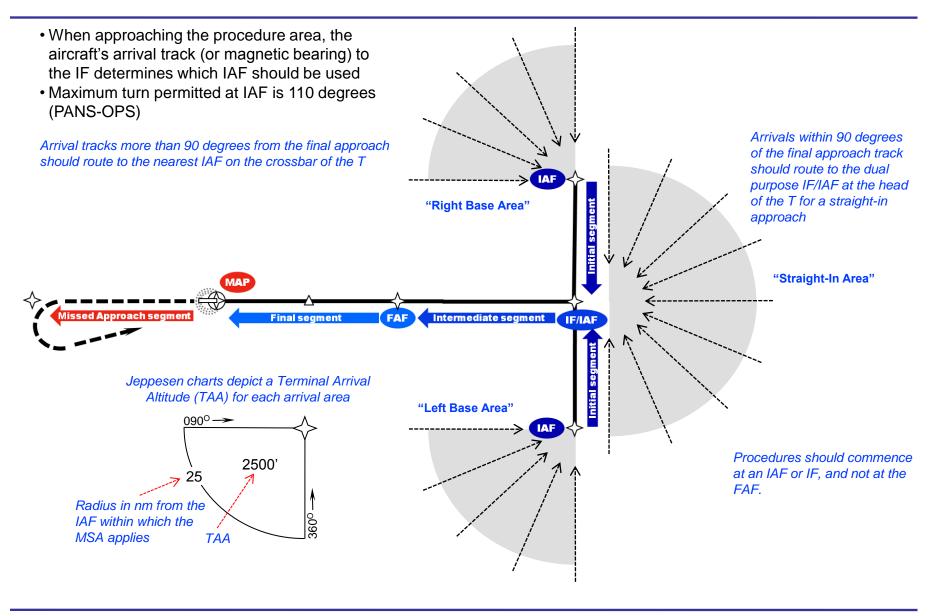




RNP Approach notes (1)



The arrival track to the IF determines which IAF is used in a "T" procedure



RNP Approach notes (2)

The "T" structure is not used in all RNP approaches

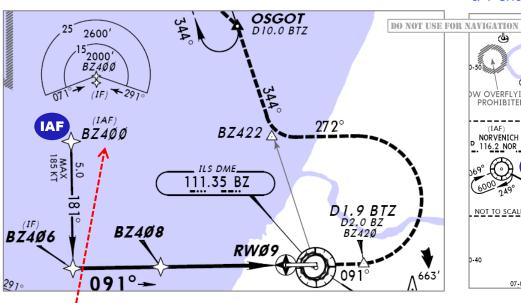


LFBZ (Biarritz) RNAV(GNSS) Rwy 09

EDDK (Cologne-Bonn) RNP Rwy 32L

Example in which terrain precludes a T-shaped procedure with low-level arrivals from all directions

Example of a larger airport, where the IAFs conform to the structure of standard arrival routes within the TMA rather than a T-shape





BZ400 is the only IAF; note in this case that arrivals to BZ400 are permitted from an arc of 220 degrees

High terrain means that the MSA for arrivals from the south of Biarritz is 6000', hence the middle and southerly IAFs that would make up a standard T procedure are not available. Southerly arrivals may route via OSGOT to descend and join the procedure at BZ400

At a larger airport like Cologne, pilots may expect a STAR terminating at one of the IAFs (eg. NORVENICH or COLA), or radar vectors to the RNP final approach or to an intermediate waypoint on the RNP approach

RNP APCH operations and minima lines LNAV



RNP approaches usually have multiple minima lines, drawn from:

- LNAV
- LNAV/VNAV
- > LPV

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

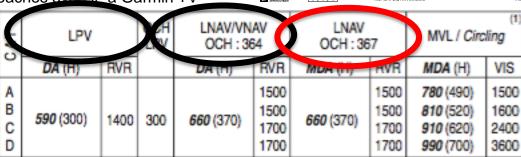
- When flown with a TSO-C129A (non-SBAS unit)
 - linear deviation indication on CDI is provided
 - Garmin annunciation APPR
- When flown with a TSO-C146A (SBAS unit)
 - angular deviation indication horizontally (localiser-like) and vertically (glideslope like)
 - Garmin annunciation LNAV
 - ➤ LNAV+V 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



RNP APCH operations and minima lines LNAV/VNAV and LPV



BREST BRETAGNE

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

- · Operated "like an ILS"
- · Airliners with FMS use Baro-VNAV to fly these
 - Vertical guidance using baro-altitude
 - Various scaling conventions
 - Minimum temperature
- When flown with a TSO-C146A (SBAS unit)
 - angular deviation indication horizontally (localiser-like) and vertically (glideslope like)
 - surveyed vertical guidance
 - Garmin annunciation L/VNAV

The **LPV minima line** corresponds to an APV.

- Operated "like an ILS"
- Requires SBAS
- When flown with a TSO-C146A (SBAS unit)
 - angular deviation indication horizontally (localiser-like) and vertically

LPV

RVR

1400

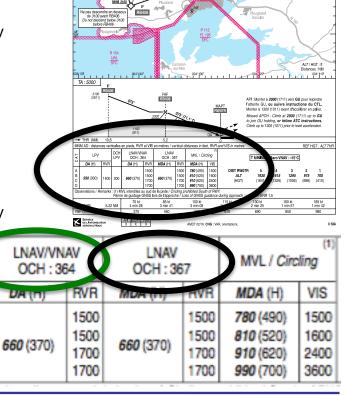
300

DA (H)

590 (300)

В

- surveyed advisory vertical guidance
- Garmin annunciation LPV
- Both LPV and LNAV/VNAV may fall back to LNAV if SBAS or integrity is lost (See also page 149)



APPROCHE AUX INSTRUMENTS

LANDI Accroche / Accroach 122.4 (L.) pendant HOR activité de LANDI APP / Du

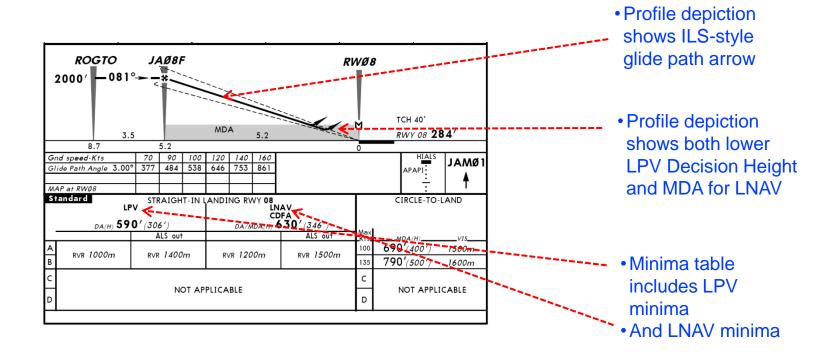
Instrument approach CAT A B C D ALT AD: 325, THR: 289 (10 hP)

RNP APCH example: Alderney EGJA Rwy 08 LPV and LNAV minima



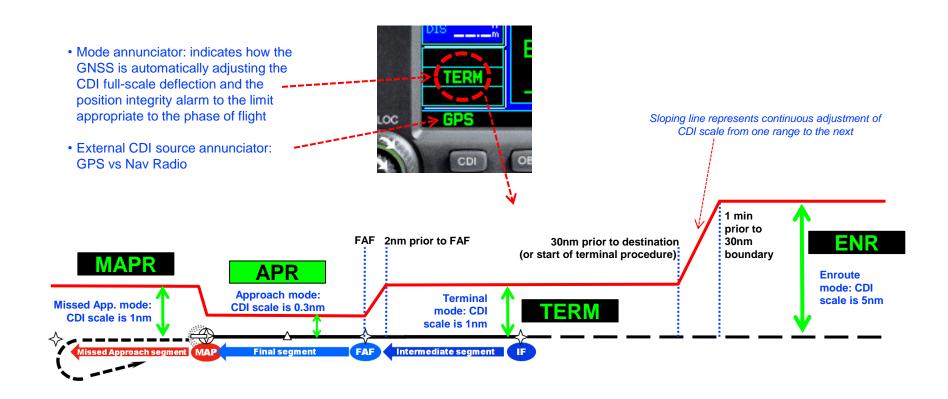
SBAS has enabled GNSS approaches with vertical guidance.

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.



GPS operating mode example: Garmin 530 (non-SBAS for comparison with SBAS)



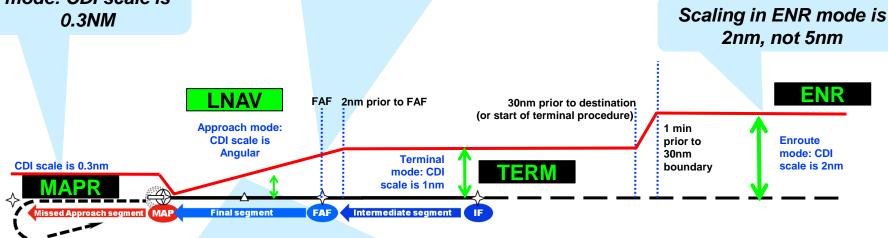




GNSS operating mode example: Garmin 530W receiving an SBAS signal

CDI scaling from the FAF on GNSS approaches is angular +/- 2 degrees (except very close to the runway +/- 350'), 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 the 530W.

Missed approach mode: CDI scale is



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

LNAV+V L/VNAV

- > use LNAV minima, no glidepath available
- > use LNAV minima, advisory glidepath will be displayed on HSI
 - > use LNAV/VNAV minima, glidepath will be displayed on HSI
- > use LPV minima and both track and vertical guidance on HSI

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European and US requirements for private aircraft and PBN



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. In some states, this requirement has been postponed until April 2019.

	1. Avionics approval	2. Pilot knowledge/training	3. Operations
FAA	 Based on aircraft original equipment: Flight Manual section on GNSS equipment must specify that the installation is approved for IFR and RNP approaches Based on retrofit equipment: Installation must be IFR approved Flight Manual supplement must specify that installation is approved for RNP approaches 	 A current FAA Instrument Rating qualifies a pilot to fly GNSS approaches 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 	 Operations under 14 CFR Part 91 (which governs IFR flight for private operators) do not require an operational approval for RNP APCH The Aeronautical Information Manual (AIM) sets out the requirements for using GNSS as a navigation aid in RNP approaches and other IFR applications
Europe EASA Firegon Autom Sidey Agency	 Based on aircraft original equipment: Flight Manual must specify the performance based navigation specifications that the aircraft is certified for Based on retrofit equipment: Flight Manual Supplement must specify the performance based navigation specifications that the aircraft is certified for Guidance Material on AFM wording for this is available at GM1 NCO.IDE.A.195 	 A current Instrument Rating must have a PBN privileges endorsement to qualify a pilot to fly PBN routes and procedures with a requirement for ground or flight training from 25 August 2018 To obtain PBN privileges, pilots with an EASA Part-FCL licence with IR must meet criteria set by the state of licence issue, which may include a Theoretical Knowledge test All EASA Part-FCL IR skill tests and proficiency checks will include at least one RNP APCH from 25 August 2018 	Operations under Part-NCO do not need an operational approval for RNP APCH



The key requirement for both N- and EASA registered aircraft is that the Approved Flight Manual (or equivalent) permits the GNSS installation to be used for the PBN route or procedure.

PBN airborne equipment requirements



- The relevant PBN specification must be documented
 - The performance of the aircraft is usually 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 qualification data, in itself, is not considered sufficient to assess 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 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.

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Summary of RNP APCH operating procedures



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 Check coding of expected GNSS approach procedure against paper charts GNSS receiver self-test, user selectable settings, LOI monitoring Flight plan entry and RAIM prediction (if necessary) Requirement to use a database coded procedure for GNSS SIDs, STARs and approaches
3. Pre-Arrival	 Selecting and checking the Arrival/Approach procedure Determining the appropriate IAF Activation of the procedure and check CDI scaling is Auto
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 selection Use of the GNSS receiver if a hold or vectors to an intermediate waypoint on the approach are required Check activation of APP, LNAV, LNAV+V, LNAV/VNAV or LPV mode as applicable
5. Flying the Missed Approach	 Activation of the Missed Approach procedure and the need to manually re-initiate 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 actionsReverting 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 <u>addition</u> to conventional IFR operating procedures and checks

RNP APCH operations (1) 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 RNAV 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-RNAV procedure to be flown for operational reasons IFR workload, particularly in demanding weather and traffic conditions, may not allow much time for a pilot to troubleshoot or reprogram a receiver; eg. after holds and vectors have disrupted guidance sequencing for an active procedure. In such circumstances, it may be safer and easier to revert to and request a conventional procedure from ATC
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. If SBAS is not available and the destination weather is such that an alternate airport is required, 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.ecacnav.com/ 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 operations (2) 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 example: extract from Garmin 530 database validity page on start-up 	
Check coding of expected RNP APCH procedures against paper charts	 Prior to using a procedure from the database, the pilot must check that it matches the published procedure chart. A review of waypoint sequence, tracks and distances is adequate; Lat/Long coordinates must only be checked if there is a potential discrepancy This review may be done pre-flight, and it is useful to check all of the potential approach and transition identifier selections at this point, in order to minimise in-flight workload Whilst coding errors are rare, it is common for GNSS databases to include some waypoints which do not appear on paper charts, or to use different identifiers (see Sections 2b and 2c of this manual) 	
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 UK CAA CAP773 (see Part 2 and Appendix 2) recommends that the status of all the user-definable receiver settings should also be checked, in particular where an aircraft is flown by a more than one pilot. Such checks may include: Set CDI scaling to 'automatic'; 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 map datum to WGS 84; 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)	 The enroute flight plan may be entered at this point and, if SBAS is not available, a GNSS RAIM prediction performed, either in lieu of or to update a prediction from an internet site such as AUGUR 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	 All the regulatory sources emphasise that an RNAV terminal or approach procedure must only be flown using guidance based on a procedure record loaded from the database This procedure record must not be amended by any user entries, and, in particular, a procedure created from user-entered waypoints may never be used 	

RNP Approach operations (3) Pre-Arrival



Operating Procedure	Notes and comments	
Selecting and checking the Approach procedure Determining the appropriate IAF	 When cleared by ATC for a RNP APCH (ideally, >30nm from the destination), the procedure should be selected from the database but not (subject to the receiver unit logic) 'activated', 'loaded' into the active flight plan, 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 (see page 130). This IAF should be selected from the transition identifier list in the procedure record ATC clearances should be read back carefully; some TMAs have a large number of similar sounding RNAV waypoints At this point, a final 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 	
scale deflection and the RA • Garmin example:	and approach procedures are active, IFR units automatically adjust the CDI full- NIM position integrity alarm to the limit appropriate for each phase of flight LNAV LNAV LNAV LNAV LPV APR The prior to FAF 2nm prior to FAF 30nm prior to destination (or start of terminal procedure) Enroute mod CDI scale is	
Missed App. mode: CDI scale LNAV 1NM LPV 0.3NM Missed Approach segment MA	CDI scale depends on SBAS Terminal mode: CDI scale is 1nm TERM 5nm (non SB or 2nm (SBAS)	

RNP APCH operations (4) 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, or which may provide supplementary guidance (eg. DME). If the missed approach is an RNAV 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 XXXO" 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 must be trained in managing such tactical changes to the flight plan (see sections 5 and 6 of this manual)
Check activation of APP mode prior to the FAF	 Within 2nm of the FAF, the pilot <u>must check that the appropriate approach mode is active</u> – 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 the alarm 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 private pilot intending to fly RNP APCH should study the appropriate official guidance material.

RNP APCH operations (5) Flying the Missed Approach



Procedure	Notes and comments
	 A strict logic applies in GNSS receivers. Up to the <u>coded</u> MAP, waypoint sequencing is automatic. At the coded MAP, automatic sequencing is suspended and the pilot must manually re-initiate guidance for the missed approach.
Activation of the Missed Approach procedure and the need to manually re-initiate waypoint sequencing	 GNSS database procedures are coded so that the Runway Threshold waypoint is always the Missed Approach Way Point 'MAWP'. This also applies to "database overlays" of conventional procedures, where the published MAP is often a beacon beyond the runway threshold (in this case, the charted MAP will be the next waypoint after a CNF at the runway threshold. This CNF is encoded as the MAWP in the database.)
	• For Continuous Descent Final Approach LNAV approaches and SBAS approaches with vertical guidance, the DA is always before the MAPW 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 MAWP 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.
	 Even if the Missed Approach procedure mode is initiated before the MAP (eg. with a direct-to the MAP), waypoint sequencing will be suspended at the MAP.
	• This logic may appear somewhat strange, but it is essential—it means that there is no risk of automatic waypoint sequencing unexpectedly changing the GPS LNAV 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 operations (6) Flying the Missed Approach



Procedure	Notes and comments
	 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.
Mode selection and pilot actions in non-RNAV missed approach 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 operations (6) ATC communications



Operating Procedure	Transcripts from UK CAA CAP773 Appendix 3
Communications during normal procedures	Pilots should request clearance to fly the procedure using the phraseology: '(Aircraft c/s), request RNAV 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 RNAV 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 shall instruct the pilot to report at the final approach fix, using 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).
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) GNSS unavailable (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 GNSS due equipment" followed by a request for an alternative course of action as appropriate

RNP APCH operations (7) 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 <u>or</u> a GNSS position alarm, 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-GPS aids as required and continue (or turn to) to the MAP. If a non-RNAV 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 RNAV 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 GPS 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

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 - Introduction to PBN
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 - d. Databases
 - e. Procedures
 - f. Error detection and warnings

- 3. RNP Approach Procedures
 - Classifications
 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
- 4. Avionics training
- Simulator and/or Flight training

Appendices

- Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

GNSS training





- GNSS training is required for PBN operations, including RNP Approaches and forms part of the Skill Test (for initial issue of the IR) and Proficiency Check (for revalidation/renewal).
- The particular challenge for Terminal and Approach RNAV operations is to be
 - -proficient in all the "combinations" of operating modes and selection changes that may be required (eg. loading a procedure, being vectored then asked to hold, having the landing runway change and needing to activate another procedure)
 - -familiar with the details of GNSS guidance in each of the operating modes and procedure variants (eg. does the CDI indicate deviation through the curved track of a fly-by turn, or flip from one track to the next halfway through?)
- Much of this proficiency is specific to individual models of receiver. The operating logic of receiver
 models is sufficiently varied that an expert user may struggle with the specialised IFR features in an
 unfamiliar model, even if they are able to use the basic navigation functions quite easily.



 Assuming basic "enroute" IFR GNSS skills as starting point, we recommend that pilots and instructors should focus RNAV training on 4 specific topics detailed on the next page

• The reference pages later in this section have an example of an approved 'basic' training syllabus for the Garmin 430/530 series

GNSS training



2. RNAV training topics (specific to individual models of receiver)

Topic	Training objectives
Loading, briefing and activating procedures	 Familiarity with terminal and approach procedure selection and briefing selecting and verifying Transition, Procedure, Runway and Airport identifiers displaying waypoints prior to activating the procedure, in order to cross-check against paper charts loading, activating or arming the procedure (terminology and logic varies by model) changing or deleting the selected procedure before and after activation/arming modifying the enroute flight plan so any 'overlap' with a procedure is removed (eg. if the enroute plan ends at a waypoint after the first waypoint of an arrival)
2. Fly-By waypoint guidance	 Understanding turn anticipation in the case of Fly-By waypoints is the waypoint ETE the time to the start of the turn, or the time to notionally cross the waypoint? roughly how many seconds prior to a waypoint do turns begin, based on track change and ground speed? when is the next track after a waypoint annunciated? when is the turn countdown annunciated? Is the countdown displayed continuously? when and how is the turn command annunciated? Understanding turn guidance through Fly-By waypoints does the map provide any curved track guidance through the turn? does the CDI 'flip' from one track to the next in mid-turn, or does it provide deviation information relative to the calculated turn path? does the coupled HSI CDI provide the same information? does the receiver provide the correct turn guidance to a Flight Director and/or Autopilot in NAV mode/roll steering mode if available? how does a Position Alarm alert you to a breach of the RNP protection limit (eg. if you miss a turn)
3. Tactically modifying a flight plan	 Changing the procedure selection after it has become active how is the new procedure activated? What if the aircraft has passed some of the initial waypoints? Selecting "Vectors-to-final" at the start of or during a procedure how do you restore procedure guidance if ATC cancel vectoring and direct you to rejoin the procedure? Following ATC instructions does the Direct-to button provide straight-line guidance to a waypoint (the leg terminator), or an intercept to the leg path prior to the terminator? Is there a choice of Direct-to or Fly-Leg guidance? if instructed to hold at a waypoint, what guidance is available? How is the procedure re-engaged at the end of a hold? Using the Missed Approach procedure proficiency in re-initiating waypoint sequencing after the MAP, and in the guidance available for non-TF path terminators found in Missed Approach procedures activating the Missed Approach procedure before the MAP. Does the mode change from "APP/LNAV/LPV" to "MAPR" immediately? What guidance is provided to the MAP from a waypoint before the FAF?
4. Refresher of GNSS basics	 GNSS validation on start-up: Database currency and coverage. Self-test. Settings. SBAS NOTAMs. RAIM prediction GNSS essentials: forms of Integrity alert and other warning messages. CDI scaling and mode annunciation. Recovering the flight plan if the GNSS receiver is powered down and restarted.

GNSS training

3. Training methods



- Receiver user manuals and other training products for non-commercial pilots tend to describe only the basics of how to load and fly a database procedure and the key operating functions (eg. RAIM prediction, alerts, CDI and mode activation)
- Proficiency to the level of depth described on the previous page is <u>probably best acquired</u>, initially, by using the manufacturer's simulator software, or the actual unit in Simulator mode if the software is not available
- Where actual procedures and airspace are not easily available for the flight training required, GNSS training will often be conducted in a synthetic training device with a suitable panel-mount receiver.
- However, this training will be more efficient and cost-effective if the pilot is already proficient in the GNSS topics described on the previous page
- · Our recommendation is that, prior to formal simulator or flight training, a pilot should
 - -re-read the user manual with particular emphasis on the operating features and functions highlighted in this manual
 - -spend at least 2-3 hours practising with the simulator software: firstly creating scenarios with suitable procedures (and with the paper charts to hand) and then 'flying' those scenarios on the software simulator, becoming proficient in the training objectives described on the prior page
- The training objectives in the prior page are also ones we recommend instructors and flight schools include in GNSS, PBN and RNP ground, simulator and flight training

Example: studying Fly-By turns for the Garmin 430/530



Garmin manual extract and illustrative simulator software screenshots

APPENDIX C MAP DATUMS

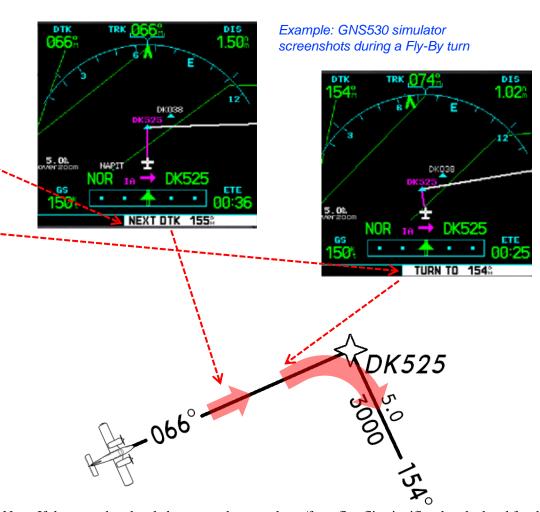
When does turn anticipation begin, and what bank angle is expected?

The GNS 530 smooths adjacent leg transitions based upon a nominal 15° bank angle (with the ability to roll up to 25°) and provide three pilot cues for turn anticipation:

- A waypoint alert ('NEXT DTK ###°) flashes in the lower right corner of the screen 10 seconds before the turn point (Figure C-6).
- A flashing turn advisory ('TURN TO ###°')
 appears along the bottom of the screen when the
 aircraft is to begin the turn. Set the HSI to the
 next DTK value and begin the turn.
- The To/From indicator on the HSI (or CDI) flips momentarily to indicate that the aircraft has crossed the midpoint of the turn. For more information on waypoint alerts and turn advisories, see Sections 6.2 and 6.3.

SECTION 16 – MESSAGES, ABBREVIATIONS, & NAV TERMS

Steep turn ahead - This message appears approximately one minute prior to a turn in one of the following three conditions: 1) the turn requires a bank angle in excess of 25° in order to stay on course, 2) the turn requires a course change greater than 175°, or 3) during a DME arc approach the turn anticipation distance exceeds 90 seconds.



Note: If the procedure level changes at the turn, the to/from flag flip signifies that the level for the next leg may be used.

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- 1. Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

Flight training

Training course objectives and structure



• Our recommendation is that a training course should have the following three parts:

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

- LNAV and associated lateral control techniques,
- 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 should, as a minimum, 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 may conduct classroom training to cover the required PBN material in this manual. This may involve several 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

Covering the four avionics topics detailed in Section 4 of this manual

Operational procedures

Covering section 3d of this manual, 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.



Our recommended content for these flight lessons is detailed in the next two pages

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 a high speed arrival Other items in accordance with the checklist or ops manual
2. RNAV 1 SID #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 1 STAR#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 1 SID #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 1 STAR#2 (autopilot) with continuous descent at required or maximum performance	 A RNAV 1 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 DME on the ILS The RNAV 1 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

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 1 SID (optional) Short cruise (optional) RNAV 1 STAR#3	 To include at least one RNAV 1 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 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 1 SID (optional) Short cruise (optional) RNAV 1 STAR#4	 As a minimum, this should include one RNAV 1/P-RNAV 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 1 operations, the course should be completed using an appropriate combination of representative PC GPS 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 1 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 Approach) and at least one tactical change (unplanned hold, change of RNAV procedure, vectors)

RNP Approach simulator and/or flight training Training course objectives and structure



• The training and operating requirements for RNP Approaches are detailed in Sections 3d and 5 of this manual and summarised in the table below. Our recommendation is that a training course should 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 only
- required navigation equipment for RNP NPAs

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

- LNAV and approaches with vertical guidance and associated control techniques,
- use of automatic pilot and flight director
- missed approach and contingency procedures (eq. 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 should, as a minimum, 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 may conduct classroom training to cover the key PBN material in this manual. This may require one or two 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

Covering the four avionics topics detailed in Section 4 of this manual

GNSS Operational procedures

Covering section 3d of this manual, 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 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.



Our recommended content for these flight lessons is detailed in the next two pages

PBN 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 the GNSS, as appropriate, for supplementary or primary guidance
3. RNP Non-Precision Approach #1 (manually flown)	 Pre-Arrival Selecting and checking the Approach procedure Determining the appropriate IAF Activation of the procedure and CDI scaling 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 at Derived Decision Altitude (ie MDA + allowance for sink) Flying the Missed Approach Activation of the Missed Approach procedure and the need to manually re-initiate waypoint sequencing Mode selection and pilot actions in non-RNAV missed approach segments
	Repositioning as required
4. LPV Approach (manually flown or using autopilot)	As above, but flying the glidepath
5. RNP Approach #3 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, emphasising that radio aids must be used as primary guidance for non-RNAV procedures

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 #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 of Lesson 2 may also include tactical changes if appropriate (unplanned hold, change of PBN procedure, vectors)
	Repositioning as required
3. GNSS contingencies: RNP Approach #5	 As a minimum, this should include 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 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)

Course contents



- PBN & RNP theory
 - Introduction to PBN
 - b. The Path-Terminator
 - c. PBN procedure design
- 2. GNSS
 - a. GNSS and the GPS system
 - b. RAIM
 - c. SBAS
 - d. Databases
 - e. Procedures
 - f. Error detection and warnings

- 3. RNP Approach Procedures
 - Classifications
 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
- 4. Avionics training
- Simulator and/or Flight training

Appendices

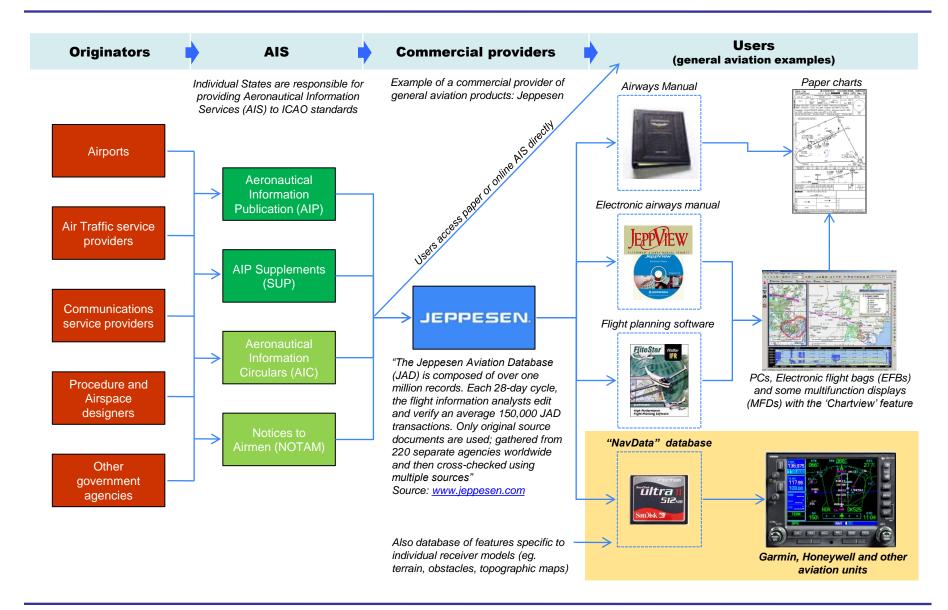
- 1. Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

Sources of navigation data



1. Concept of the "aeronautical data chain"

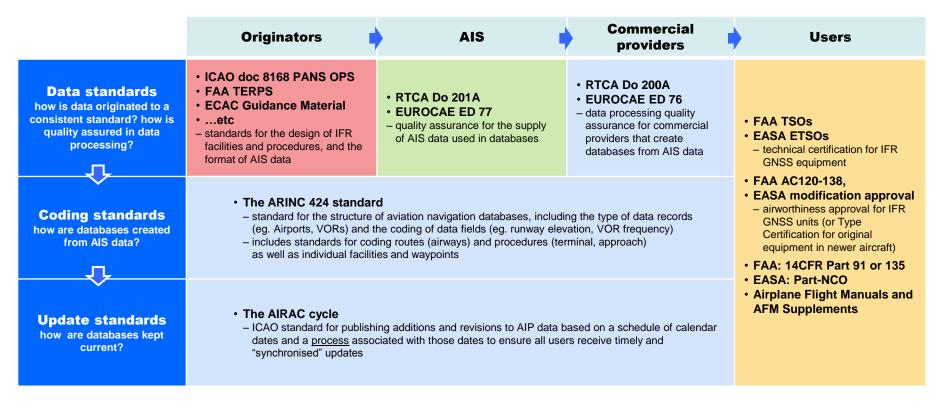


Sources of navigation data

PPL/IR EUROPE

2. 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'



- 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 will be on the basics of the Do200A/ED76 standards and the AIRAC cycle, and details of ARINC 424 relevant to users of GNSS equipment

What are the Do200A and ED76 standards?



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



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



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 (eg. see JAA TGL 9) 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 (from JAA TGL 9)
- 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.

Database Supplier approvals relating to Do200A and ED76 The 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 <u>specified</u> 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

Introduction to ARINC 424



- 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

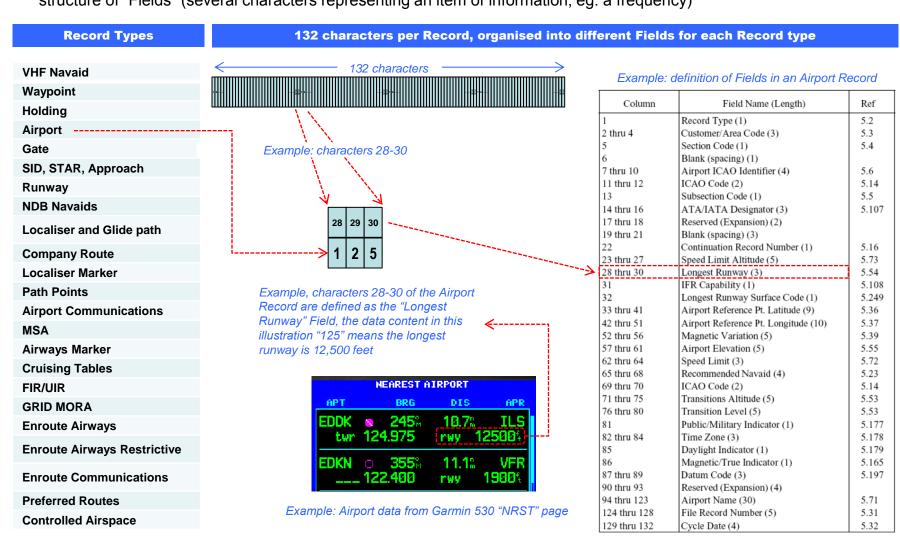


- The rest of this section will cover two ARINC 424 topics relevant to GA pilots
 - the structure of navigation databases and records
 - the conventions used for coding and naming database waypoints

ARINC 424: 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)



There are four kinds of ARINC 424 Record



"Points" **Routes Procedures** Examples: Examples: **VHF Navaid Company Route MSA** SID, STAR, Approach Wavpoint-FIR/UIR **Enroute Airways** Holding **Enroute Airways Restrictive GRID MORA** Airport **Preferred Routes** Runway Example: waypoint record included in route & procedure sequences **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 (eq. 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 associated records for individual runways, gates, ILS facilities etc.

- · 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

- Complex routes coded as a named sequence of Path-Terminators (see Section 1b)
- May include Speed and Altitude limits associated with each fix

Miscellaneous

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





- 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



IMPORTANT NOTE

 Most GNSS maps only 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

ARINC 424 coding: coordinates

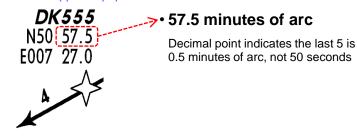


Coordinate fields in ARINC 424

- 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



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

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 <u>not</u> 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



1. 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	EGLL	
Daventry	DTY	DITY	
waypoint name is the same as identifier <	KENET	KENET	
Lambourne Three Alpha	LAM 3A	LAM3A	
a CNF created by the databa	G127		

• 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



An understanding of naming conventions and coding is essential for PBN operations

Why is an understanding of naming conventions and coding essential for PBN operations?



Example of an accident resulting in 160 fatalities



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	1 R
both in Colombia	APINIC 424 door not norm	t duplicate identifiers within

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

N651AA

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

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

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

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

"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."

"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 course through the FMS"

"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
- •14 years after the Cali accident, these issues are still very relevant to GNSS database users

2. Overview of databases identifiers

Published identifiers and database

identifiers are generally identical

NDBs)

· Note that some identifiers are not unique,

region (within Europe, mainly applies to

except within a country or geographic



"Points"	Routes and Procedures	Procedure Waypoints	
Airports • 4 letter ICAO identifier eg. EGLL • 'K' added to US 3 letter codes, eg. KLAX	 Airways Alphanumeric identifiers of 2-5 characters. But, not supported in most panel-mount GPS units 	Terminal waypoint names "Strategic" waypoints: • Terminal waypoints of major significance to ATC, often designating the start and end or routes and major transitions	
 VORs and VOR-DMEs Usually a 3 letter identifier eg. ABC Sometimes a 2 letter identifier, but no longer used for VORs in Europe 	 Terminal procedure names ARINC 424 permits alphanumeric identifiers of up to 6 characters (see page 80) The leading letters usually refer to a fix at the start 	 Use the 5LNC or the 3 letter identifier of a navaid "Tactical" waypoints: Terminal waypoints solely for use in the specific terminal area 	
NDBs 1, 2 or 3 letter identifier eg. A, AB, ABC	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"	 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 	
 Enroute waypoints 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 again 	 Approach procedure names 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' 	 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 (see later pages) 	
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	They may be specified as starting from an approach transition waypoint or starting with vectors to intercept the final approach track	 Approach waypoint names various – see next pages 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 (see later pages) using the Airport CNF convention 	
•	•	-	

Terminal procedure database identifiers are

published in [square brackets] on paper

Approach procedure identifiers are usually

but see page 92 for potential ambiguities

the same as the charted procedure names,

charts

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Procedure waypoint names are only unique

convention for CNFs

within a terminal area or for a particular airport

Note the similar format used for RNAV Tactical

waypoint identifiers and the Bearing/Distance



3. 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 that duplicate records exi Select the record with the geographic region 	ist for an identifier	 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 RN _n paper chart and radio ins		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		
Ţ	j	Garmin 530	examples		<u> </u>	
ARREST DUPLICATE HAVPOINT HPT AB NDB AUSTRIA NDB FRANCE Example: select geographic region from GNS530W list of duplicated records available for a given identifier selection	, ABSAM	FRED HX BRDCST 32 313.0 No me data for gross error check and radio cross-check	2.Select procedure to identifier 4.	RUNHAY ALL Loud? 1.Confirm airport ransition	Public APPROACH ILS BSU TRANS VECTORS BIG 16 BNN 16 EPM 16 LAM 18 2. Select procedure identifier – check list for multiple similar procedures	



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

1. When paper chart names are not suitable for ARINC 424

- 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

2. When waypoints are not named on paper charts, or where only a generic "label" is used

- 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

3. When a waypoint does not exist on paper charts, but is required for coding a procedure

- 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



5. Enroute waypoint naming

If an <u>enroute</u> 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 GOTON
 eq. 'CLEAR LAKE' becomes GLAKE

Jeppesen E(LO)2 low altitude

- B. If the 5LNC rule results in duplicate identifiers, a 4 letter name with a suffix number is used, eq.
- C. Where more than one short identifier is published, ARINC 424 uses a long name for one of the duplicates eq. R and R 0 M

If an <u>enroute</u> fix or intersection is published without a name

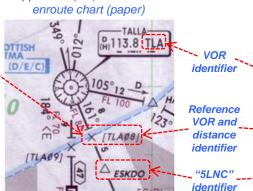
- The identifier is constructed from the identifier of, typically, the nearest airway VOR (which is the reference for the waypoint) and the distance from that VOR
- If the distance is less than 100nm, the identifier format is the three letters of the VOR ident followed by a two digit distance, eg a waypoint 35nm from "ABC" VOR: A B C 3 5
- 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:
- If unnamed waypoint is collocated with a named waypoint on a <u>different</u> route structure then the named waypoint's identifier is used

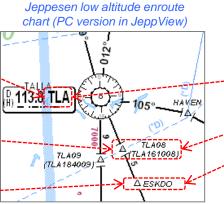


- European enroute charts have been updated with airway waypoint identifiers that are always compatible with ARINC 424, hence the paper charts and databases should be highly consistent
- The three formats used are navaid identifiers, 5LNCs and the 'reference VOR plus 2 digit distance'

Example of Airway waypoints

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







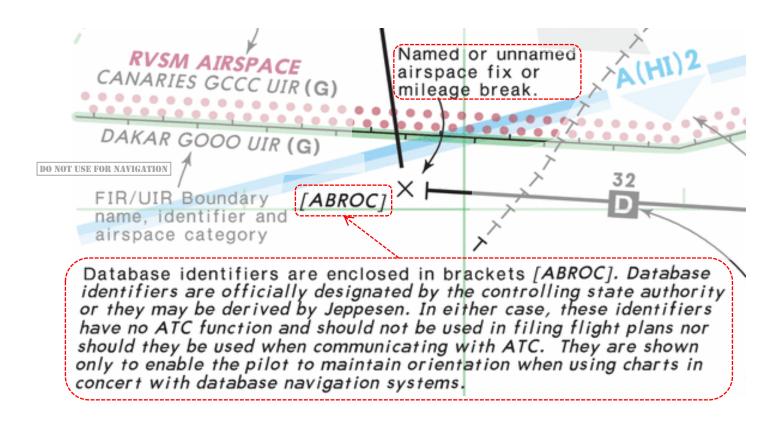
Garmin GNS480 airway route

DO NOT USE FOR NAVIGATION

Reference: extract from Jeppesen Enroute Chart legend



Source: Jeppesen Airway Manual Introduction section



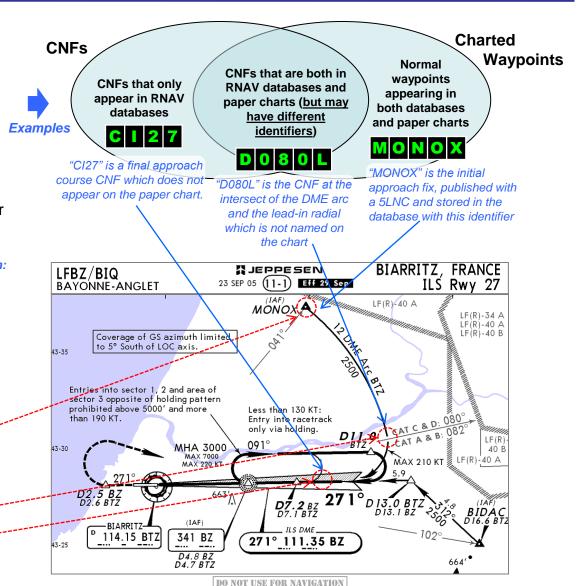
- Note: the nomenclature of waypoint names is sometimes confusing.
- "Database identifier" can be a generic term for the ARINC 424 short, coded name of any navaid, fix, airport etc.
- In the context of the chart legend above, "database identifier" means a Computer Navigation Fix name which is not part 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

ARINC 424 name and coding conventions 6. Introduction to Computer Navigation Fixes (CNF)



- CNFs are created when a waypoint required for coding Terminal or Approach Procedures is
 - either marked in paper charts without an identifier, or with an identifier too "generic" to meet ARINC 424 standards
- or 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

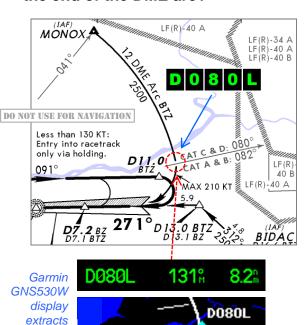
LFBZ ILS 27 Procedure. MONOX transition: Garmin GNS530W display extracts HONOX Other CNFs. DO80L see next pages Approach ILS 27 1310 is the initial MONOX 16 049⁶ tangential track along the DME dme arc 12.00 arc from MONOX 131° 8.2 D080L 271° 4.00



PPL/IR EUROPE

7. Procedure "bearing/distance" CNFs

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

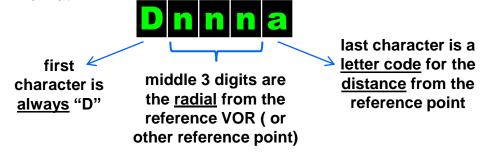






Procedure waypoint "bearing/distance" CNF convnetion

- 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:



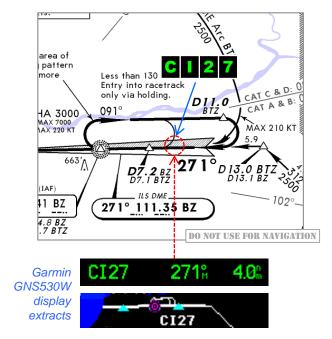
- The distance letter code is A=1nm, B=2nm....Z=26nm
- Distances are rounded to the nearest integer (i.e. A is used for 0.1nm to 1.4nm, B for 1.5nm to 2.4nm etc)
- If the distance is greater than 26nm, the Enroute waypoint convention is used (3 letters of the VOR ident plus 2 digit distance)
- The A-F 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 within a TMA

ARINC 424 name and coding conventions



8. Airport CNFs

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





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:

1st letter defines ¹ the waypoint type

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

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

2 digits are the runway identifier

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



- In the "Cl27" example above, the "C" indicates a final approach course 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 "Cl27" associated with LFBZ. Many other airports, including ones in the same TMA, can have an identically named CNF

ARINC 424 name and coding conventions 9. Airport CNF codes



A single approach procedure exists for a given runway

<u>First two</u> characters of the CNF identifier are the Waypoint Type

identifier are the maybe	, , , ,
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

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

<u>First</u> 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

	ILS Approach
L	Localiser Approach
_D	VOR/DME Approach
_V	VOR Approach
_N	NDB Approach
_Q	NDB/DME Approach
_R	RNP APCH
_P	GPS 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

used

to a runway, so no need

for a single

letter code

Reference: extract from Jeppesen NavData documentation



Source: www.jeppesen.com > GPS NavData Services > Documentation and Support

	Full List of 25 Approach types
Α.	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
Н.	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
٧.	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					
IAF IF FACF FAF MAP TDP RCI Step-Down	ILS(I) AI II CI FI MI TI RI SI	ILS(L) AL IL CL FF ML TL RL SL	ILS(B) AB IB CB FB MB TB RB SB	VOR(D) AD ID CD FD MD TD RD SD	VOR(V) AV IV CV FV MV TV RV SV	VOR(S) AS IS CS FS MS TS RS SS
IAF IF FACF FAF MAP TDP RCI Step-Down	NDB(N) AN IN CN FN MN TN EN SN	NDB(Q) AQ IQ CQ FQQ MQ RQ RQ SQ	MLS(M) AM IM CM FM MM TM RM SM	RNAV(R) AR IR CR FR MR TR RR SR	TACAN(T) AT IT CT FT MT TT RT ST	LORAN(C) AC IC CC FC MC TC RC SC
IAF IF FACF FAF MAP TDP RCI Step-Down	IGS(G) AG IG CG FG MG TG RG SG	LDA(X) AX IX CX FX MX TX RX SX	SDF(Z) AZ IZ CZ FZ MZ TZ RZ SZ	FMS (F) 1F 2F 3F 4F 5F 6F 7F 8F	GPS(P) AP IP CP FP MP TP RP SP	HEL(H) AH IH CH FH MH TH RH SH
IAF IF FACF FAF MAP TDP RCI Step-Down	VOR C-T-L(E) AE IE CE FE ME TE RE SE	NDB C-T-L(U) AU IU CU FU MU TU RU SU	CCC-L(J) AJ JCJFJ MJ RJ RJ RJ	BAC C-T-L(K) AK IK CK FK MK TK RK SK	MLS (W) AW IW CW FW MW TW RW SW	MSL (Y) AY IY CY FY MY TY RY SY

ARINC 424 name and coding conventions

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10. 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		
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)	& identifier usually one symbol	
Waypoint	In general, any of the above, also locations of a radio aid. Sometimes specifically an RNAV waypoint	Any of the above	used for all fix and waypoint types,	
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	except radio aids	
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	the published name, will be in [square brackets]		

Approach waypoints

Term	Definition	Traditional procedure	PBN procedure
IAF	Initial Approach Fix, Intermediate	Δ	\Leftrightarrow
IF	Fix and Missed Approach Point definitions are exactly the same in PBN procedures as in	& name	& name
MAP (or MAPt)	'traditional' IFR approaches	symbol & name	symbol & name
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, refix, but a DME dismarked at the FA In databases, an defined at the FA	stance may be AP "FF/F_" CNF is
FAF	Final Approach Fix – used only in a non-precision approach (NPA), the fix which defines the start of the descent to MDA/MDAH	Fix and fix name paper charts and be a CNF identifi NPAs without a fix based only on timin "FF/F_" CNF define	databases (may er for a DME fix) (eg. NDB approach g) will have a
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			



- This completes the Databases and Coding section
- The next section will review how ARINC 424 is used to code both traditional procedures (the "database overlay") and PBN procedures, and how GNSS units provide procedure guidance

Course contents



- 1. PBN & RNP theory
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 - c. SBAS
 - d. Databases
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- 3. RNP Approach Procedures
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 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
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- Simulator and/or Flight training

Appendices

1. Database Coding and Naming Conventions

2. PBN Learning Objectives

Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations



- This appendix lists the Learning Objectives (LOs) of the EASA IR 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 AMC to EASA Part-FCL (Amendment 4, 08/02/2018). 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 IR, 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 3. We have kept explanation of such topics to an absolute minimum, so that you have enough information to pass any relevant exam questions.



Section	Learning Objective	Page
P	BN 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)	21
	State that these RNAV and RNP systems are necessary to optimise the utilisation of available airspace	8
	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	13
	Define accuracy as the conformance of the true position and the required position	21
	Define continuity as the capability of the system to perform its function without unscheduled interruptions during the intended operation	21
	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	21
	State that, unlike conventional navigation, performance-based navigation is not sensor specific	11
	Explain the difference between raw data and computed data	200
	Define availability as the percentage of time (annually) during which the system is available for use	59



Section	Learning Objective	Page
PBN components	List the components of PBN as NAVAID infrastructure, navigation specification and navigation application	12
PBN scope	State that in oceanic/remote, enroute and terminal phases of flight, PBN is limited to operations with linear lateral performance requirements and time constraints	11
	State that in the approach phases of flight, PBN accommodates both linear and angular laterally guided operations, and explain the difference between the two	11
	Navigation Specifications	
RNAV and RNP	State the difference between RNAV and RNP in terms of the requirement for on- board performance monitoring and alerting	10,13
Navigation functional requirements	List the basic functional requirements of RNAV and RNP specifications (continuous indication of lateral deviation, distance/bearing to active waypoint, groundspeed or time to active waypoint, navigation data storage and failure indication)	67
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	13



Section	Learning Objective	Page
Designation of RNP and RNAV specifications	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	13
•	State that RNAV 10 and RNP 4 are used in the oceanic/remote phase of flight	16, 18
	State that RNAV 5 is used in the enroute and arrival phase of flight	16, 19
	State that RNAV 2 and RNP 2 are also used as navigation specifications	16, 19, 18
	State that RNP 2 is used in the enroute, and oceanic/remote phases of flight	16, 18
	State that RNAV 2 might be used in the en-route continental, arrival and departure phases of flight	16, 19
	State that RNAV 1 and RNP 1 are used in the arrival and departure phases of flight	16, 19, 20
	State that RNP APCH is used in the approach phase of flight	14, 15
	State that RNP AR APCH is used in the approach phase of flight	16, 202
	State that RNP 0.3 navigation specification is used in all phases of flight except for oceanic/remote and final approach, primarily for helicopters	16
	State that RNAV 1, RNP 1 and RNP 0.3 may also be used in en-route phases of low-level instrument flight rule (IFR) helicopter flights	16



Section	Learning Objective	Page
	Use of PBN	
Specific RNAV and	Recognise the definition of an RF leg	24,37
RNP system functions	Recognise the definition of a fixed radius transition (FRT)	17
	State the importance of respecting the flight director guidance and the speed constraints associated with an RF procedure	37
	Explain the difference between a fly-by-turn and a flyover	28,29
	State that the Aeronautical Radio, Incorporated (ARINC) 424 path terminators set the standards for coding the SIDs, STARs and instrument approach procedures (IAPs) from the official published government source documentation into the ARINC navigation database format	23
	State that the path terminators define a specific type of termination of the previous flight path	24,25
	Recognise the definition of an 'offset flight path'	200



Section	Learning Objective	Page
	PBN Operations	
PBN principles	Define 'path definition error' (PDE)	21
	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	21
	Define 'navigation system error' (NSE) and state that the accuracy of a navigation system may be referred to as NSE	21
	Define 'total system error' (TSE) and state that the geometric sum of the PDE, FTE and NSE equals the TSE	21
	State that navigation accuracy depends on the TSE	21
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	112
	State that on board performance monitoring and alerting of navigation system error is a requirement of on-board equipment for RNP	113
	State that, dependent on the navigation sensor, the estimated position error (EPE) is compared with the required navigation specification	21
	Explain how a navigation system assesses the EPE	21
	Give an example of how the loss of the ability to operate in RNP airspace may be indicated by the navigation system	149 (LPV to LNAV)
	State that on board performance monitoring and alerting of path definition error are managed by gross reasonableness checks of navigation data	112



		Page		
Section	Learning Objective			
Abnormal situations	State that abnormal and contingency procedures are to be used in case of the loss of PBN capability			
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			
Requirements	s of specific RNAV and RNP specificati	ions		
RNAV10	State that RNAV 10 requires that aircraft operating in oceanic and remote areas be equipped with at least two independent and serviceable LRNSs comprising an INS, an IRS FMS or a GNSS	18		
	State that operators may extend their RNAV 10 navigation capability time by updating	18		
RNAV5	State that manual data entry is acceptable for RNAV 5			
RNAV/RNP1/2	State that pilots must not fly an RNAV/RNP 1/2 SID or STAR unless it is retrievable by route name from the on- board navigation database and conforms to the charted route	18		
	State that the route may subsequently be modified through the insertion (from the database) or deletion of specific waypoints in response to ATC clearances	76		
	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	76		



Section	Learning Objective	Page
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	76
	State that an RNP APCH to LNAV minima is a non-precision instrument approach procedure designed for 2D approach operations	123
	State that an RNP APCH to LNAV/VNAV minima has lateral guidance based on GNSS and vertical guidance based on either SBAS or BaroVNAV	197
	State that an RNP APCH to LNAV/VNAV minima may only be conducted with vertical guidance certified for the purpose	197
	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	197
	State that the correct altimeter setting is critical for the safe conduct of an RNP APCH using BaroVNAV	197
	State that an RNP APCH to LNAV/VNAV minima is a 3D operation	123
	State that an RNP APCH to LPV minima is a 3D operation	123
	State that RNP APCH to LPV minima requires a FAS datablock	196
	State that RNP approaches to LPV minima require SBAS	124
	State that the FAS data block is a standard data format to describe the final approach path	196



Section	Learning Objective			
RNP AR APCH	State that RNP AR APCH requires authorisation			
A-RNP	State that Advanced RNP incorporates the navigation specifications RNAV5, RNAV 2, RNAV 1, RNP 2, RNP 1 and RNP APCH			
PBN Point in Space	State that a PinS departure is a departure procedure designed for helicopters only	198		
(PinS) Departure	State that a PinS departure procedure includes either a 'proceed VFR' or a 'proceed visually' instruction from landing location to initial departure fix (IDF)	198		
	Recognise the differences between 'proceed VFR' and 'proceed visually' instruction	198		
PBN Point in Space (PinS) Approach	State that a PinS approach is an instrument RNP APCH procedure designed for helicopter only and that may be published with LNAV minima or LPV minima	199		
	State that a PinS approach procedure includes either a 'proceed VFR' or a 'proceed visually' instruction from the MAPt to a landing location	199		
	Recognise the differences between 'proceed VFR' and 'proceed visually' instruction	198		

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Appendices

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- 2. PBN Learning Objectives
- 3. Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations



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.



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.
 - 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 17

See also http://www.eurocontrol.int/sites/default/files/publication/files/2013-introducing-pbn-a-rnp.pdf



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).

Course contents



- 1. PBN & RNP theory
 - Introduction to PBN
 - b. The Path-Terminator
 - c. PBN procedure design
- 2. GNSS
 - a. GNSS and the GPS system
 - b. RAIM
 - c. SBAS
 - d. Databases
 - e. Procedures
 - f. Error detection and warnings

- 3. RNP Approach Procedures
 - Classifications
 - b. Approach types
 - c. Requirements and approvals
 - d. Approach operations
- Avionics training
- Simulator and/or Flight training

Appendices

- 1. Database Coding and Naming Conventions
- 2. PBN Learning Objectives
- Additional items mentioned in the PBN Learning Objectives

Glossary of Abbreviations

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.

2D	Two Dimensional				
3D	Three Dimensional				
5LNC	Five-Letter Name-Codes	80			
ADF	Automatic Direction Finder				
AF	Arc to a Fix	25			
AFM	Aircraft Flight Manual				
AIM	Aeronautical Information Manual (FAA)				
AIRAC	Aeronautical Information Regulation And Control	69			
AIS	Aeronautical Information Service				
AOPA	Aircraft Owners and Pilots Association				
APCH	Approach	16			
APR	Approach	135			
APV	Approach with Vertical Guidance				
ARINC	Aeronautical Radio Inc	167			
A-RNP	Advanced RNP	201			
ATC	Air Traffic Control				
ATS	Air Traffic Services				
BIH	Bureau International de l'Heure	53			
BIPM	Bureau International des Poids et Mesures	48			
BPSK	Binary Phase Shift Keying	45			
B-RNAV	Basic Area Navigation	13			
C/A	Coarse/Acquisition	45			
CA	Course to Altitude	25			
CAA	Civil Aviation Authority				
CD	Course to DME Distance	25			
CDA/CDFA	Constant Descent (Final) Approach				
CDI	Course Deviation Indicator				
CF	Course to Fix	24			
CFR	Code of Federal Regulations (FAA)				
CI	Course to an Intercept	25			
CNF	Computer Navigation Fix	74			

CR	Course to Radial	25				
CRC	Cyclic Redundancy Check	196				
CS	Control Segment					
CTP	Conventional Terrestrial Pole					
DA	Decision Altitude					
DF	Direct to Fix					
DIS	Distance (to next waypoint)	145				
DME	Distance Measuring Equipment					
DP	Departure Procedure	77				
DTK	Desired Track	171				
EASA	European Aviation Safety					
	Agency					
EGM96	Earth Geodetic Model 96	56				
EGNOS	European Geostationary	65				
	Navigation Overlay Service					
ENR	Enroute	135				
ETA	Estimated Time of Arrival					
ETSO	European Technical Standard Order					
EU	European Union					
FA	Fix to an Altitude	24				
FAA	Federal Aviation Authority (US)					
FAF	Final Approach Fix	127				
FAS	Final Approach Segment	196				
FC	Fix to a Distance	24				
FD	Fix to a DME Distance	24				
FD	Fault Detection	62				
FDE	Fault Detection and Exclusion	62				
FM	Fix to Manual termination	25				
FMS	Flight Management System					
FRT	Fixed Radius Transition	197				
G/S	Glideslope					
GA	General Aviation					
GA	Go-Around					
GAGAN	GPS Aided GEO Augmented Navigation	64				
GBAS	Ground-based Augmentation System	64				
GDOP	Geometric Dilution of Precision	58				

GLONASS	Global Navigation Satellite	43			
	System				
GLS	GNSS Landing System				
GNSS	Global Navigation Satellite	43			
	System	43			
GPS	Global Positioning System				
GPSS	GPS Steering	29			
GS	Groundspeed				
HA	Racetrack to Altitude	26			
HAL	Horizontal Alarm Level				
HDOP	Horizontal Dilution of Precision	58			
HF	Racetrack to Fix	26			
НМ	Racetrack to Manual	26			
HPL	Horizontal Position Level				
IAF	Initial Approach Fix	128			
ICAO	International Civil Aviation				
	Organization				
IDF	Initial Departure Fix				
IF	Initial Fix	24			
IF	Intermediate Fix				
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	14			
L of A	Letter of Authorization				
L1	see page				
L2	see page				
L5	see page				
LDA	Localiser type Directional Aid				
LNAV	Lateral Navigation				
LNAV+V	Lateral Navigation + Advisory				
	Glidepath	166			
LoA	Letter of Acceptance				
LOI	Loss of Integrity	117			

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	Localizer Performance with Vertical Guidance	134			
MA	Missed Approach				
MAP or MAPt	Missed Approach Point				
MCA	Minimum Crossing Altitude	198			
MDA/H	Minimum Descent Altitude (Height)				
MEA	Minimum Enroute Altitude				
MNPS	Minimum Navigation Performance Specification				
MOC	Minimum Obstacle Clearance	32			
MSA	Minimum Sector Altitude				
MSAS	MTSAT Satellite Augmentation System	64			
MSL	Mean Sea Level				
NOTAM	Notice to Airmen				
NPA	Non Precision Approach				
NSE	Navigation System Error	21			
PA	Precision Approach				
PANS-OPS	Procedures for Air Navigation Services – Aircraft Operations				
PAR	Precision Approach Radar				
PBN	Performance Based Navigation	11			
PDE	Path Definition Error	21			
PDOP	Position Dilution of Precision	58			
PI	Procedure Turn	26			
PinS	Point in Space	198			
РОН	Pilot Operating Handbook				
PRN	Pseudorandom Number	45			
P-RNAV	Precision Area Navigation	19			
PSE	Path Steering Error	21			
PSK	Phase Shift Keying	45			
QNH	Atmospheric Pressure at MSL				
RAIM	Receiver Autonomous Integrity Monitoring	61			
RF	Radius to Fix	37			

RF	Radio Frequency	49			
RAIM	Receiver Autonomous				
	Integrity Monitoring				
RF	Radius to Fix	37			
RF	Radio Frequency	49			
RIMS	Ranging and Integrity	65			
	Monitoring Station				
RNAV	Area Navigation	7			
RNP	Required Navigation				
	Performance				
RNP AR	RNP Authorisation Required	202			
APCH	Approach				
RWY	Runway				
SBAS	Satellite based	64			
	Augmentation System				
SID	Standard Instrument				
	Departure				
SPS	Standard Positioning Service 45				
SRA	Surveillance Radar				
	Approach				
SS	Space Segment	44			
STAR	Standard Arrival				
STC	Supplemental Type				
	Certificate				
SV	Satellite Vehicle	44			
TC	Type Certificate				
TDOP	Time Dilution of Precision	58			
TERM	Terminal	135			
TERPS	Terminal Instrument	23			
	Procedures	0.4			
TF	Track to Fix	24			
TGL	Temporary Guidance Leaflet (JAA)				
TAI	International Atomic Time	48			
TMA	Terminal Manoeuvring Area				
TOA	Time of Arrival				
TOAC	Time Of Arrival Control	17			
TSE	Total System Error	21			
TSO	Technical Standard Orders				

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UERE	User Equivalent Range Error					
UK	United Kingdom (Britain)					
US	United States					
US	User Segment	44				
UT1	Earth Time	48				
UTC	Universal Co-ordinated Time					
VA	Heading to Altitude	25				
VAL	Vertical Alarm Level					
VD	see page	25				
VDOP	Vertical Dilution of Precision	58				
VFR	Visual Flight Rules					
VI	see page 26					
VLOC	VOR/Locator					
VM	Heading to DME Distance 2					
VMC	Visual Meteorological Conditions					
VNAV	Vertical Navigation	11				
VOR	VHF Omnidirectional Range					
VPL	Vertical Position Level					
VR	Heading to Radial	26				
WAAS	Wide Area Augmentation System	64				
WFDE	WAAS RAIM Fault Detection & Exclusion	119				
WGS84	World Geodetic System datum 1984	53				
WIDN	What's it doing now?	41				



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