# PPL/IR Europe

# RNAV Training Manual

**Vasa Babic**

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**http://www.pplir.org**

# Introduction

- This manual covers the RNAV theoretical knowledge and ground training for an Instrument Rated pilot operating single-pilot general aviation aircraft under IFR in Europe, specifically
  - to meet the requirements of JAA TGL10 and FAA AC90-96A for P-RNAV qualification
  - to meet various national requirements or recommendations for flying RNAV(GPS) Approaches, eg. UK CAA CAP 773
- The manual also has a recommended syllabus to meet flight training requirements for P-RNAV and RNAV(GPS) Approaches
- It is intended to be used in a classroom training seminar, distance-learning course or for self-study

- Some of the detailed content and reference material is beyond the scope of what is required for pilot training. The pages of the document are coded, in the top right corner, as follows:

**P**

*Indicates that page content is required for P-RNAV training based on this Manual*

**A**

*Indicates that page content is required for GPS Approach training based on this Manual*

**P A**

*Indicates that page content is required for both P-RNAV and GPS Approach training based on this Manual*

*Indicates that page content is not essential for a training course*
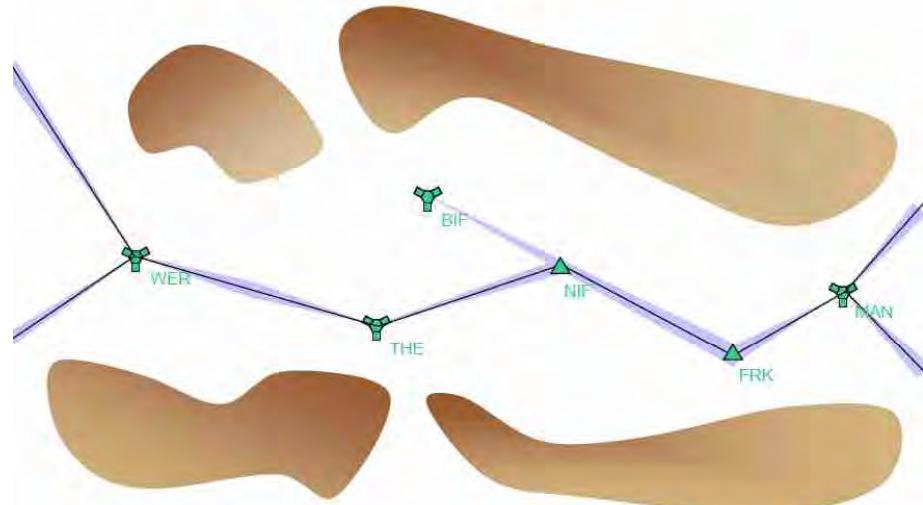
# Acknowledgements and notes

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- The author would like to thank Mr. Julian Scarfe for reviewing this document in detail and for his very knowledgeable feedback. Errors and omissions are entirely the author's responsibility

- *The document, in PDF form, is available for free to the aviation community. If you find this material valuable, you are asked to:*
  - *please consider joining and/or donating to PPL/IR Europe (www.pplir.org). This small voluntary organisation serves GA IFR pilots in Europe by publishing and exchanging information to help promote the safety and utility of IFR flight in single-pilot aircraft, and works with regulators in Europe to ensure they have input on the specialised needs of private IFR from a credible and qualified source*
  - *please also 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*
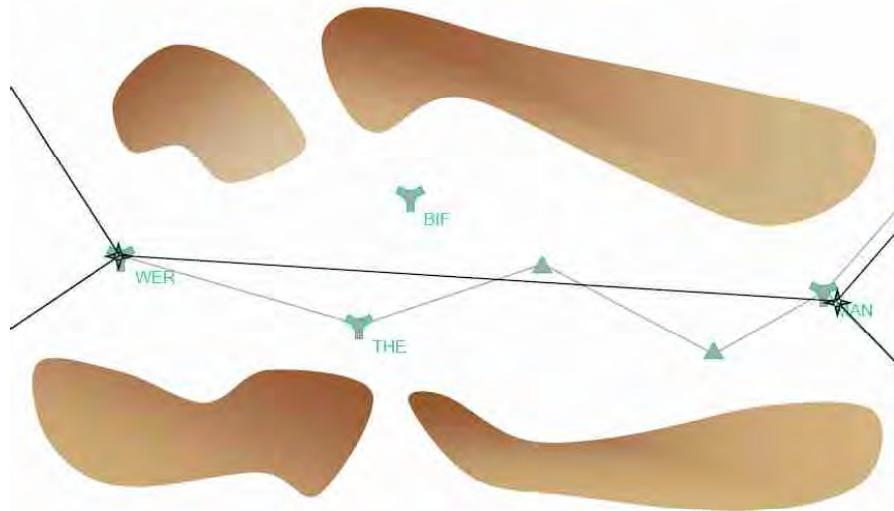
# What is the basic concept of RNAV?

**"Traditional" IFR Navigation**

**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 panel-mounted GPS. Transport aircraft also use Inertial Reference and DME-DME in multi-sensor Flight Management Systems (FMS)
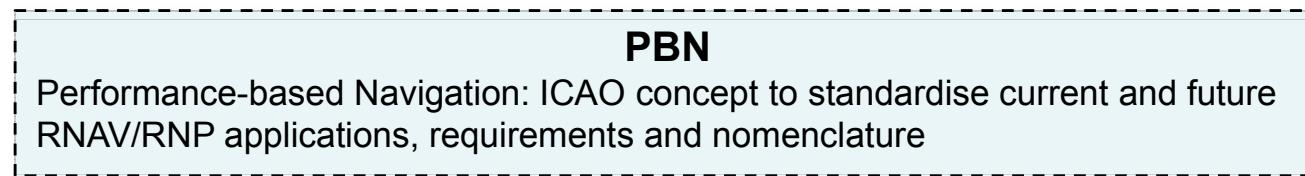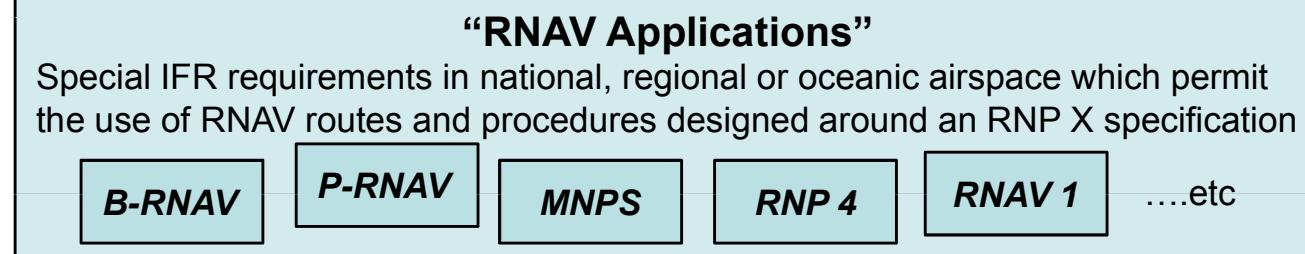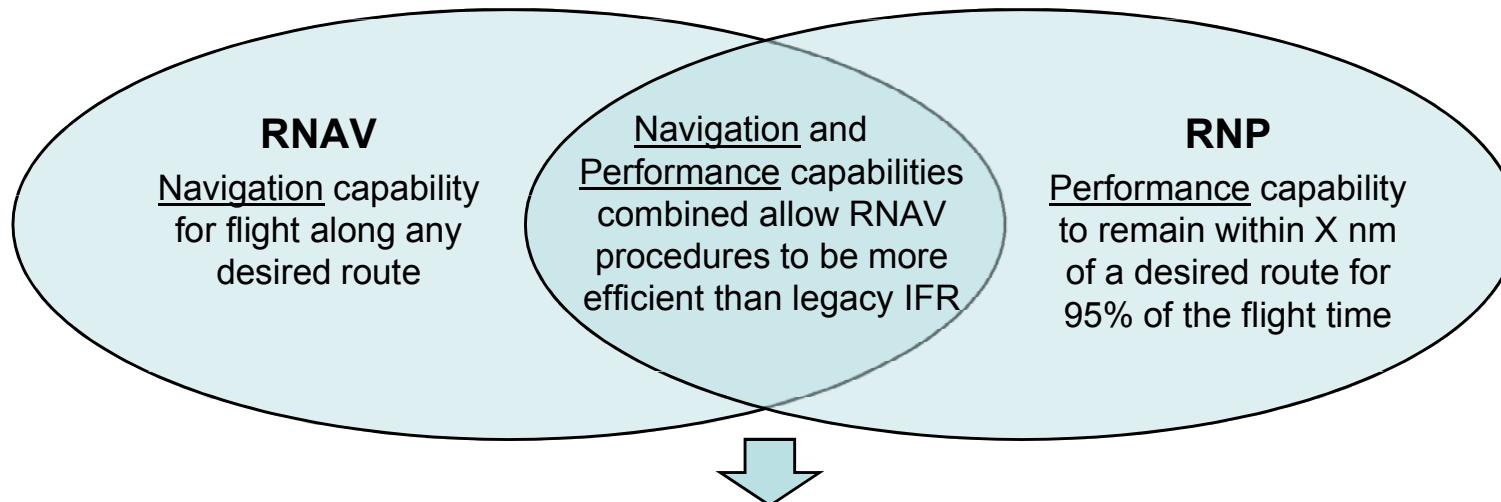
Source: charts from the ICAO Performance Based Navigation manual, Draft March 2007

# 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 fuel-efficient descent management

- However, to date, 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. B-RNAV and P-RNAV in Europe, MNPS in the North Atlantic, RNAV 1 and RNAV 2 in the US

# What is RNP (Required Navigation Performance) ?

- RNP terminology can be confusing, because it means slightly different things in different contexts

- RNP, *conceptually,* is "a measure of the navigation performance accuracy necessary for operation within a defined airspace"

- RNP, as a *performance specification,* is a measure 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 "RNP-X" where the "X" may be, for example, 5nm

- RNP is also used as the name for *RNAV applications* that include a specific RNP-X requirement
  - For example, RNP 10 is the name for an Oceanic RNAV application. Aircraft operating on routes designated as RNP 10 must conform to a variety of equipment, crew and operator approval requirements.
  - However, RNAV application names are not standardised: in the North Atlantic, the RNAV application is very similar to RNP 10, but it is called "Minimum Navigation Performance Specifications" (MNPS). Europe and the USA both have Terminal RNAV applications based on RNP-1, but they are called P-RNAV and RNAV 1 respectively

- ICAO is in the process of standardising RNAV and RNP applications and specifications. The general term for this is "Performance Based Navigation" (PBN); this will change, and in some cases replace, the use of RNP concepts

# Summary of concepts
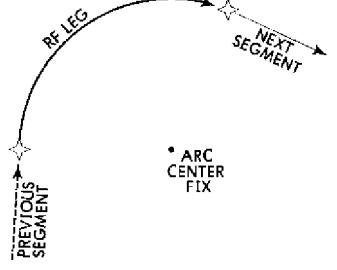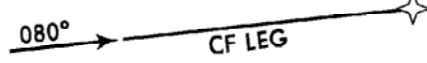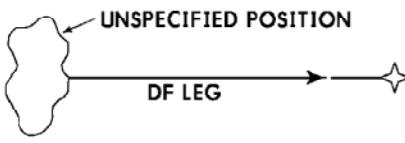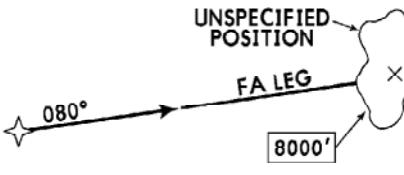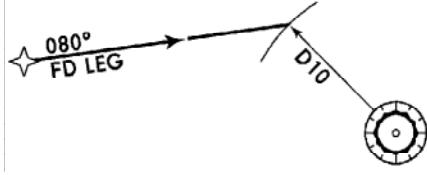
**RNAV**

Navigation capability for flight along any desired route

Navigation and Performance capabilities combined allow RNAV procedures to be more efficient than legacy IFR

**RNP**

Performance capability to remain within X nm of a desired route for 95% of the flight time

**"RNAV Applications"**

Special IFR requirements in national, regional or oceanic airspace which permit the use of RNAV routes and procedures designed around an RNP X specification

| B-RNAV | P-RNAV | MNPS | RNP 4 | RNAV 1 | ….etc |

**PBN**

Performance-based Navigation: ICAO concept to standardise current and future RNAV/RNP applications, requirements and nomenclature

1. RNAV and RNP theory
   a. Introduction
   b. **The Path-Terminator**
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

# 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 <u>codify</u> 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" – 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**

- In a panel-mounted GPS Navigator, 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 path-terminators that make up the procedure. Note: some GPS units do not support all the leg types used at the start and end of RNAV procedures, or in an unpublished GPS "overlay"
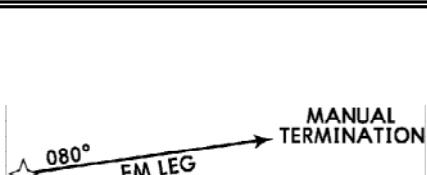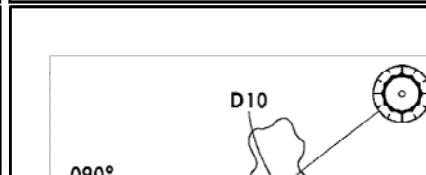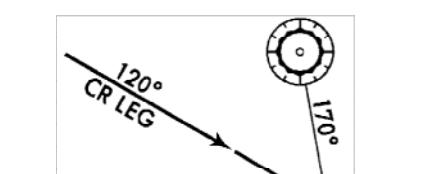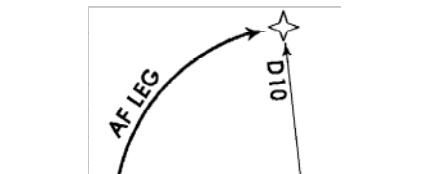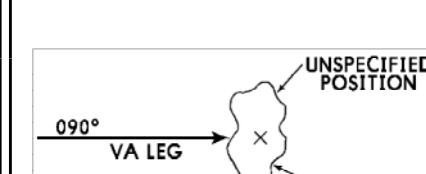
## IF leg type

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



## TF leg type

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



## RF leg type

- Constant Radius Arc Leg defines a constant radius turn between two database fixes, lines tangent to the arc and a center fix



## 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
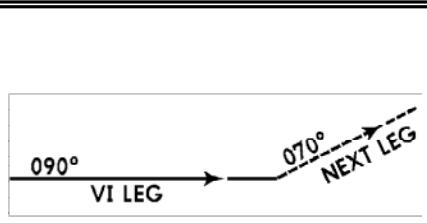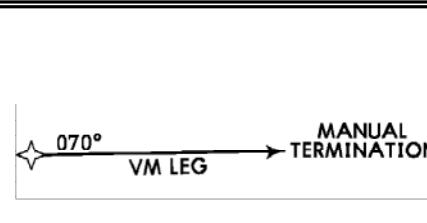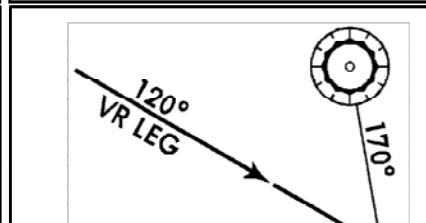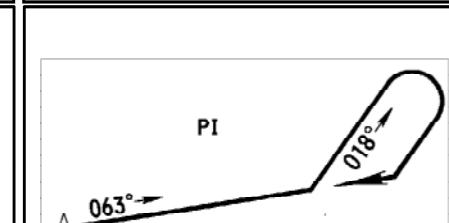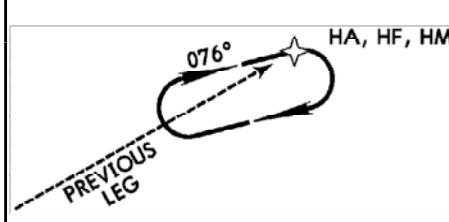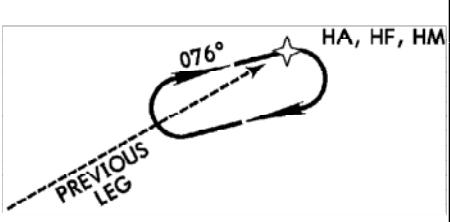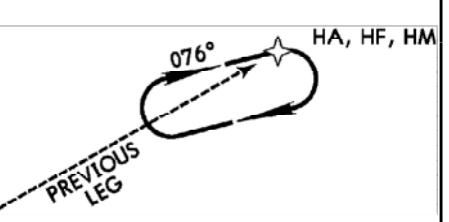
## FM leg type

- 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



## VD leg type

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

## 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

# The ARINC 424 "periodic table" of 23 Path-Terminator legs

## Paths

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

**Terminators**

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

14

# 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
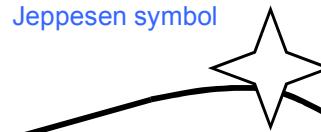
| Fly-By waypoint | Fly-Over waypoint |
|---|---|
| Jeppesen symbol     ICAO symbol<br><br>Note: Jeppesen sometimes depict the curved fly-by track, sometimes the two straight tracks are joined under the fly-by symbol | Jeppesen symbol     ICAO symbol<br><br>Note: radio aid or other symbols may be overlaid 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<br><br>• The aircraft navigation system calculates the start of the turn onto the next route leg before the waypoint<br><br>• 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<br><br>• The aircraft starts to turn onto the next route leg as it passes over the waypoint<br><br>• 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<br><br>• RNAV Procedure designers are increasingly avoiding the use of Fly-Over waypoints |
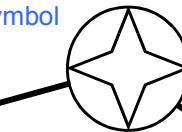
# Aircraft trajectory in Fly-By and Fly-Over waypoints

| Fly-By | Fly-Over |
|---|---|



*trajectory more consistent and controlled*

*trajectory less consistent and controlled*
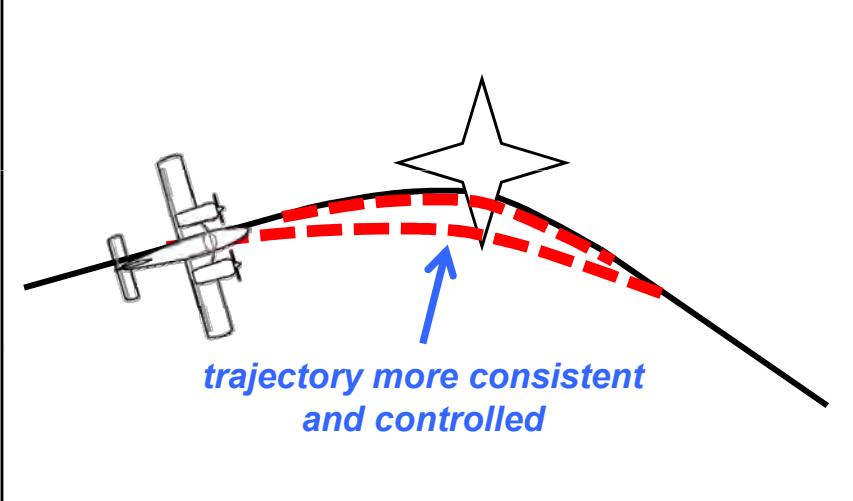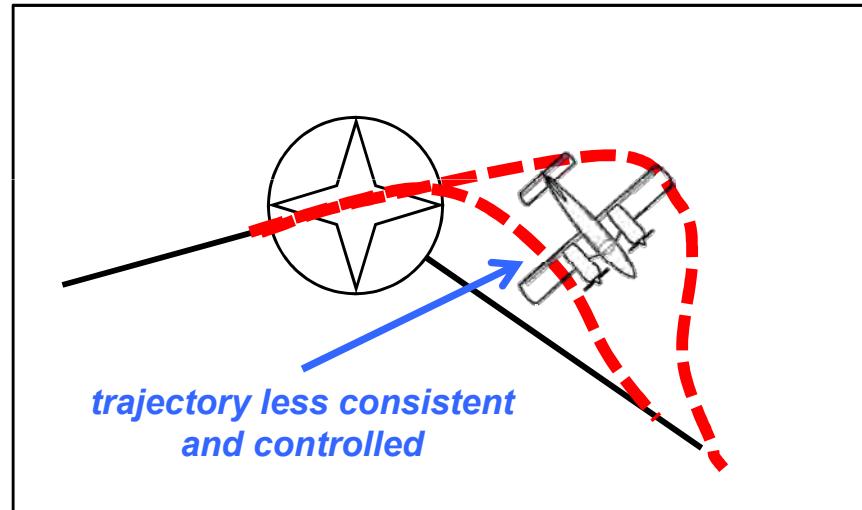
| | |
|---|---|
| • Turn is a Rate 1 curved path tangential to both the inbound and outbound track | • Turn consists of roll-in, Rate 1 turn, roll-out and intercept elements |

- Both types of trajectory are subject to variations in wind, aircraft speed and bank angle, navigation system logic and Pilot or Autopilot performance. However, flight paths resulting from Fly-By turns are, in practice, much more consistent and predictable, and thus preferred in RNAV procedure design (eg. they require a smaller protected area)

- **Although the Fly-By turn is a simple concept, it is important for the pilot to understand exactly how turns are annunciated and displayed on the GPS navigator 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**

# Course contents

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   e. RNAV and RNP applications

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# 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)

**Profile of Protected Area**
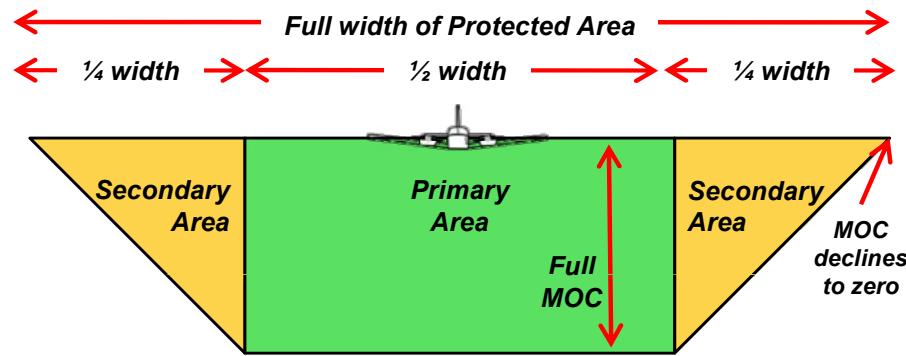
**Plan View of Protected Area**

Full width of Protected Area

¼ width    ½ width    ¼ width

Secondary Area

Primary Area

Secondary Area

Full MOC

MOC declines to zero

Secondary Area

Primary Area

Secondary Area
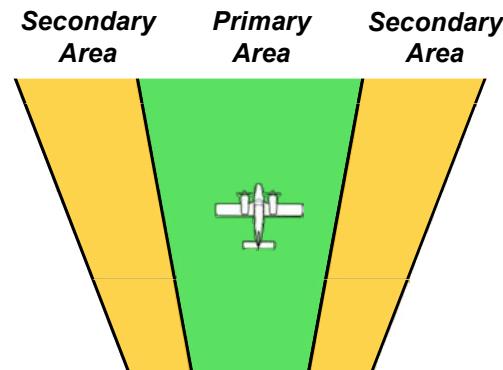
- The key design criteria is to provide safe obstacle and terrain clearance whilst an aircraft is flown in accordance with the published procedure
  - *horizontally*, within a Protected Area
  - *vertically*, with a specified Minimum Obstacle Clearance (MOC)

# 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

**Illustrative plan view of the Protected Area in a leg from a VOR**

*Protected Area widens at an angle of 7.8⁰ relative to the leg track, in the case of a VOR*

*The angle is 10.3⁰ for an NDB and 15⁰ for flying a heading*

*Protected Area width is initially 2nm*

*Note that fix tolerances are different from path tracking tolerances*
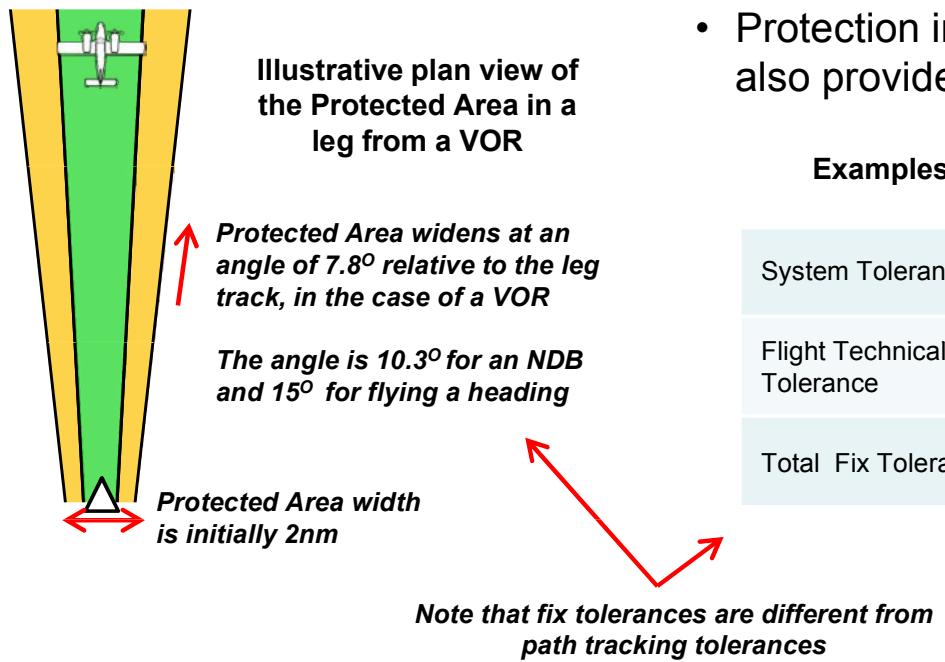
- Protection in a descent or a turn initiated at a fix is also provided by including a Fix Tolerance

| Examples | VOR | NDB | DME | LOC |
|---|---|---|---|---|
| System Tolerance | 4.5⁰ | 6.2⁰ | 0.25nm plus 1.25% of the DME distance | 1.4⁰ |
| Flight Technical Tolerance | 0.7⁰ | 0.7⁰ | | 1.0⁰ |
| Total Fix Tolerance | 5.2⁰ | 6.9⁰ | | 2.4⁰ |

*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)

Source: Jens Gerlev's book, "Instrument Flight Procedures"

- 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

**Illustration of traditional Fly-Over turn**

*"Nominal" track : ie. the zero error, zero wind track an aircraft would follow*

*Fix tolerance*

*Fix tolerance*

*Reaction time, 6s*

*Extra protected area required in traditional Fly-Over turns*
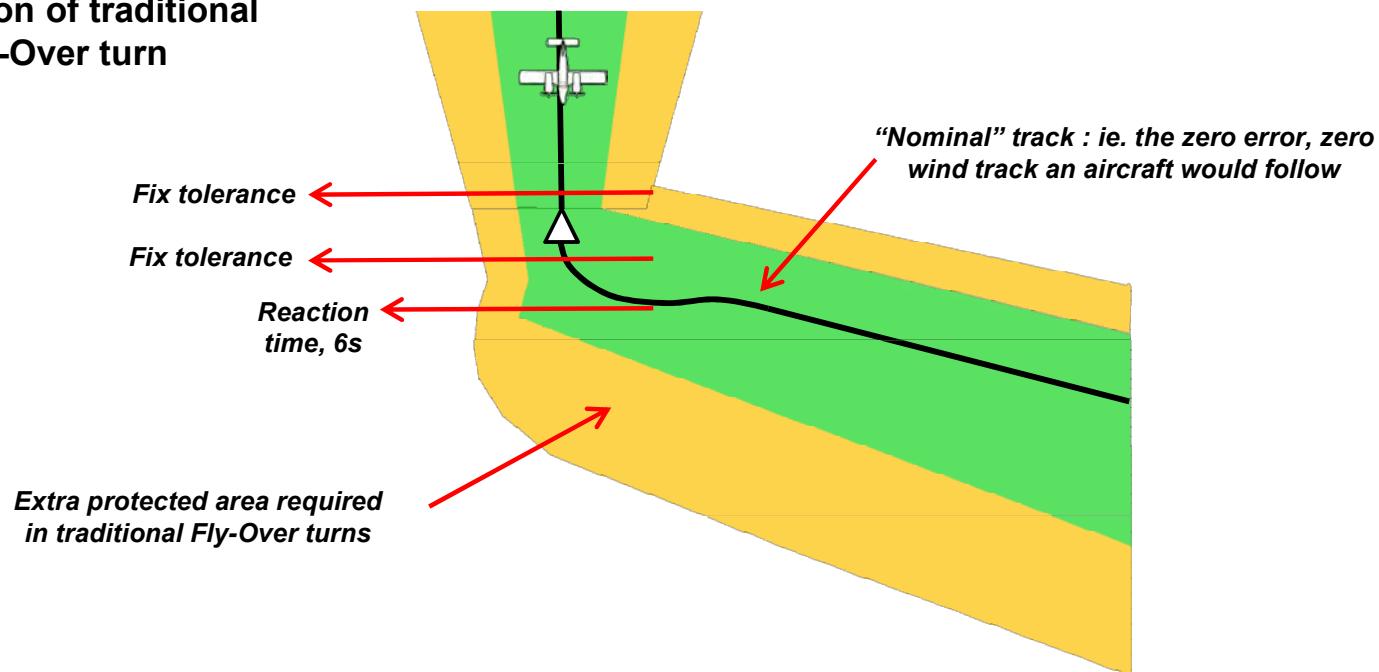
Source: Jens Gerlev, "Instrument Flight Procedures"

# 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 |
| B | 91-120 | 120-180 | 85-130 | 135 |
| C | 121-140 | 160-240 | 115-160 | 180 |
| D | 141-165 | 185-250 | 130-185 | 205 |
| E | 166-210 | 185-250 | 155-230 | 240 |

*All speeds are KT IAS*

- Most general aviation aircraft are Categories A or B. However, in busy Terminal airspace, ATC will often request a higher than normal speed from light aircraft. If appropriate, the pilot should also elect to follow a higher-Category procedure and observe the corresponding minima
    – note that GPS databases usually <u>only</u> include the Category C&D procedures

# How are RNAV Procedures different?
## 1. Definition of Protected Area based on RNAV system performance or RNP

| **Based on RNAV system type** | **Based on RNP** |
|---|---|

**Based on RNAV system type**

- RNAV procedures designated for specific navigation systems, eg

  - RNAV$_{(GNSS)}$

  - RNAV$_{(DME-DME)}$

  - RNAV$_{(EXCEPT\ CLASS\ A\ GNSS)}$

  *ie. FMS GPS only, not panel mount GPS*

- Each procedure type has a system-specific "semi area width", which is the lateral protection either side of the nominal track, eg. 3nm for GPS STARs

- Modern approach is to define procedures based on RNP, not on specific navigation systems

- Fix Tolerance is based on system-specific linear Along Track (ATT) and Cross-Track (XTT) tolerances, rather than angular splays

**Based on RNP**

- PANS OPS protected area width is 2x RNP + a buffer

- Buffer is 2nm for arrival, 1nm for initial and intermediate approach and 0.5nm for final, missed approach and departure

*Full width of Protected Area*

*buffer* — *4x RNP* — *buffer*

*Buffer Area* — *Buffer Area*

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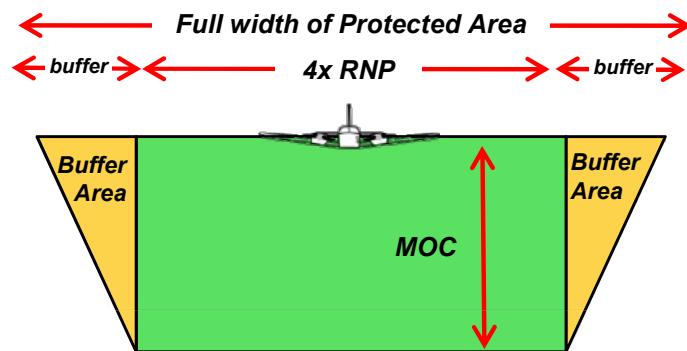
- Fix Tolerance is simply a 1x RNP radius around the waypoint

See the Eurocontrol publication "*Guidance Material for the Design of Terminal Procedures for Area Navigation*", at http://www.ecacnav.com/downloads/iss3_0.pdf
This is an excellent document, with detailed content on many topics that are only briefly touched upon in this manual. It is well worth downloading and saving as a reference.

# How are RNAV 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 RNP-X (eg. 1nm in P-RNAV)
  - aircraft turn at Rate 1 ($3^O$/sec), up to a maximum bank angle of $25^O$, whichever is lower
  - a 5 seconds allowance, from the time the aircraft's navigation system computes that a turn should start, for either the pilot or autopilot to react and to establish the appropriate bank angle

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

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



Illustration of a delay in initiating the turn until approx 1 minute after waypoint crossed

Secondary Area

Primary Area

Secondary Area

**Fly-Over**

Secondary Area

Primary Area

Secondary Area

**Fly-By**

Source:  based on diagrams in "*Guidance Material for the Design of Terminal Procedures for Area Navigation*", at http://www.ecacnav.com/downloads/iss3_0.pdf
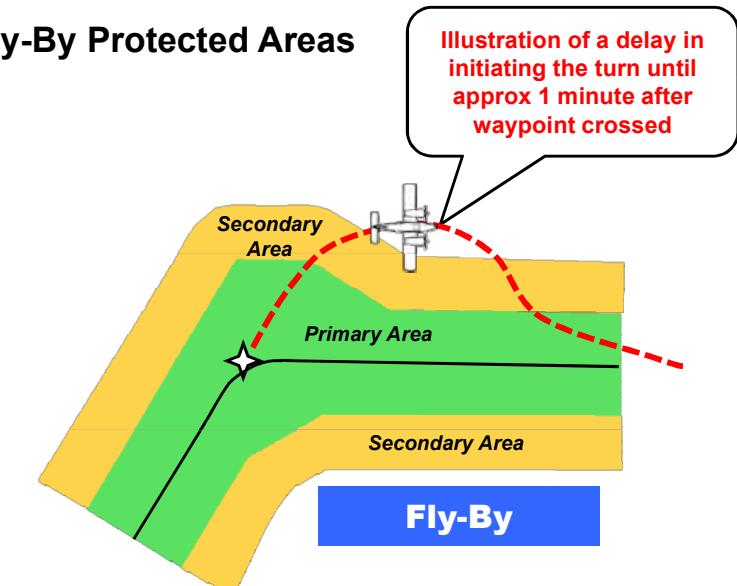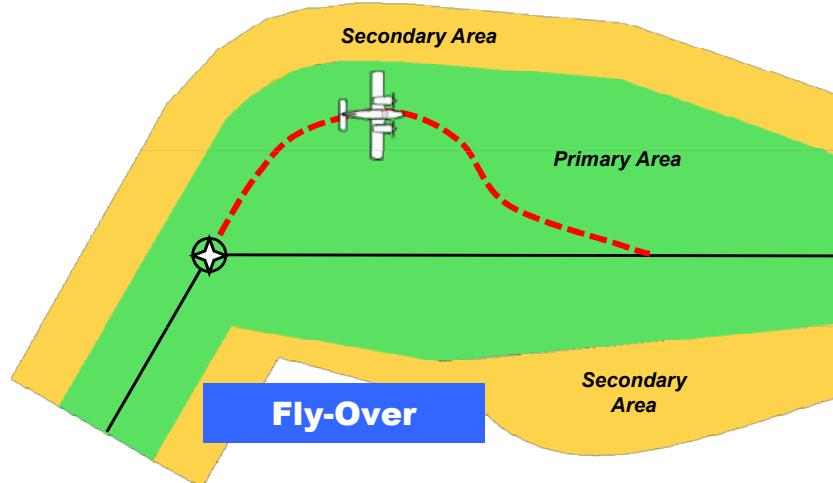
# How are RNAV Procedures different?
## 3. Procedures use only a few of the most "predictable" Path-Terminators



PPL/IR EUROPE

**Paths**

| Terminators | 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 | | |
| Manual Termination | | **FM** Fix to man. term. | | **VM** Heading to man. term. | | **HM** Racetrack to man. term. | | |
| Distance | | **FC** | | | | | | |
| DME Distance | | **FD** | **CD** | **VD** | | | | |
| Intercept | | | **CI** | **VI** Course to Intercept | | | | |
| Radial | | | **CR** | **VR** | | | | |
| Procedure Turn | **PI** | | | | | | | |

**Red:** "best practice" RNAV leg types

**Orange:** RNAV leg types used mainly at the start and end of procedures when required (eg. VA as the first leg of a SID)

**Blue:** non-RNAV leg types

# How are RNAV Procedures different?
## 4. There is a distinct RNAV procedure "style"

- "Style" features typical of RNAV procedures:

<table>
<tr>
<td><strong>"traditional" Entry Fix</strong></td>
<td>

- 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(GPS) approaches may require a user-defined check for gross error, since they often start with a 'pure' RNAV waypoint

</td>
<td>

TEKRU
524648.9N 0020050.9W
GAM R235.0/D49.0

Conventional initial fix

</td>
</tr>
<tr>
<td><strong>Use of many Waypoints</strong></td>
<td>

- 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

</td>
<td>

multiple waypoints

</td>
</tr>
<tr>
<td><strong>Turns are Fly-by</strong></td>
<td>

- 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

</td>
<td>

Fly-By

</td>
</tr>
<tr>
<td><strong>Legs are TF, except at the start/end of procedures</strong></td>
<td>

- TF (and, in the future, RF) legs are used to provide the most predictable flight paths and the most FMS/GPS-"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

</td>
<td>

TF

</td>
</tr>
<tr>
<td><strong>Many altitude and speed constraints</strong></td>
<td>

- 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

</td>
<td>

Examples:

3000 "or above"

4000
2000 "between"

3000 "at"

Max IAS
220KT  speed limit

3000 "or below"

IAS
180KT  speed target

</td>
</tr>
</table>

**Example: NEMAX2B trial P-RNAV Arrival to Rwy 27 ILS at Nottingham East Midlands (EGNX)**

*Extract from UK CAA AIP SUP S1/2008*

All turns are Fly-by

Many altitude and speed constraints

GAM 235 radial 49.0 DME

"traditional" Entry Fix

All legs are TF (after the IF)

Many Waypoints

DO NOT USE FOR NAVIGATION

Note: QNH setting instruction after passing waypoint

| Sequence Number | Path Term-inator | Waypoint Name | Course/Track°M (T°) | Turn Direction | Level Constraint | Speed Constraint | Co-ordinates DD°MM'SS.S" DDD°MM'SS.S" | Co-ordinates DD°MM.M' DDD°MM.M' | Remarks & Distance to Rwy |
|---|---|---|---|---|---|---|---|---|---|
| 001 | IF | LONLO | 056°M (052.8°T) | – | FL 190 MIN | – | 524649.0N 0020051.0W | 52468N 002009W | 52.7 nm |
| 002 | TF | NXN37 | 076°M (073.3°T) | R | FL 100 MIN | – | 525624.0N 0013957.0W | 52564N 001400W | 36.9 nm |
| 003 | TF | NXN31 | 110°M (106.5°T) | R | FL 120 MAX FL 70 MIN | – | 525812.0N 0013000.0W | 52582N 001300W | 30.6 nm |
| 004 | TF | NXN21 | 104°M (100.9°T) | L | FL 55 MIN | MAX 230 kt | 525530.0N 0011449.2W | 52555N 001148W | Set QNH 21.0 nm |
| 005 | TF | NXN13 | 183°M (180.0°T) | R | 4000 MIN | At 190 kt | 525400.0N 0010157.0W | 52540N 001020W | 13.1 nm |
| 006 | TF | NXN10 | 244°M (240.7°T) | R | 3500 MIN | – | 525109.0N 0010157.0W | 52512N 001020W | IAF 10.3 nm |
| 007 | TF | NEMAX | 271°M (268.3°T) | R | At 3000 | – | 525007.8N 0010457.5W | 52501N 001050W | IF 8.2 nm |
| 008 | TF | FAP ILS 27 | 271°M (268.3°T) | – | At 2000 | At 160 kt | 525002.4N 0010955.1W | 52500N 001099W | 5.2 nm |

## 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

**Example: Vertical profile of NEMAX1B trial P-RNAV Arrival procedure at Nottingham East Midlands (EGNX)**
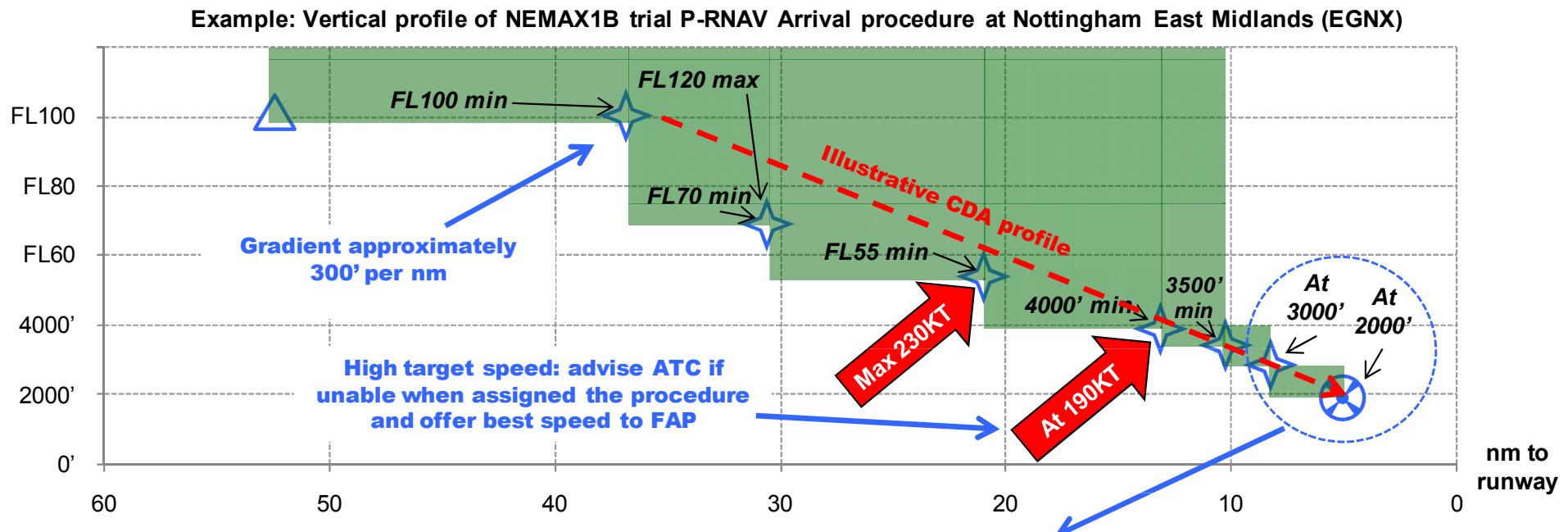


- Note the aircraft performance and pilot workload required during the transition to the final approach
  - descending at ~300' per nm whilst decelerating from 190KIAS (or speed attainable) to approach speed
  - no distinct level-off available for slowing down
  - cockpit transition of CDI, GPS course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

# How are RNAV Procedures different?
## Summary

| Traditional Procedures | RNAV Procedures |
|---|---|

- <u>Execution</u> is demanding
  - selecting, identing and displaying navaids
  - following track, distance and timing from raw data
  - repeated for each leg

- <u>Management</u> is easy
  - select the right chart and then follow the execution steps

- <u>Execution</u> is easy
  - following the GPS guidance from waypoint to waypoint

- <u>Management</u> is more complex
  - valid database, correct procedure loaded and verified
  - RAIM availability checked; GPS, CDI and Autopilot mode selection
  - avoidance of gross errors and "WIDN?" (what's it doing now?) confusion with GPS receivers

- The focus of most of the following sections of this course is on the proficient and safe *management* of RNAV flight

# Course contents

1. RNAV and RNP theory
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   b. The Path-Terminator
   c. RNAV procedure design
   **d. RNP principles**
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

# Objectives of the RNP concept

| Traditional procedure design | RNAV procedures pre-RNP | RNP procedure design |
|---|---|---|
| • Standard infrastructure of ground radio aids<br><br>• Aircraft carry a standardised suite of navigation receivers and instruments<br><br>• Procedure tolerances designed around these standards | • Proliferation of different RNAV navigations systems<br><br>• 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<br><br>• Procedure design increasingly complex and restricted | • Standard performance specifications established: "RNP-X"<br><br>• Procedure tolerances designed around these RNP-X standards<br><br>• Navigation and autopilot systems certified to RNP-X criteria |

• RNP 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

• The new PBN model aims to further improve upon the benefits of the RNP concept

# Definition of RNP accuracy requirement

- There are five main navigation performance criteria:
    1. <u>Accuracy</u> is the difference between the true and indicated position and track
    2. <u>Integrity</u> is the ability to provide timely warnings when the system is not safe to use
    3. <u>Availability</u> is the ability of the total system to perform its function at the initiation of the intended operation
    4. <u>Continuity</u> is the ability of the navigation system to provide its service without interruption during an operation
    5. <u>Vulnerability</u> is the susceptibility to unintentional or deliberate interference

- 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

- TSE is defined as follows:



**Desired Path**

**Path Definition Error (PDE)**

**Defined Path**

**Path Steering Error (PSE)**

*Estimated Position*

**Position Estimation Error (PEE)**
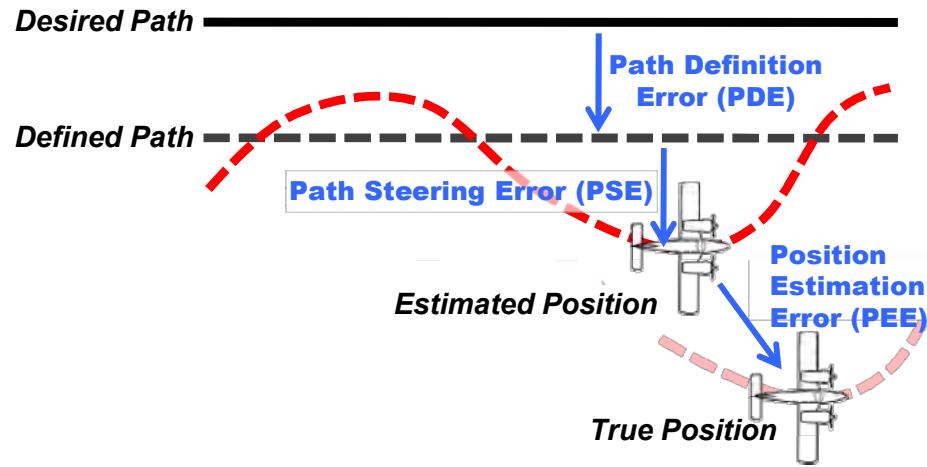
*True Position*

**Total System Error (TSE) is the vector sum of**
- **Path Definition Error (PDE)**
- **Path Steering Error (PSE)**
- **Position Estimation Error (PEE)**

- 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

- Position Estimation Error is the combination of navigation system/sensor (GPS) error and computation error (GPS software). PEE is expressed as a 95% confidence radius, called the Estimate of Position Uncertainty (EPU) or Actual Navigation Performance (ANP). PEE is sometimes also called Navigation System Error (NSE)

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

# The current RNP-X specifications published in Europe
## (see next section for future PBN specs)

**Used for RNAV(GPS) Approaches** ➡

**Used for P-RNAV** ➡

**Used for B-RNAV** ➡

| RNP Type | Required Accuracy (95% Containment) | Description |
|---|---|---|
| 0.3 | ± 0.3 NM | Supports Initial/Intermediate Approach, 2D RNAV Approach, and Departure. Expected to be the most common application. |
| 0.5 | ± 0.5 NM | Supports Initial/Intermediate Approach and Departure. Only expected to be used where RNP 0.3 cannot be achieved (poor navaid infrastructure) and RNP 1 is unacceptable (obstacle rich environment) |
| 1 | ± 1.0 NM | Supports Arrival, Initial/Intermediate Approach and Departure; also envisaged as supporting the most efficient ATS route operations. Equates to P-RNAV. |
| 4 | ± 4.0 NM | Supports ATS routes and airspace based upon limited distances between navaids. Normally associated with continental airspace but may be used as part of some terminal procedures. There are no plans at present to use RNP 4 in ECAC. |
| 5 | ± 5.0 NM | An interim type implemented in ECAC airspace to permit the continued operation of existing navigation equipment. Equates to B-RNAV. |
| 10 | ± 10 NM | Supports reduced lateral and longitudinal separation minima and enhanced operational efficiency in oceanic and remote areas where the availability of navigation aids is limited.[9] |
| 12 6 | ± 12.6 NM | Supports limited optimised routing in areas with a reduced level of navigation facilities |
| 20 | ± 20.0 NM | The minimum capability considered acceptable to support ATS route operations. |

⬅ US RNAV 1

⬅ Oceanic & remote enroute

⬅ Oceanic

Source: Eurocontrol publication *"Guidance Material for the Design of Terminal Procedures for Area Navigation"*

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   c. P-RNAV operations

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# Current RNAV applications in Europe: an overview

| **Enroute/Terminal** | **Terminal** | **Approach** |
| --- | --- | --- |
| **(Basic) B-RNAV** | **(Precision) P-RNAV** | **RNAV (GPS) Approaches** |

## Enroute/Terminal — (Basic) B-RNAV

- Requires RNP-5 capable navigation equipment (sufficient condition)
- Compulsory, since 1998, in almost all European airways and TMAs
- Private GA operators can meet requirements through carriage of an approved IFR GPS installation

  (for UK registered aircraft, AFM supplement must specify BRNAV approval; for US aircraft, requirements are similar – see AC90-96A Appendix 1)

- B-RNAV SIDs and STARs are implemented which meet en-route design criteria (eg. are above MSA) and which start & end at a conventional fix

  (note: both B-RNAV and P-RNAV procedures are designated "RNAV". Check approach plate detail, airport text pages and AIPs/AICs as appropriate – some RNAV terminal procedures formerly requiring only B-RNAV are migrating to needing P-RNAV approval)

## Terminal — (Precision) P-RNAV

- Requires RNP-1 capable navigation equipment (necessary but not sufficient)
- Europe is in the early stages of implementing P-RNAV procedures and all such TMAs currently offer conventional alternatives
- Private GA operators must obtain a Letter of Authorisation from their state of registry. JAA TGL10 and FAA AC90-96A Appendix 2 specify requirements for navigation system function, database approval, pilot training and operating procedures

**See Section 3**

## Approach — RNAV (GPS) Approaches

- Requires RNP-0.3 capable navigation equipment
- Europe is in the early stages of implementing GPS approaches
- Private GA operators requirements for equipment carriage are similar to B-RNAV: (E)TSO C129a or C146a GPS with installation conforming to FAA AC20-138 or EASA AMC 20-5 and AFM approval for Approaches
- National air law generally requires GA pilots to have some theoretical and flight training specific to GPS Approaches

**See Section 4**

Source: see website of the Eurocontrol Navigation Domain http://www.ecacnav.com/Home which has a comprehensive set of documents and HTML resources

# Future RNAV applications in Europe:
# The new Performance-Based Navigation (PBN) model
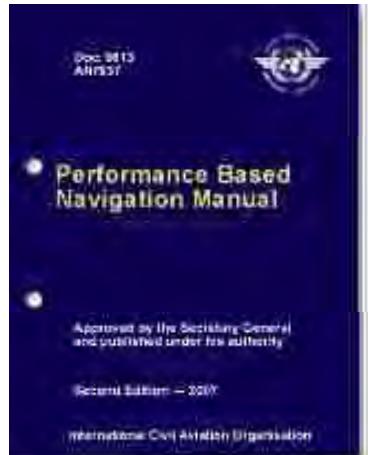
*Available from*
*http://www.ecacnav.com/Document_Library*

- PBN is the new formal model of how RNAV is implemented

- It is a move from a limited statement of required performance accuracy (ie. basic RNP-X) to more extensive statements of required performance in terms of accuracy, integrity, continuity and availability, together with descriptions of how this performance is to be achieved in terms of aircraft and crew requirements.

- The Required Navigation Performance (RNP) concept has been replaced by the PBN concept. Therefore, a lot of RNP terminology has been replaced by PBN terminology

- The ICAO 'Performance Based Navigation Manual (Final Draft)' replaces the 'Manual on Required Navigation Performance (RNP) ICAO Doc 9613-AN/937'.

- Global definitions of terms are provided that are aimed at removing any previous regional differences.

- A set of globally compatible Navigation Specifications are also provided. These are to be used as a basis for local or regional Navigation Applications in the en route, terminal and approach environments

*Source: the ECACNAV free online course on PBN http://www.ecacnav.com/WBT/PBN/frames/firstwin1.htm*

- PBN has no current or imminent relevance to European IFR operations. However, because a GA pilot may increasingly encounter the terminology and specification of future PBN applications in various articles and documents, this section provides a brief overview for the sake of completeness and orientation

- This Manual will revert to the current RNAV terminology in sections 2-6, and no further reference to PBN will be necessary

# Performance-Based Navigation (PBN) specifications

| PBN |
| --- |
| ....introduces 2 new classes of specification |
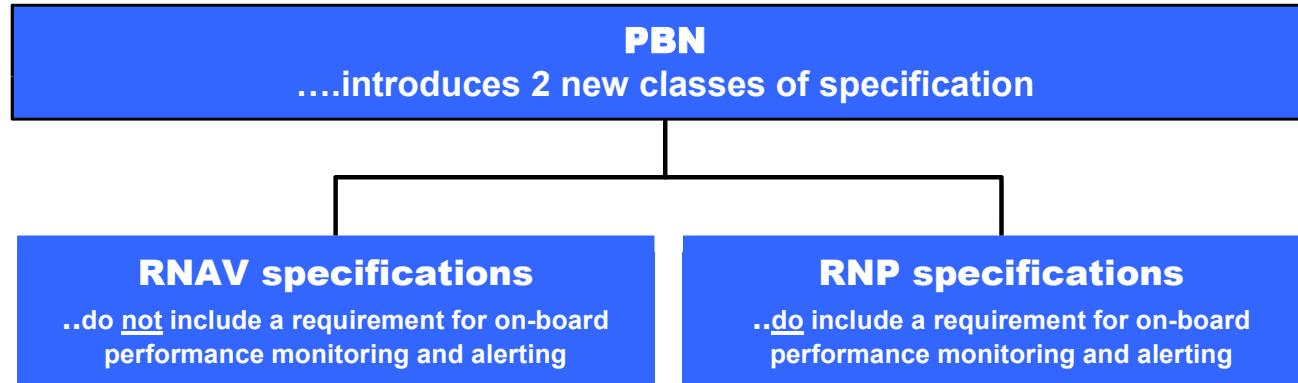
"on board performance monitoring" is not a problematic requirement for modern GPS units

| RNAV specifications | RNP specifications |
| --- | --- |
| ..do not include a requirement for on-board performance monitoring and alerting | ..do include a requirement for on-board performance monitoring and alerting |

• These are essentially a re-naming of existing specifications with a new RNAV X convention, in which the X is 95% lateral accuracy in nm

| Current name | PBN name |
| --- | --- |
| RNP 10 | RNAV 10 |
| B-RNAV | RNAV 5 |
| RNAV 2 (USA) | RNAV 2 |
| P-RNAV (Europe), RNAV1 (USA) | RNAV 1 |

• These add some (modest) extra "containment"/alerting requirements to existing RNP specs, and introduce some new applications

| PBN name | Used in: |
| --- | --- |
| RNP 4 | Oceanic |
| Basic RNP 1 & 2 Advanced RNP 1 | Various flight phases |
| RNP APCH | Similar to RNAV(GPS) |
| RNP AR APCH | More demanding "Authorisation Required" approaches |
| RNP "3D", "4D" | ..to be defined |

| NAVIGATION SPECIFICATION | FLIGHT PHASE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | En Route OCEANIC /REMOTE | En Route Continental | ARR | APPROACH | | | | DEP |
| | | | | Initial | Interm. | Final | MISSED | |
| RNAV 10 | 10 | | | | | | | |
| RNAV 5 | | 5 | 5 | | | | | |
| RNAV 2 | | 2 | 2 | | | | | 2 |
| RNAV 1 | | 1 | 1 | 1 | 1 | | $1^b$ | 1 |
| RNP 4 | 4 | | | | | | | |
| Basic-RNP 1 | | | $1^{a,c}$ | $1^a$ | $1^a$ | | $1^{ab}$ | $1^{a,c}$ |
| RNP APCH | | | | 1 | 1 | 0.3 | 1 | |
| RNP AR APCH | | | | 1-0.1 | 1-0.1 | 0.3 – 0.1 | 1-0.1 | |

Notes:

*The numbers given in the table refer to the 95% accuracy requirements (NM)*

*RNAV 5 is an en-route navigation specification which may be used for the initial part of the STAR outside 30NM and above MSA*

*RNP 2 and Advanced-RNP 1 are expected to be included in a future revision of the PBN Manual;*

*1a means that the navigation application is limited to use on STARs and SIDs only;*

*1b means that the area of application can only be used after the initial climb of a missed approach phase*

*1c means that beyond 30 NM from the airport reference point (ARP), the accuracy value for alerting becomes 2 NM*

The above table shows the navigation specifications and their associated navigation accuracies published in Parts B and C of this Volume. It demonstrates, for example, that the designation of an oceanic/remote, en route or terminal navigation specification includes an indication of the required navigation accuracy, and that the designation of navigation specifications used on Final Approach is different.

Most important, the above table shows that for any particular PBN operation, it is possible that a sequence of RNAV and RNP applications is used. A flight may commence in an airspace using a Basic RNP 1 SID, transit through En Route then Oceanic airspace requiring RNAV 2 and RNP 4, respectively, and culminate with Terminal and Approach operations requiring Advanced RNP 1 and RNP AR APCH.

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# The Global Satellite Navigation System (GNSS)

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

**GNSS**

*Note that the terms GNSS and GPS are sometimes used interchangeably*

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

| **GPS** | **GLONASS** | **"Galileo"** |
|---|---|---|
| • The USA's "Navstar" Global Positioning System | • Russian "Global Navigation Satellite System" | • The European Union's GNSS project |
| • A military system that became fully operational for worldwide civilian use in 1995 | • Introduced during the Soviet era for military applications | • After some controversy, formally approved in Nov 2007 |
| • Designed around a network of 24 medium-earth orbit satellites | • At present, only partially operational, with 13 of 24 required satellites functioning and approx ~60% global coverage | • Should be operational by ~2013 |
| • "Selective Availability" (SA) degradation of civilian signal accuracy ended in 2000 | • Russia intends to fully restore GLONASS by ~2011, in partnership with the Indian government | • USA/EU agreement that Galileo and GPS will be "interoperable" |
| | | • Will use a 30 satellite constellation; 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**

• **The rest of this manual will refer only to GPS**

# How does GPS work?

## 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 GPS Receivers to compute accurate 3D position, speed and time**

### The Navigation Message

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

### C/A (Coarse/Acquisition) code

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

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

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

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

### L1 Carrier

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

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

Navigation message
50 bps

*The 1023Mbits/s is sometime also referred to as the "chipping" rate, and each BPSK modulated bit of data as a "chip" (change in phase)*
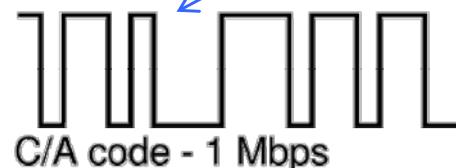
C/A code - 1 Mbps

**"Modulo 2 Adder"**

*The Navigation Message is encoded onto the C/A at 50bits/s by changing its sign*
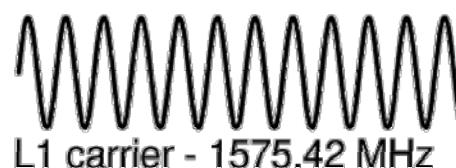
L1 carrier - 1575.42 MHz

**Broadcast Signal**

**"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*

Reference: Colorado Centre for Astrodynamics Research, R.S. Nerem & E. W. Leuliette, lecture #25, http://ccar.colorado.edu/asen5060/lectures.html

# How does GPS work?
## 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 synchronize 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

*Frame:1500 bits long; 30s @ 50bps*

| Frame |
|-------|

*5 Subframes each 300 bits long: 6s @ 50bps*

| Subframe 1 | Subframe 2 | Subframe 3 | Subframe 4 | Subframe 5 |
|------------|------------|------------|------------|------------|

**Clock data**
*for this satellite*

← **Ephemeris data** →
*for this satellite*

← **Almanac data** →
*common to all GPS satellites*

- Data that allows the GPS receiver to calculate the small offset between the satellite's internal clock time and GPS time defined by the ground station atomic clocks

- An "ephemeris" is a table of values that gives the position of astronomical objects in the sky. In a GPS context, it means the detailed model of a satellite's orbit

- The almanac consists of basic orbit and status information for all satellites, an ionospheric model, and information to relate GPS time to UTC

*A Subframe is made up of 10 Words, each 30 bits long: 0.6s @ 50bps*

| Word 1 | Word 2 | Word 3 | Word 4 | Word 5 | Word 6 | Word 7 | Word 8 | Word 9 | Word 10 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|

*30bits in a word*

| 1 | 2 | .. | .. | | | | | | | | | | | | | | | | | | | | | | | .. | .. | 29 | 30 |
|---|---|----|----|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|----|----|----|----|

← First 6 bits are parity data →  ← Final 24 bits carry the data content →

→ • **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**

# How does GPS work?

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

### Non-civilian GPS transmissions

**L1 Carrier**
1575.42 MHz

**C/A Code**
1.023 MHz

**Nav.Msg.**
50 Hz

**P(Y) Code**
10.23 MHz

*Civilian-use signal*

**L2 Carrier**
1227.60 MHz

**P(Y) Code**
10.23 MHz

*Same P(Y) Code transmitted on L1 and L2*

- The P (Precise) code is a 10,230bit psuedo-random number, it is a 10x more accurate version of the C/A code

- Normally, the P code is encrypted by a "Y" code, creating the 10.23 MhZ P(Y) signal which can only be decrypted by military users – known as the "Precise Positioning Service" (PPS)

- The encryption is an "anti-spoofing" technique ,which provides some assurance that the signal received is not being sent by a non-GPS "spoofing" transmitter. The C/A code is potentially vulnerable to such spoofing.

- The ionosphere delays or "disperses" radio signals differently according to their frequency. Military (and some specialised civilian) receivers can compensate for this by comparing P(Y) signal reception between the L1 and L2 carriers.

### Future enhancements

| Existing | Future |
|---|---|
| **L1 Carrier** 1575.42 MHz | • **L1C** New version of C/A code |
| • C/A Code • P(Y) Code | • **M (Military) code** |
| **L2 Carrier** 1227.60 MHz | • **L2C signal** CM (civilian moderate) code CL (civilian long) code |
| • P(Y) Code | • **M (Military) code** |
| **L5 Carrier** 1176.45 MHz | • **"Safety of Life" signal** |

- These new signals are being implemented progressively by new satellite launches over the next 5 years

- 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

- *Author's note: Existing GPS receivers will be supported for very many years. It is likely that after ~2013, some RNAV applications will begin to require new GPS receivers, capable of using the more accurate signals and multiple GNSS systems*

# How does GPS work?
## 5. International time and the GPS time system

| International Atomic Time (TIA) | Universal Coordinated Time (UTC) | "GPS Time" |
|---|---|---|
| • The standard international scientific time scale | • "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 | • The GPS system uses a time reference ("GPS Time") maintained by the Master Control ground station's atomic clocks |
| • 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 | • Fluctuations in the earth's spin mean that UT1 deviates from the precise TIA reference | • GPS time uses the TIA second, and was set equal to UTC in 1980. It does not introduce leap seconds, and today is 14s ahead of UTC (the difference between TIA & UTC was 19s in 1980, hence today's 33s-19s=14s). The Navigation Message transmits a correction for UTC, so that GPS receivers can display UTC and local time zones. |
| • TIA is derived from 230 atomic clocks in 65 sites around the world, and 11 different laboratory caesium frequency standards | • UTC, the "official world time" is a compromise between Earth time and TIA; it uses the TIA second, but introduces leap seconds to account for changes in the earth's spin and maintain a useful consistency with UT1 | • 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 |
| • The data is collated by the BIPM (Bureau International des Poids et Mesures) in Paris, who calculate TIA and promulgate the results to various international centres | • At any given time, UTC equals TIA minus an integer number of seconds. In January 2008, UTC was 33s behind. Typically, a leap second is subtracted once a year | • 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**

# How does GPS work?

## 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)

**Antenna**

**Preamplifier and Down Converter**

**Demodulation and Code control**

**C/A code generator**

**Clock**

*Navigation Message*

*C/A Code Measurement*

*Time Measurement*

**Navigation and Signal Processor**

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

*Position, Velocity, Time*

**Nav functions and user interface**

**Aviation navigation database and charts. Radios and other sensors.**

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

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

Sources: Peter H. Dana article 29/7/95 and Jeppesen JAA ATPL Manual Edition 2, Radio Navigation volume.

45

## Stage 1: The "pseudorange"

- When the GPS receiver is started-up, its internal or "local" clock will be inaccurate by an unknown error, called clock *bias* or *offset*, compared to the reference GPS Time

- A modern quartz clock may be accurate to one part in a million (ie. drift by one microsecond every second). This means that after only 1s, the internal clock error can be the equivalent of hundreds of metres (1μs = ~300m at the speed of light). A unit that's been switched off for a week or two could be inaccurate by ~1s or hundreds of thousands of km.

- The first stage of the navigation problem is to calculate "pseudoranges" from the visible satellites to the GPS, ignoring the local clock offset. These ranges are "pseudo" because they are all known to be wrong by the same (unknown) local clock error

- For any given satellite, the Receiver generates the satellite's PRN code internally, based on its "code book", and starts the code sequence at the time its local clock says the satellite should have started its PRN transmission. The internal PRN code is then time-shifted until it matches (locks-on) to the PRN code signal from the satellite. This time-shift, or *offset,* is the (pseudo) elapsed time between transmission and the reception Time of Arrival (TOA)

- The Pseudorange is derived from the TOA, assuming a given speed for radio wave travel and the decoded time of transmission from the satellite

- The 1023 bit PRN code is transmitted at 1000 times per second, and the Receiver can judge the "start" of a bit to about 1%, so the maximum accuracy of the C/A code is ~3m

- By decoding the Navigation Message, the Receiver gets data that allows it to correct Pseudorange for the following errors
  – The SV (Satellite Vehicle) time offset from GPS time
  – Basic ionospheric corrections from the Almanac
  – Relativistic effects and receiver noise

- The Receiver calculates pseudoranges from different satellites simultaneously, so they are all subject an identical local clock error

## Stage 2: The accurate fix

- The Receiver then uses the ephemeris (orbital) data in each satellite's Navigation Message to establish the satellite's position in space at the time of the Pseudorange calculation

- It requires a minimum of 4 satellite pseudoranges to determine a 3D navigational fix for the Receiver.

- The GPS system specification is that 5 satellites should always be available above a mask (elevation) angle of 7.5 degrees (usually it is 6 or more)

- With 4 satellite positions known and 4 pseudo ranges 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

# How does GPS work?

## 8. Illustration of the GPS navigation calculation

*Sample of the C/A PRN codes*



**1023 bits**

**31 rows**

Each row is the code from one satellite

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

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

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

- **Low correlation: wrong PRN code**

- **Better correlation: correct PRN code, but time shift wrong**

- **Best correlation: correct PRN code and best time shift**

**time shift**

Sources: Peter H. Dana, University of Colorado website: http://www.colorado.edu/geography/gcraft/notes/gps/gps.html  and  *Id* prior pages (R.S. Nerem & E. W. Leuliette, lecture #25)

# How does GPS work?

**Stage 2: The accurate fix**

## _Two dimensional illustration of the GPS navigation calculation_

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

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

**Satellite position known from Navigation Message ephemeris data**

**Pseudoranges calculated from PRN correlation time shift**

**Clock bias unknown, thus receiver position unknown**

**Best fit local clock bias**
(all three black arrows represent the same clock bias)

**Pseudorange arc**

**True range arc**

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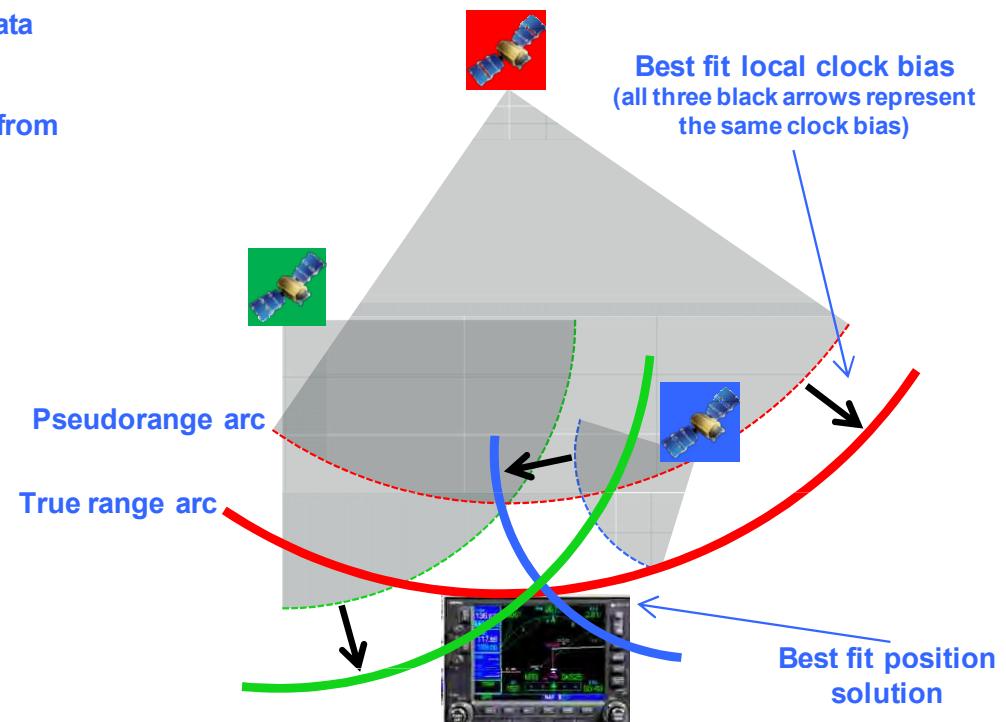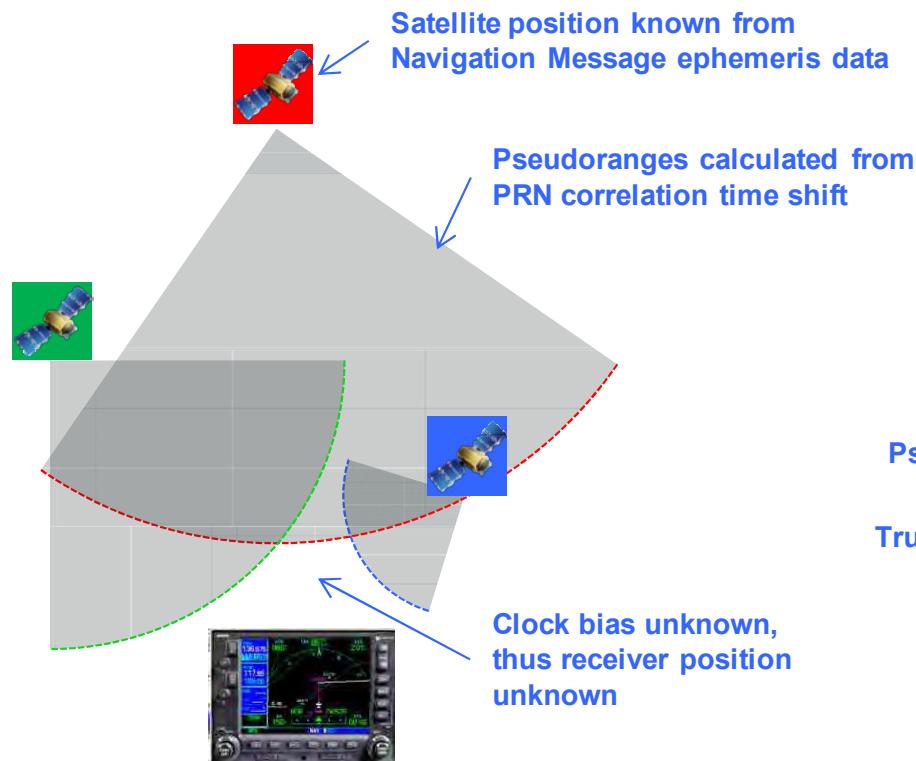
- **The actual method used is analogous to this; 4 satellites provide 4 range spheres, and thus 4 equations to solve for the unknown 3D x,y,z position of the receiver and its clock bias**

## 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), realized 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)**
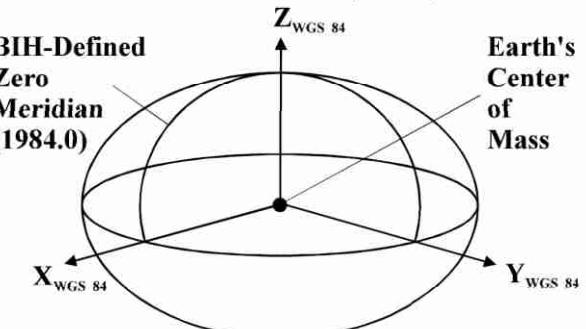
## Aviation charting datums

- Aviation charts use 3 types of position data
  - <u>Surveyed</u> positions for topographic and terrain features, navaid positions and physical references, like runway thresholds
  - <u>Declared</u> positions, defined by latitude and longitude (rather than any surveyed point) for airspace boundaries and oceanic entry/exit points
  - <u>Calculated</u> points, defined by a geometric relationship to a surveyed position (eg. a fix based on a VOR/DME radial and distance)

- RNAV waypoints are either <u>calculated</u> relative to navaids or at <u>declared</u> latitudes and longitudes (although, of course, charts will often show both the navaid reference and the lat/long of a waypoint)

- Historically, each country used its own geodetic datum for aviation charts. Navigating with ground-based aids, an aircraft could fly between countries that used datums hundreds of metres apart without any problem, since IFR terminal and approach charts used in the cockpit were published with the appropriate <u>local</u> datum

- However, work in Europe on radar and navaid trajectories in the 1970s demonstrated the inconsistency of national datums. For example, an aircraft could appear on one 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 <u>relative</u> to the aircraft WGS84 position – based on the objects' stored WGS84 coordinates. Navigation data (eg. track and distance to waypoint, cross-track error) is also calculated from the relative WGS84 co-ordinates of the aircraft and the waypoint or flight plan track.

- **In most aviation GPS Receivers, the WGS84 datum can not be changed**

- In non-aviation GPS, the datum may be changeable (eg. to be consistent with maps used for hiking or marine navigation)

*Example from Garmin GNS530 Pilot's Guide*



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

Figure 10-38 Units/Position Page

Note: see http://www.jeppesen.com ..*Online Publications..IFR Pilot Information* for an online status report of countries whose AIPs conform to WGS84
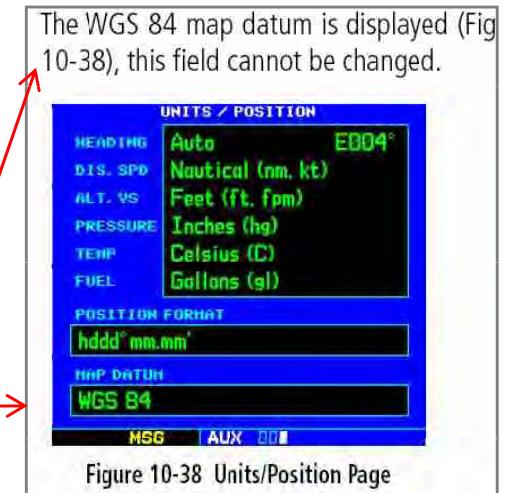
# How does GPS work?

## 12. GPS mapping illustration

Satellite C/A Code and Navigation Message

Data card with current database

**Navigation and Signal Processor**

*Using WGS84 datum*

Database supplier encodes AIP data from the current AIRAC cycle

Aircraft's position relative to WGS84 datum

GPS map objects, coded with WGS84 datum, depicted relative to aircraft's position

GPS satellite orbits, GPS-derived aircraft position, electronic charts, in-flight paper charts and AIP charts all referenced to the same WGS84 datum

Chart supplier publishes paper charts for in-flight use based on the current AIP

National AIS publishes WGS84-referenced charts and procedures in ICAO format in the AIP, updating them according to the AIRAC schedule

- **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 (VNAV)

## 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 GPS 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 1013mb 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 (LNAV). There is <u>no</u> corresponding standard datum for Mean Sea Level in vertical navigation (VNAV). 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 IFR VNAV uses barometric altimetry, <u>not</u> 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 Performance

## 1. A model of GPS performance measures and factors affecting them

|  | Accuracy | Integrity | Availability | 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 | the ability to perform without interruption | susceptibility to unintentional or deliberate interference |
| **GPS System and Satellite Signal** | • Ephemeris error<br>• SV clock error<br>• Ionospheric error<br>• Tropospheric error<br>• Multipath error<br>• Dilution of Precision<br>• Signal noise | • Ground monitoring of the Space segment and provision of RAIM data in the Almanac | • Satellite coverage<br>• Satellite reliability<br>• Terrain masking<br>*situation where terrain creates a mask angle greater than the 7.5 degrees the GPS constellation model is designed to provide coverage for*<br>• System is unaffected by number of users |  | • Spoofing potential<br>– *Civilian GPS is vulnerable to 'fake' transmissions from 'spoofing' equipment* |
| **GPS Receiver** | • Receiver noise<br>• Receiver processing error<br>• Receiver display error | • Receiver RAIM prediction and monitoring<br>*(see Section 2d on RAIM and FDE)*<br>• Other receiver alarms and alerts | • Reliability of receiver hardware, software and antenna<br>• Quality of installation and power supply | • Receiver FDE<br>• Reliability of receiver hardware, software and antenna<br>• Quality of installation and power supply<br>• Dynamic masking | • Installation vulnerability to RF interference |
| **GPS Database** | • Coding error | • Quality assurance by database supplier | • Completeness of database<br>• 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<br>• User "conceptual" error | • Use of RAIM tools | • Database updating | • Inadvertent mis-operation |  |

# GPS System Performance

| | Accuracy | Nature of error | Size of error |
|---|---|---|---|
| **GPS System and Satellite Signal** | • **Ephemeris error** | • Satellite orbits, although precisely positioned, can deviate from the ephemeris model data transmitted in the Navigation Message | **2.5m** |
| | • **SV clock error** | • Satellite clock errors are monitored by the Ground Segment and corrections are included in the Navigation message. These aren't "real-time" and a small residual error can develop | **2m** |
| | • **Ionospheric error** | • Inconsistencies in how the ionosphere disperses radio signals can only be partially compensated for by the model data in the Almanac<br>   – this is the largest single source of error in civilian GPS | **5m** |
| | • **Tropospheric error** | • Different concentrations of water vapour in the atmosphere cause an inconsistency in how radio waves are refracted. This error is small, but can not be easily corrected by modelling or calculation | **0.5m** |
| | • **Multipath error** | • In ground-based applications, a satellite signal may arrive at a receiver via a reflection from a building or terrain. This type of error is inherently less present in most phases of flight, although it is an issue for future precision approach systems | **-** |
| | • **Dilution of Precision** | • Like any position line fix, 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<br>• 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** |
| **GPS Receiver** | • **Receiver noise** | • The result of noise in the receiver further compromising the accuracy of the decoded PRN | **1m** |
| | • **Receiver processing error and display error** | • Not operationally significant, unless there is a failure or software bug. Unlike an Inertial system, whose estimated position drifts away from true position over time, 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 or accuracy failures that are not identified by a Receiver RAIM or Loss of Integrity alert | | At the <u>system</u> level, very low risk of a loss of service not predicted by RAIM tools<br><br>At the <u>local</u> level, terrain and satellite geometry surveying is part of the RNAV procedure design process and thus a very low risk of local availability or continuity problems | | |
| **GPS Receiver** | Very low risk of design problems with TSO/ETSO certified hardware and software | | Approved installations have proven highly reliable in millions of hours of service. Of course, like all radio aids, they depend on aircraft power | | |
| **GPS Database** | Generally highly reliable. However, in the current phase of rapid deployment of RNAV (both new procedures and approaches and <u>new designs</u> 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 | | | | |
| **Pilot input and interpretation** | ➡ The major risk is pilot error in operating and interpreting GPS navigation equipment | | | | |

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

➡ • **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**

# 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

### Differential GPS (DGPS)

• Differential GPS (DGPS) systems originated in the time before "Selective Availability" was permanently switched off by the US DoD and civilian GPS accuracy was ~100m. This proved inadequate for safe marine navigation and, in the late 1990s, the US Coast Guard implemented a DGPS system in US waters. Similar systems were developed in Europe, partly also to replace the defunct Decca marine navigation system

### Local Area Augmentation System (LAAS)

• An aviation application designed to provide precision approach capabilities to CAT III Autoland levels of accuracy and integrity

• "Local" in the sense that reference receivers are around a single airport at precisely surveyed locations. The system calculates a differential correction which is transmitted via a VHF data link. The LAAS Receiver on board an aircraft can then create a 'synthetic' ILS display

• First-generation LAAS proved more expensive and not significantly more accurate than WAAS. However, future versions will be used as CAT II and III precision approach aids, to improve on the CAT I limit of WAAS

## 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
  – A SBAS-enabled GPS receiver which decodes the data and applies the corrections

• There are a number of regional SBAS systems, two key ones are the FAA's Wide Area Augmentation System (WAAS) and the European Geostationary Navigation Overlay Service (EGNOS). These systems are compatible, so that current WAAS-enabled GPS receivers can work in Europe

### WAAS

• 38 reference stations in the continental US, Canada, Alaska, Mexico and Hawaii

• Commissioned in 2003 for aviation use. WAAS GPS is approved as a primary (sole) navigation aid for Enroute and Oceanic navigation, and CAT I Precision Approaches (LPV)

### EGNOS

• Europe's equivalent to WAAS

• The system is fully deployed and undergoing certification trials

• See the EGNOS section of the European Space Agency website http://www.esa.int/esaNA/egnos.html

# Course contents

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. **Databases and Coding**
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

| Originators | → | AIS | → | Commercial providers | → | Users (general aviation examples) |

*Individual States are responsible for providing Aeronautical Information Services (AIS) to ICAO standards*

*Example of a commercial provider of general aviation products: Jeppesen*

**Originators:**
- Airports
- Air Traffic service providers
- Communications service providers
- Procedure and Airspace designers
- Other government agencies

**AIS:**
- Aeronautical Information Publication (AIP)
- AIP Supplements (SUP)
- Aeronautical Information Circulars (AIC)
- Notices to Airmen (NOTAM)

*Users access paper or online AIS directly*

JEPPESEN

*"The Jeppesen Aviation Database (JAD) is composed of over one million records. Each 28-day cycle, the flight information analysts edit and verify an average 150,000 JAD transactions. Only original source documents are used; gathered from 220 separate agencies worldwide and then cross-checked using multiple sources"*
*Source: www.jeppesen.com*

*Airways Manual*

*Electronic airways manual*

JEPPVIEW

*Flight planning software*

FliteStar

*Paper charts*

PCs, Electronic flight bags (EFBs) and some multifunction displays (MFDs) with the 'Chartview' feature

**"NavData" GPS database**

SanDisk Ultra II 512MB

*Also database of features specific to individual GPS models (eg. terrain, obstacles, topographic maps)*

**Garmin, Honeywell and other aviation GPS units**

# Sources of navigation data
## 2. An overview of standards relevant to RNAV databases

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

| | Originators | AIS | Commercial providers | Users |
|---|---|---|---|---|
| **Data standards** <br> how is data originated to a consistent standard? how is quality assured in data processing? | • ICAO doc 8168 PANS OPS <br> • FAA TERPS <br> • ECAC Guidance Material <br> • …etc <br> – standards for the design of IFR facilities and procedures, and the format of AIS data | • RTCA Do 201A <br> • EUROCAE ED 77 <br> – quality assurance for the supply of AIS data used in RNAV databases | • RTCA Do 200A <br> • EUROCAE ED 76 <br> – data processing quality assurance for commercial providers that create RNAV databases from AIS data | • FAA TSOs <br> • EASA ETSOs <br> – technical certification for IFR GPS equipment <br> • FAA AC120-138, <br> • EASA modification approval <br> – airworthiness approval for IFR GPS units (or Type Certification for original equipment in newer aircraft) <br> • FAA: 14CFR Part 91 or 135 <br> • EASA: national laws (private) or JAR-OPS (commercial) <br> • Airplane Flight Manuals and AFM Supplements <br> • P-RNAV: FAA AC90-96A, JAA TGL10 <br> – operator requirement to use current data as a condition of approval for RNAV applications |
| **Coding standards** <br> how are databases created from AIS data? | • The ARINC 424 standard <br> – standard for the structure of aviation navigation databases, including the type of data records (eg. Airports, VORs) and the coding of data fields (eg. runway elevation, VOR frequency) <br> – includes standards for coding routes (airways) and procedures (terminal, approach) as well as individual facilities and waypoints | | | |
| **Update standards** <br> how are databases kept current? | • The AIRAC cycle <br> – ICAO standard for publishing additions and revisions to AIP data based on a schedule of calendar dates and a process associated with those dates to ensure all users receive timely and "synchronised" updates | | | |

• Navigation data management and quality assurance is a specialised topic, most of which is beyond the scope of this course

• The focus in this section will be on the basics of the Do200A/ED76 standards and the AIRAC cycle, and details of ARINC 424 relevant to users of RNAV GPS equipment

• Sections 3 and 4 will cover operational approval requirements for P-RNAV and GPS Approaches

# 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 new RNAV RNP applications, such as P-RNAV**

- 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 private 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 GPS unit may only use an approved database and data card, they have part numbers like any other aviation component)
  - for B-RNAV, a current database is not required, but paper charts must be used to verify data in an expired database
  - **for GPS approaches, a current database will be a requirement specified in the approved Flight Manual GPS section or supplement**
  - **a P-RNAV Letter of Authorisation will require use of both a current database and a supplier conforming to Do200A/ED76 (See next page and Section 3)**

## 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

- As RNP RNAV procedures were being implemented circa 2003, many FMS and GPS systems were not available with conforming databases. It was the responsibility of AOC Operators to manually check such databases against co-ordinates on paper charts

- International agreements were 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

- **For P-RNAV approval, databases sourced from the major suppliers holding Type 2 LoAs are compliant with JAA TGL10 and FAA AC90-96A**. Where a Type 2 LoA or Do200A/ED76 compliant database is not available, the Operator must continue to manually cross-check navigation data (eg. in accordance with JAA TGL10 Revision 1 para 10.6.2)

- **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 GPS 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 P-RNAV requirement. The operator must check the status of their individual GPS model

- Also see ECACNAV document "Database Compliant Suppliers and Integrity Checking" http://www.ecacnav.com/content.asp?PageID=86 and Garmin website http://www8.garmin.com/aviation/type2_loa.jsp

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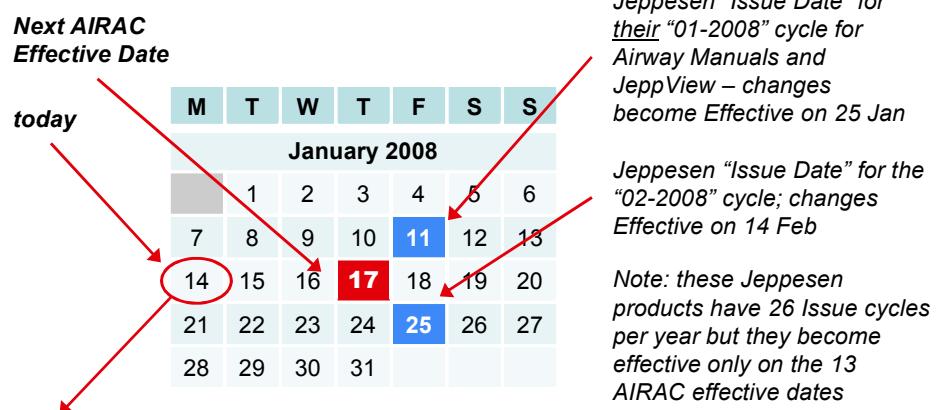
  *AIRAC stands for Aeronautical Information Regulation And Control and stems from the ICAO Annex 15 - Aeronautical Information Services (AIS) document. AIRAC defines a series of common dates and an associated standard aeronautical information publication procedure for States*

  *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 January 2008, the next AIRAC Effective Date is 17 January 2008:

**Next AIRAC Effective Date**

**today**

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

| M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|
| | | | | | | |
| **January 2008** | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| 28 | 29 | 30 | 31 | | | |

*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 GPS 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 GPS 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: GPS databases usually do not include Category A and B approaches

## Currency

- **Ensure that the GPS 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 P-RNAV and GPS approaches
- It is not legal or practical to try and enter these as user waypoints. An approved, current database is essential
- Note that paper charts and software products may distributed up to 2 weeks before they become effective

## Cross-Check

- **Cross-check the GPS 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 GPS databases
- In addition, RNAV databases are an inherently different format from paper charts and some waypoints will not be identical in both (see ARINC 424 pages later in this section)
- Flying an RNAV procedure is not the right time to be puzzling over such discrepancies

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

# If my GPS database is approved and current, do I really need to cross-check it with published charts?

**Example: Jeppesen NavData alerts for Europe in the 4 weeks to 22 December 2007**

**December 22, 2007**
Germany, Multiple Locations
Step Down Fixes, Cycles 0713 and 0801
**Step-Down Fixes on German RNAV (GPS) Approach Procedures**

**December 13, 2007**
Erfurt, Germany, Erfurt (EDDE)
RNAV (GPS) RWY 10 [R10], Cycle 0713
**INCORRECT ALTITUDE ON 'ERF' APPROACH TRANSITION**

**December 10, 2007**
Cagliari, Italy, Cagliari Elmas (LIEE)
RWY14/32, I32, D14, D32, N32, Cycle 0713
**INCORRECT RUNWAY AND APPROACH PROCEDURE INFORMATON**

**November 25, 2007**
Cologne-Bonn, Germany, Cologne-Bonn Airport (EDDK)
GULKO 14 [GUL14], KOPAG 14 [KOP14], and NORVENICH 14 [NOR14] Rwy 14L/R RNAV Transitions, Cycle 0712
**INCORRECT COORDINATES FOR SUPPLEMENTAL RNAV WAYPOINTS**

*Over 4 weeks, 4 problems in the European GPS database significant enough to warrant coding changes and a user alert.*

## JEPPESEN
### NavData® Alert

### !! URGENT !!

Date:        21 December 2007

Subject:     Germany
             Multiple Locations
             Step Down Fixes
             Cycles 0713 and 0801

*Step-Down Fixes on German RNAV (GPS) Approach Procedures*

Jeppesen received source information for RNAV (GPS) approaches from the German DFS (Deutsche Flugsicherung) that we interpreted as requiring step down fixes between the FAF and MAP. DFS recently informed us that these step down fixes should not be included in Jeppesen NavData and requested that we remove them (reference NOTAM A3539/07). For NavData cycle 0713, effective 20 December, RNAV (GPS) approach procedures for airports in Germany (FIRs EDWW, EDGG and EDMM) are unusable for operators with avionics equipment that processes final approach stepdown fixes.
Please note that step down segments do not appear in all avionics systems that use Jeppesen NavData. Step down segments are filtered out by Jeppesen as requested by the avionics manufacturer when their equipment cannot properly handle step down data.  If you have any questions concerning this, please contact Jeppesen at 303-328-4445 or the email address or fax number below.

The affected step down segments and waypoints will be deleted from the approach coding for the procedures listed below in NavData cycle 0801, effective 17 Jan 2008:

The affected step down segments and waypoints will be deleted from the approach coding for the procedures listed below in NavData cycle 0801, effective 17 Jan 2008:

| Airport (Identifier) | City Name | Procedure Name [Identifier] |
|---|---|---|
| Brandensteinsebene (EDQC) | Coburg, Germany | RNAV (GPS) Rwy 30 [R30] |
| Hannover (EDDV) | Hannover, Germany | RNAV(GPS) Rwy 09L [R09L] |
| Hannover (EDDV) | Hannover, Germany | RNAV(GPS) Rwy 09R [R09R] |
| Hannover (EDDV) | Hannover, Germany | RNAV(GPS) Rwy 27L [R27L] |
| Hannover (EDDV) | Hannover, Germany | RNAV(GPS) Rwy 27R [R27R] |
| Magdeburg (EDBM) | Magdeburg, Germany | RNAV(GPS) Rwy 27 [R27] |
| Straubing (EDMS) | Straubing, Germany | RNAV(GPS) Rwy 28 [R28] |

## ➡ YES

# If my GPS 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** | **EGBJ: Airfield NOTAMs 3 Feb 08** |
|---|---|

*GPS Approach published, current and included in databases*

*…but GPS Approaches NOTAMed not available*



DO NOT USE FOR NAVIGATION

EGBJ      GLOUCESTERSHIRE          GLO

REF: L0004/08
From: 2008-Jan-01 Tue 10:57 To: 2008-May-31 Sat 10:00
ICAO:EGBJ GLOUCESTERSHIRE
RNAV (GNSS) APPROACHES NOT AVBL

REF: L0019/08
From: 2008-Jan-02 Wed 08:00 To: 2008-Mar-31 Mon 23:59
ICAO: EGBJ GLOUCESTERSHIRE
ROTORS RUNNING REFUELS NOT AVAILABLE DURING FOLLOWING
PERIODS: MON-THURS 0830-0900 1815-1900 FRI 0830-0900 1530-
1600 1815-1900 SAT 1100-1130 SUN 1400-1430 1700-1730

REF: L0387/08
From: 2008-Feb-01 Fri 13:32 To: 2008-Feb-29 Fri 09:00
ICAO: EGBJ GLOUCESTERSHIRE
OBST LGT BRG 075 DEG MAG 804M FM ARP U/S

➡ **YES**

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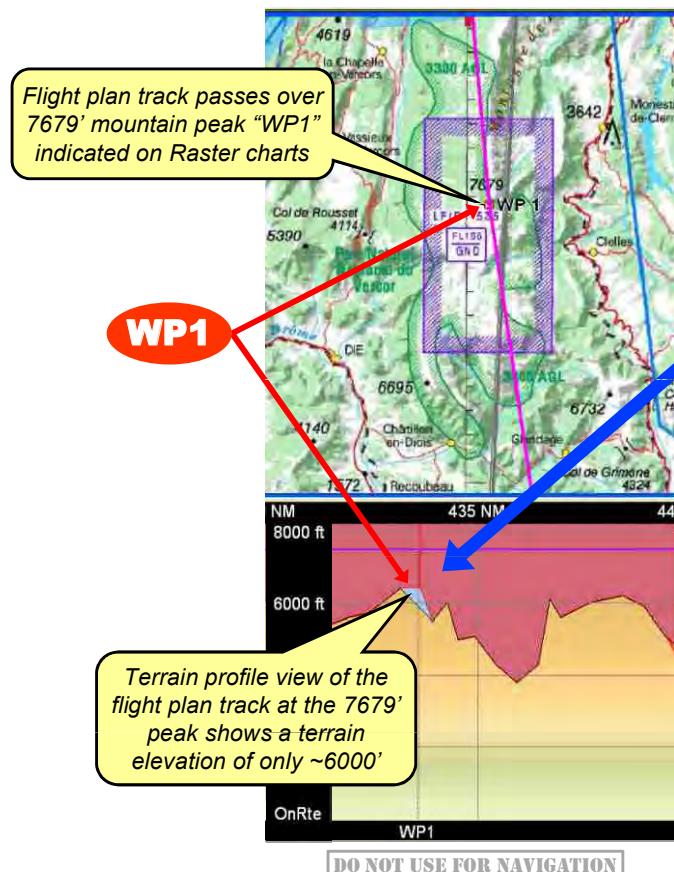
**Comparison of Vector chart with Raster chart position data and vertical profile data**



Flight plan track passes over 7679' mountain peak "WP1" indicated on Raster charts

Terrain profile view of the flight plan track at the 7679' peak shows a terrain elevation of only ~6000'

DO NOT USE FOR NAVIGATION

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**

Underlying terrain data 'block' values used in the vertical profile view. Note that the 7000' contour line conflicts with this data

7000' contour line from Vector chart, shown in red for emphasis

The implied position of the 7569' peak based on the 7000' contour line in the Vector chart (actual peaks not shown)

The position of the 7569' Peak "WP1" from the Raster chart

**➡ YES**

# 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 2008) is 424-18

- **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**
- **Section 2c will cover the coding of 'traditional' and RNAV procedures**

# 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)

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

**Record Types:**

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

← 132 characters →

*Example: characters 28-30*

| 28 | 29 | 30 |
|---|---|---|
| 1 | 2 | 5 |

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

```
NEAREST AIRPORT
APT      BRG      DIS      APR
EDDK     245°     10.7%    ILS
twr 124.975       rwy  12500↑

EDKN     355°     11.1%    VFR
    122.400       rwy  1900↑
```

*Example: Airport data from Garmin 530 "NRST" page*

*Example: definition of Fields in an Airport Record*

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

# There are four kinds of ARINC 424 Record

| "Points" | Routes | Procedures | Miscellaneous |
|---|---|---|---|
| *Examples:* | | | *Examples:* |
| VHF Navaid | Company Route | SID, STAR, Approach | MSA |
| Waypoint | Enroute Airways | | FIR/UIR |
| Holding | Enroute Airways Restrictive | | GRID MORA |
| Airport | Preferred Routes | | Enroute Communications |
| Runway | | | Controlled Airspace |
| NDB Navaids | | | |

*Example: waypoint record included in route & procedure sequences*

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

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

- 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

- Other record types, mostly relating to communications and airspace

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

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

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

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

# GPS units vary in terms of which ARINC data they support

*Garmin examples:*

| | "Points" | Routes | Procedures |
|---|---|---|---|
| **Garmin 430, 530 and piston aircraft G1000** | Fully supported | Not supported | LNAV supported VNAV and Speed not supported |
| **Garmin 480** | Fully supported | Fully supported | LNAV supported VNAV and Speed not supported |
| **Garmin G1000 in turbine aircraft** | Full, modern Flight Management System (FMS) implementation of LNAV, VNAV and Speed in all IFR routes and procedures | | |

- *WAAS GPS units do provide a 'synthetic' glideslope during the final approach phase of an LPV procedure, but not VNAV throughout a procedure. The Garmin "Advisory VNAV" feature relies on manual entry of target levels along a flight plan – it does not support database coded target and limiting altitudes within a procedure*

➡ • **Variations in how data is treated also occur between identical GPS models with different software versions**

• **The only definitive guide is the GPS manual that is part of the aircraft Flight Manual in an IFR approved installation**

# 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

- GPS 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*

DK555
N50 57.5
E007 27.0
4

- **57.5 minutes of arc**

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

*Example: from Garmin 530 database*

INT DK555
REGION
GERMANY
POSITION
N 50° 57.51'
E007° 27.03'

- **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 P-RNAV or RNAV 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

- RNAV equipment 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

## GPS calculation and display of magnetic tracks

- There are various magnetic north references available

  - local (at a given point) or regional

  - measured at a given time, or values valid for a period of time such as 1 year or 5 years

- Although ARINC databases do include the magnetic track or VOR radial along routes and procedures, these will typically not be used by GPS navigation processors

- Instead, the GPS 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 GPS unit's internal magnetic variation model

- **Small differences of ~1 degree are common between charted magnetic tracks and GPS-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**

# ARINC 424 name and coding conventions
## 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 an RNAV database. Generally the same as the ICAO identifier, but ARINC 424 may require some variation. CNFs may only have a database identifier and no published chart designator |
| **Examples** | | |
| London Heathrow | EGLL | E G L L |
| Daventry | DTY | D T Y |
| waypoint name is the same as identifier ← | KENET | K E N E T |
| Lambourne Three Alpha | LAM 3A | L A M 3 A |
| a CNF created by the database supplier and not published in paper charts ← | | C I 2 7 |

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

➡ **• An understanding of naming conventions and coding is essential for RNAV operations**

# Why is an understanding of naming conventions and coding essential for RNAV 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**

*N651AA*

| Names | ICAO Identifiers | Database Identifiers |
|---|---|---|
| Rozo NDB | R | R O Z O |
| Romeo NDB | R | R |

*both in Colombia*

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

**Comment relating to non-unique 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 RNAV challenges that have defeated experienced professional crews from the best airlines**

- **14 years after the Cali accident, these issues are still very relevant to RNAV database users**

# ARINC 424 name and coding conventions
## 2. Overview of databases identifiers

| "Points" | Routes and Procedures | Procedure Waypoints |
|---|---|---|

### "Points"

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

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

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

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

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

### Routes and Procedures

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

**Terminal procedure names** `a a a n a`
- ARINC 424 permits alphanumeric identifiers of up to 6 characters (see section 2c)
- The leading letters usually refer to a fix at the start or end of a procedure. In the case of a 3 letter VOR identifier, the "aaana" format is used. If the fix is a 5LNC, the last letter of the 5LNC is dropped and the procedure name format is "aaaana"

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

### Procedure Waypoints

**Terminal waypoint names**

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

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

**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

---

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

- **Terminal procedure database identifiers are published in [square brackets] on paper charts**
- **Approach procedure identifiers are usually the same as the charted procedure names, but see Section 2c for potential ambiguities**

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

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

PPL/IR EUROPE

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

**Garmin 530 examples**



*Example: select geographic region from GNS530 list of duplicated records available for a given identifier selection*
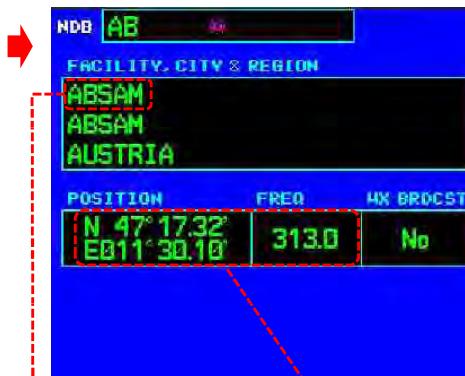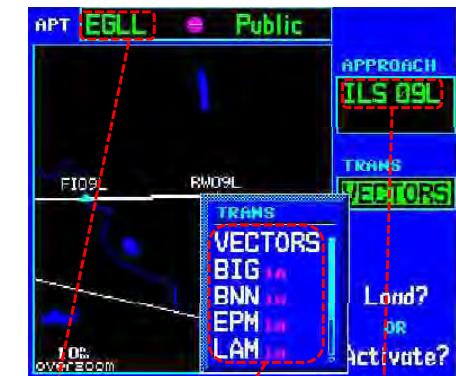
*Confirm facility name correct*

*data for gross error check and radio cross-check*

*1.Confirm airport correct*
*2.Select procedure identifier*

*3. Select transition*
*4. If applicable, select runway*

*1.Confirm airport correct*

*3.Select transition*

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

# ARINC 424 name and coding conventions
## 4. When are database waypoints different from those on paper charts?

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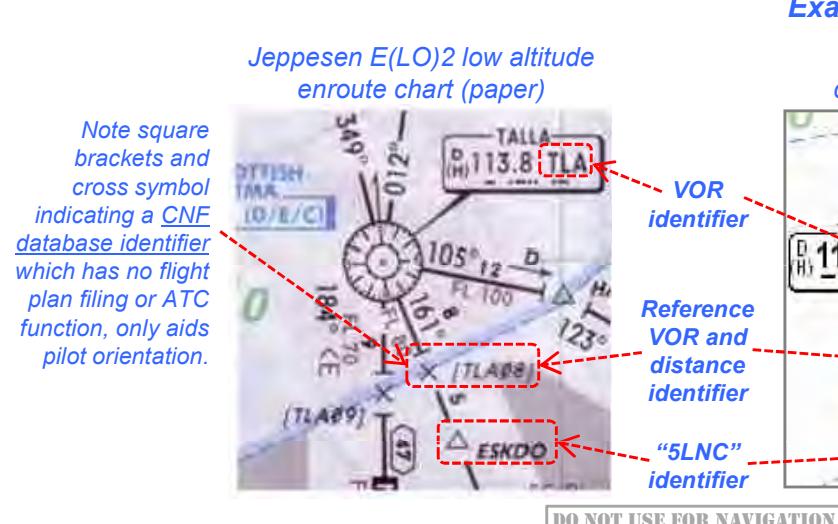
# ARINC 424 name and coding conventions
## 5. Enroute waypoint naming

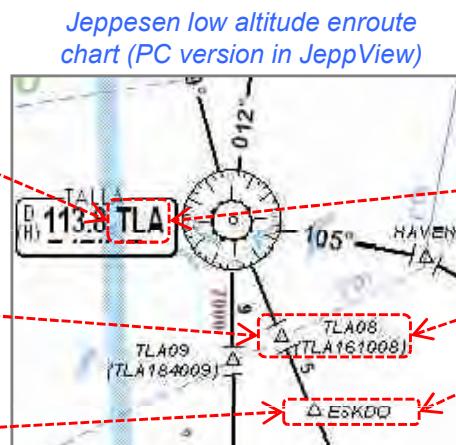### If an enroute fix has a published name which is not suitable for ARINC 424

- The method applied in ARINC 424 coding is as follows

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

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

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

### If an enroute fix or intersection is published without a name

- The identifier is constructed from the identifier of, typically, the nearest airway VOR (which is the reference for the waypoint) and the distance from that VOR

- If the distance is less than 100nm, the identifier format is the three letters of the VOR ident followed by a two digit distance, eg a waypoint 35nm from "ABC" VOR: `ABC35`

- If the distance is 100-199nm, the identifier format is the three letters of the VOR ident preceded by the last two digits of the distance eg a waypoint 135nm from "ABC" VOR: `35ABC`

- If unnamed waypoint is collocated with a named waypoint on a different route structure then the named waypoint's identifier is used

➡ • **European enroute charts have been updated with airway waypoint identifiers that are always compatible with ARINC 424, hence the paper charts and databases should be highly consistent**

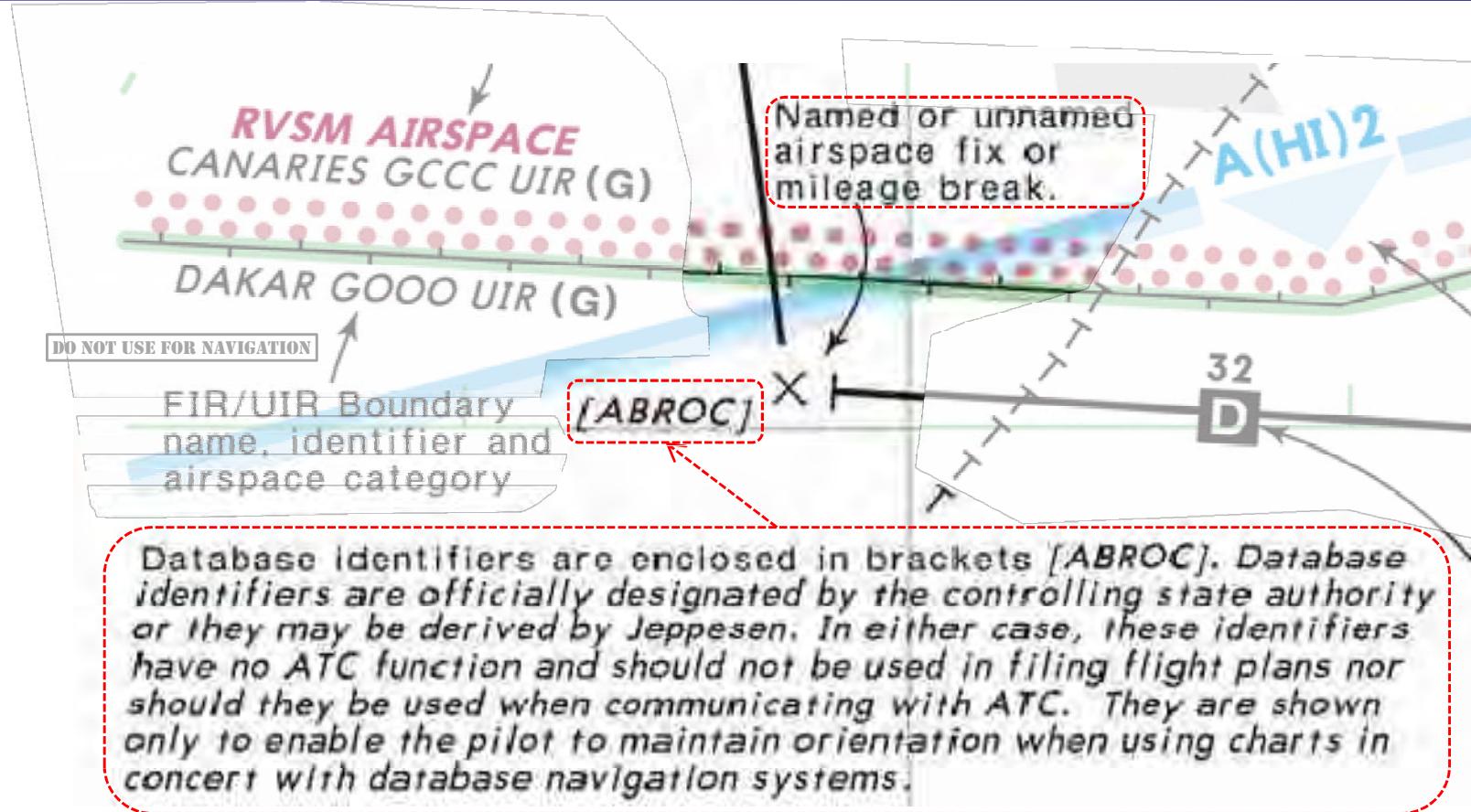• **The three formats used are navaid identifiers, 5LNCs and the 'reference VOR plus 2 digit distance'**

### Example of Airway waypoints



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

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

VOR identifier

Reference VOR and distance identifier

"5LNC" identifier

*Jeppesen low altitude enroute chart (PC version in JeppView)*

DO NOT USE FOR NAVIGATION

*Garmin GNS480 airway route*

**RVSM AIRSPACE**
CANARIES GCCC UIR (G)

DAKAR GOOO UIR (G)

DO NOT USE FOR NAVIGATION

FIR/UIR Boundary name, identifier and airspace category

Named or unnamed airspace fix or mileage break.

A(HI)2

32 D

[ABROC]

Database identifiers are enclosed in brackets [ABROC]. Database identifiers are officially designated by the controlling state authority or they may be derived by Jeppesen. In either case, these identifiers have no ATC function and should not be used in filing flight plans nor should they be used when communicating with ATC. They are shown only to enable the pilot to maintain orientation when using charts in concert with database navigation systems.
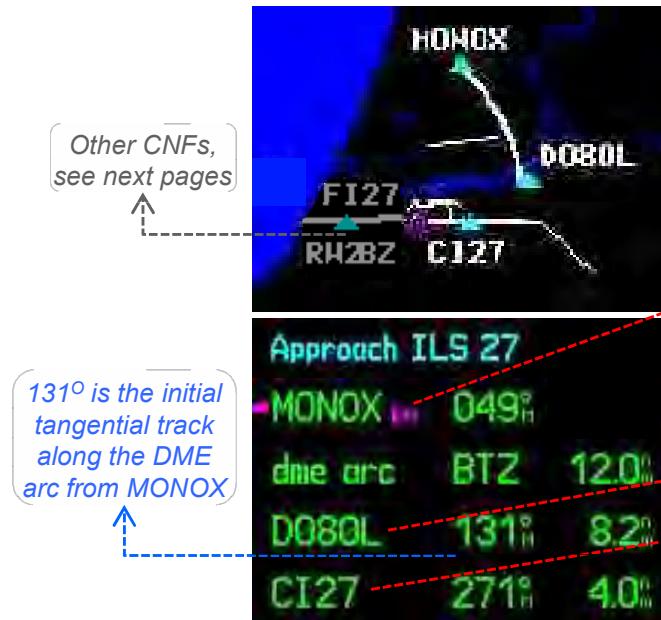
- Note: the nomenclature of waypoint names is sometimes confusing.
- "Database identifier" can be a generic term for the ARINC 424 short, coded name of any navaid, fix, airport etc.
- In the context of the chart legend above, "database identifier" means a Computer Navigation Fix name which is not part 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 GPS database

- 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

**CNFs**

**Charted Waypoints**

**CNFs that only appear in RNAV databases**

**CI27**

**CNFs that are both in RNAV databases and paper charts (but may have different identifiers)**

**D080L**

**Normal waypoints appearing in both databases and paper charts**

**MONOX**

*Examples*

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

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

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

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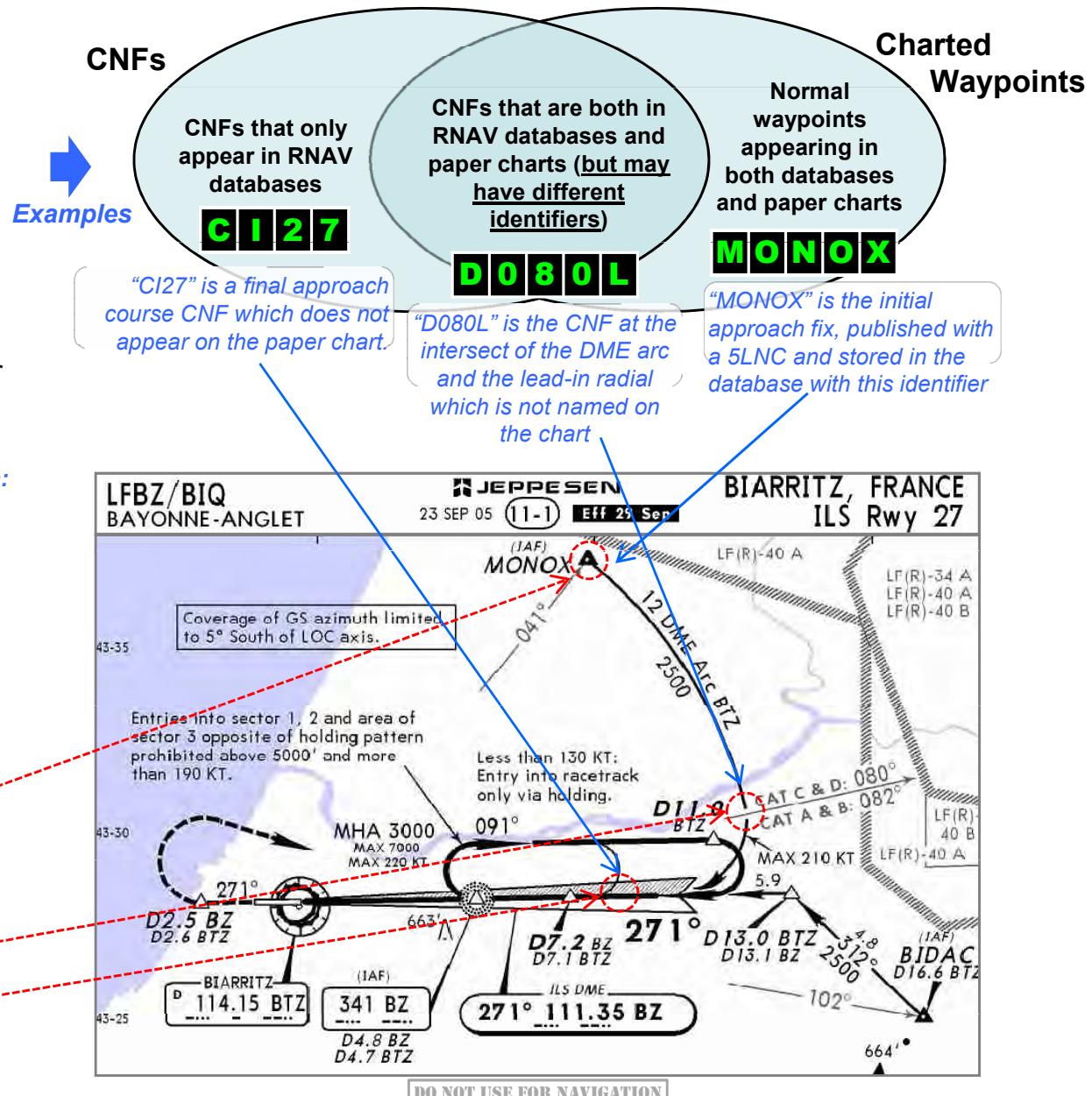


*Other CNFs, see next pages*

*131° is the initial tangential track along the DME arc from MONOX*

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



DO NOT USE FOR NAVIGATION

*Garmin GNS530W display extracts*
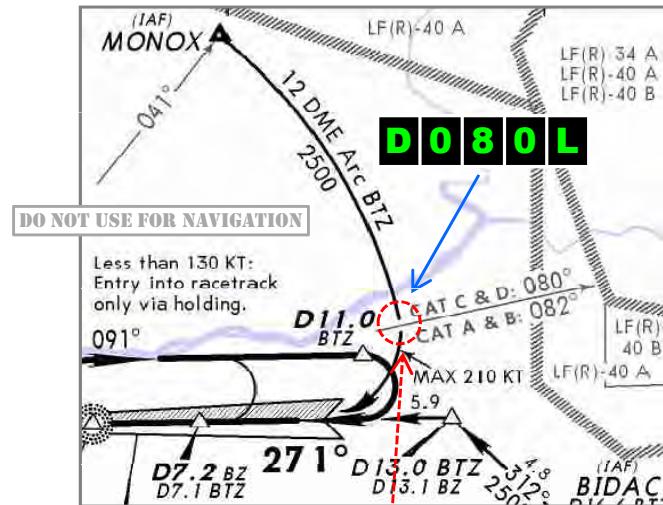


**Procedure waypoint "bearing/distance" CNF convnetion**

- In SIDs, STARs and Approaches, this convention is used to create an identifier for unnamed fixes or DME fixes

- The identifier is always a 5 character alphanumeric in the format:

**D n n n a**

**first character is always "D"**

**middle 3 digits are the radial from the reference VOR ( or other reference point)**

**last character is a letter code for the distance from the reference point**

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

- **Hence, in the example above, the waypoint on the BTZ 080 radial and 12nm DME arc is given the identifier "D080L"**

- **Procedure "bearing/distance" CNFs are only unique <u>within</u> a TMA**

- **Note that this 080 radial represents the CAT C & D procedure: the Jeppesen database does <u>not</u> code any CAT A & B procedures**

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



*Garmin GNS530W display extracts*

**Airport CNF convention**

- This convention allows CNFs to be created for all the fixes RNAV equipment needs to provide guidance throughout an approach procedure, which may not be published or have an ARINC 424 compatible name

- The identifier is a 4 or 5 character alphanumeric in the format:

**a a n n a**

**1st letter defines the waypoint type**

**2nd letter defines the approach type, 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**

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

- The various codes for the waypoint type and approach type are detailed on the next page
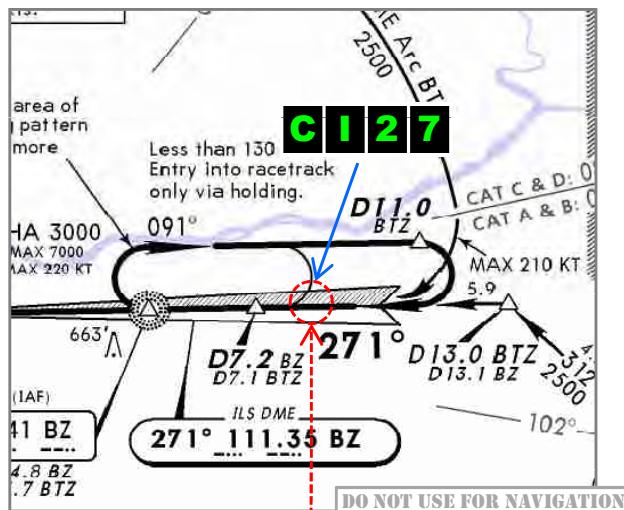
- In the "CI27" example above, the "C" indicates a final approach course fix, the "I" indicates an ILS procedure, and the "27" that the procedure is for runway 27

- 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 "CI27" 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 | | More than one procedure exists for a given runway | | Procedure type codes used | |
|---|---|---|---|---|---|
| **First two characters of the CNF identifier are the Waypoint Type** | | **First character of the CNF identifier is the Waypoint Type** | | **Second character of the CNF identifier is the Procedure Type** | |
| Initial Approach Fix | **AF** | Initial Approach Fix | **A_** | **_I** | ILS Approach |
| Intermediate Approach Fix | **IF** | Intermediate Approach Fix | **I_** | **_L** | Localiser Approach |
| Final Approach Course Fix | **CF** | Final Approach Course Fix | **C_** | **_D** | VOR/DME Approach |
| Final Approach Fix | **FF** | Final Approach Fix | **F_** | **_V** | VOR Approach |
| Missed Approach Point | **MA** | Missed Approach Point | **M_** | **_N** | NDB Approach |
| Step-Down Fix | **SD** | Step-Down Fix | **S_** | **_Q** | NDB/DME Approach |
| Runway Centreline Fix | **RC** | Runway Centreline Fix | **R_** | **_R** | RNAV Approach |
| Touchdown point | **TD** | Touchdown point | **T_** | **_P** | GPS Approach |
| **Runway Fix** | **RW** | | | | |
| **Outer Marker** | **OM** | | | | |
| Middle Marker | **MM** | | | | |
| Inner Marker | **IM** | | | | |
| Back course Marker | **BM** | | | | |

*Rarely used* (for Step-Down Fix, Runway Centreline Fix, Touchdown point)

*CNFs unique to a runway, so no need for a single letter code* (for Runway Fix through Back course Marker)

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

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

▶ • The only unfamiliar, but frequently used, waypoint type is the Final Approach Course (or Capture) fix, CF or C_

• Many older RNAV 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**

## Full List of 25 Approach types

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

## Matrix of Waypoint and Approach type combinations

| Waypoint types | ILS(I) | ILS(L) | ILS(B) | VOR(D) | VOR(V) | VOR(S) |
|---|---|---|---|---|---|---|
| IAF | AI | AL | AB | AD | AV | AS |
| IF | II | IL | IB | ID | IV | IS |
| FACF | CI | CL | CB | CD | CV | CS |
| FAF | FI | FF | FB | FD | FV | FS |
| MAP | MI | ML | MB | MD | MV | MS |
| TDP | TI | TL | TB | TD | TV | TS |
| RCI | RI | RL | RB | RD | RV | RS |
| Step-Down | SI | SL | SB | SD | SV | SS |

| Waypoint types | NDB(N) | NDB(Q) | MLS(M) | RNAV(R) | TACAN(T) | LORAN(C) |
|---|---|---|---|---|---|---|
| IAF | AN | AQ | AM | AR | AT | AC |
| IF | IN | IQ | IM | IR | IT | IC |
| FACF | CN | CQ | CM | CR | CT | CC |
| FAF | FN | FQ | FM | FR | FT | FC |
| MAP | MN | MQ | MM | MR | MT | MC |
| TDP | TN | TQ | TM | TR | TT | TC |
| RCI | RN | RQ | RM | RR | RT | RC |
| Step-Down | SN | SQ | SM | SR | ST | SC |

| Waypoint types | IGS(G) | LDA(X) | SDF(Z) | FMS (F) | GPS(P) | HEL(H) |
|---|---|---|---|---|---|---|
| IAF | AG | AX | AZ | 1F | AP | AH |
| IF | IG | IX | IZ | 2F | IP | IH |
| FACF | CG | CX | CZ | 3F | CP | CH |
| FAF | FG | FX | FZ | 4F | FP | FH |
| MAP | MG | MX | MZ | 5F | MP | MH |
| TDP | TG | TX | TZ | 6F | TP | TH |
| RCI | RG | RX | RZ | 7F | RP | RH |
| Step-Down | SG | SX | SZ | 8F | SP | SH |

| Waypoint types | VOR C-T-L(E) | NDB C-T-L(U) | LOC C-T-L(J) | BAC C-T-L(K) | MLS (W) | MSL (Y) |
|---|---|---|---|---|---|---|
| IAF | AE | AU | AJ | AK | AW | AY |
| IF | IE | IU | IJ | IK | IW | IY |
| FACF | CE | CU | CJ | CK | CW | CY |
| FAF | FE | FU | FJ | FK | FW | FY |
| MAP | ME | MU | MJ | MK | MW | MY |
| TDP | TE | TU | TJ | TK | TW | TY |
| RCI | RE | RU | RJ | RK | RW | RY |
| Step-Down | SE | SU | SJ | SK | SW | SY |

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

### *Approach waypoints*

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

**Note: in the late 1990s, it was proposed that the waypoints in RNAV approaches 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 RNAV procedures, and how GPS units provide procedure guidance**

# Course contents

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. **Procedures**
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

# Important note

- There is significant variation in the methods and structures used in instrument procedure design, and the corresponding chart titles and text

- These designs and descriptions change over time, particularly as RNAV is being implemented in Europe. When new conventions are introduced, older charts are often not systematically updated

- Hence, it is not possible to give an exhaustive "set of rules" or an exhaustive set of examples to cover every permutation of charts, procedures and coding

- This section of the manual is intended as a guide, not an complete rule book

- **A current, approved chart is the definitive source of navigation data; and, in operations where this is approved, a suitable, current RNAV 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 an RNAV database is required (eg. P-RNAV, or GPS approaches), a discrepancy between the database and chart means that the RNAV procedure <u>may not be flown</u>, and an alternative must be used.

- 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 GPS screen shots in this manual may be used for navigation purposes

# Procedure titles and names
## 1. Overview

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

| 3 kinds of procedure ➡ | Departures | Arrivals | Approaches |
|---|---|---|---|
| | collectively known as "Terminal Procedures" | | |
| **Paper chart procedure "titles"** | • "SID"<br>• "Departure",<br>• FAA charts also use "Departure Procedure" and "DP" | • "STAR"<br>• "Arrival"<br>• "Transition"<br>• "Initial Approach"<br>• Continuation charts between a STAR and an approach | • Many types of approach: ILS, VOR, SRA, RNAV etc<br>• 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<br>• Procedure name on chart, plus…..<br>• Procedure ICAO identifier in (curved brackets)<br>• Database identifier in [square brackets] if different from ICAO identifier | | • Chart title has the full procedure name |

- The coding of procedure identifiers in GPS 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<br>• Transition identifier<br>• Runway identifier | • Arrival identifier<br>• Transition identifier<br>• Runway identifier | • Approach identifier (which also specifies the runway)<br>• Transition identifier or "Vectors" |
|---|---|---|---|

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

➡ • **The key links between published procedures and database coded procedures are the <u>procedure identifier</u> and <u>transition identifier</u>**

• **If the ICAO and database identifiers are not the same, the database identifier will be included on the paper chart in [square brackets]**

# GPS databases encode both RNAV and "traditional" procedures

- In paper chart form, procedures are 'conventional' or 'traditional' (in the sense of requiring radio navigation) <u>by default</u>, unless specifically designated as RNAV procedures in the chart title, procedure name or chart notes

- Generally, all published, route-based procedures are coded in GPS databases (omnidirectional and radar procedures are not)

- From the point of view of "coding style" and how GPS procedure guidance may be used, this results in three kinds of database-coded procedure:

| | 1. "Database Overlays" | 2. "Published Overlays" | 3. RNAV 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> RNAV guidance may be used | Procedures designed and published for use only with RNAV. |
| **Terminal Procedures** | • In Europe, most terminal procedures are still 'traditional' (except in the major TMAs that use B-RNAV or P-RNAV procedures)<br>• 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 <u>same ICAO procedure identifiers</u> as the conventional SID or STAR chart | • B-RNAV or P-RNAV procedures<br>• Coding uses RNAV waypoints and mainly the CF and TF path-terminators, with few, if any, CNFs needed |
| **Approaches** | • Most approaches in Europe are based on conventional navaids<br>• These are coded in GPS 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 an RNAV method of navigation (eg. "VOR DME or GPS Rwy 27") | • Non-precision GPS approaches are increasingly common in Europe. A variety of names are used (RNAV, GNSS, GPS)<br>• All the CNFs required are usually published on the paper charts (including Airport CNFs) |
| **Use of GPS for primary navigation guidance?** | **Generally, no. GPS guidance is supplemental to radio aids.** *Some operators/installations may be approved to use database overlays as primary guidance: details are beyond the scope of this course* | **RNAV optional, if approval requirements are met** | **RNAV <u>required</u>; radio aids only used for gross error check. Appropriate RNAV 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 non-RNAV procedures**

· **GPS units will generally provide a message alert when "advisory only" guidance is activated for a non-RNAV procedure**

- 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

- The FAA also uses some slightly different procedure titles which are not detailed in this manual

  - **The main European standards and structures are described in the next pages**

# Procedure titles and names
## 3. Departures

**_Departure titles in Jeppesen charts:_**

|  | 'general' IFR procedures | standard IFR procedures |
|---|---|---|
| **Traditional** | **DEPARTURE** | **SID** |
| **RNAV** | **RNAV DEPARTURE** (not used at present) | **RNAV SID** also **RNAV SID (OVERLAY)** |

**_SID name format in Jeppesen charts:_**

| _waypoint_ | _1 digit_ | _1 letter_ | _(ICAO designator)_ | _[database identifier]_ |
|---|---|---|---|---|
| ↓ | ↓ | ↓ | ↓ | ↓ |

**Example:** BUZAD   THREE   JULIETT   (BUZAD 3J)   [BUZA3J]

_In Europe, usually the full name of the waypoint or fix at the end of the procedure_

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

_Often the code letter for a particular departure runway. More than one letter may be used for the same runway, and the letter codes may have another meaning (eg. routes for Jet vs Prop aircraft)_

_The ICAO procedure "designator" is used for flight plan filing. It uses the ICAO identifier for the final waypoint instead of its full name (if these are different, eg. Lambourne Three Alpha vs. LAM 3A)_

_The ARINC 424 procedure name is limited to 6 characters. If the name of the final fix is a 3 letter VOR ident, the ICAO procedure identifier will be 5 characters (3+1+1) and used as the database identifier._
_If the final waypoint name is a 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



Jeppesen chart: EGHH/BOH BOURNEMOUTH, BOURNEMOUTH, UK — 9 MAR 07 (10-3B) Eff 15 Mar — DEPARTURE

Trans level: By ATC    Trans alt: 4000'
1. Departures include noise preferential routes and apply to all jet and turbo prop aircraft unless otherwise instructed by ATC.
2. Climb as rapidly as compatible with safety.
3. On departure from any runway all prop aircraft are to climb on runway heading to 540' or above before turning, unless otherwise instructed by ATC.

Apt Elev 38'

MSA BIA Lctr

RWYS 08, 26 DEPARTURES TO SOUTH & WEST

BOURNEMOUTH 339 BIA

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

## DEPARTURE
## RWYS 08, 26 DEPARTURES
## TO SOUTH & WEST

*Garmin GNS530W procedure selection page*

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

*Garmin GNS530W flight plan waypoint list*

Runway ID — RW08
Bearing/Distance CNFs — D078B / D078E
5LNC — THRED

### CNF comment

*Note that the Procedure bearing/distance CNF names in this example appear to be referenced to the BIA NDB at the centre of the airport, the "078" bearing implicit in both names is only approximate, the alphabet distance codes are more accurate. The naming convention's purpose is to create a distinct identifier for CNFs but no navigation meaning should be inferred from the identifier text (eg. "the next waypoint is D078B so I must fly a track of 078 degrees") – navigation data is accurately depicted in the path-terminator information to the right of the waypoint name and the GPS Nav or Map pages provide the approved source of guidance*

# Example of a conventional SID
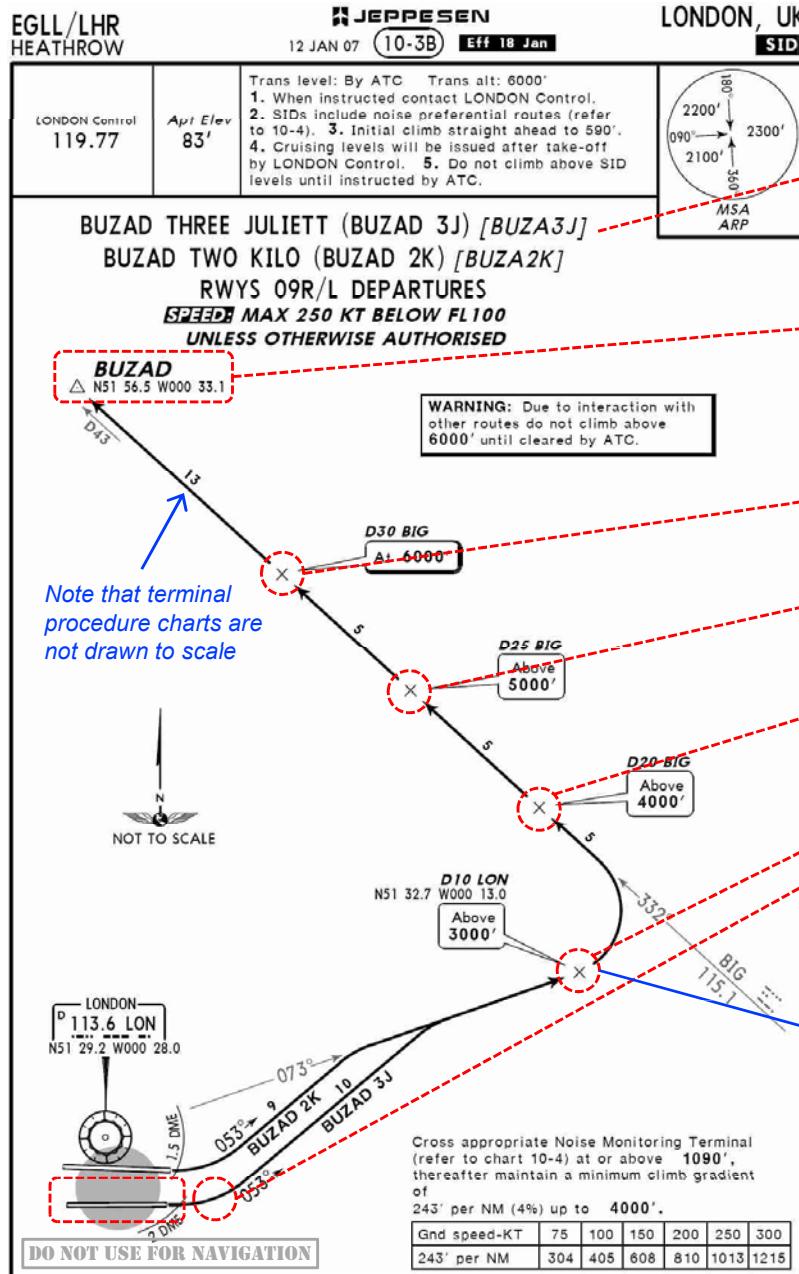


Jeppesen chart: EGLL/LHR HEATHROW, LONDON, UK — 12 JAN 07 (10-3B) Eff 18 Jan — SID

BUZAD THREE JULIETT (BUZAD 3J) [BUZA3J]

*Garmin GNS530W procedure selection page*

*Garmin GNS530W flight plan waypoint list*

*Note that terminal procedure charts are not drawn to scale*

*Runway ID*

*Bearing/ Distance CNFs*

*Enroute CNF*

*5LNC*

**CNF example**

On the paper chart, "D10 LON" is a fix on the LON 073 radial and 10 DME. In the Procedure bearing/distance CNF convention, this results in the identifier "D073J", where J is the alphabetical code for 10nm.

"BIG30" uses the Enroute CNF convention because the DME distance from its reference VOR exceeds the 26nm available in the Procedure bearing/distance CNF alphabetical code

# Example of an RNAV SID

**LFPB/LBG** JEPPESEN **PARIS, FRANCE**
LE BOURGET 9 MAR 07 (30-3M) Eff 15 Mar **RNAV SID**

Apt Elev 218' — Trans level: By ATC   Trans alt: 4000'
SIDs are also minimum noise routings.

**EVREUX, L'AIGLE**
**RWYS 07, 09, 21 RNAV DEPARTURES**
RNAV (GNSS OR DME/DME OR VOR/DME BT-PGS)
JETS & PROPS ABOVE FL115
LETTER J & M  ASSIGNED SIDS TO WEST

2000'
089°
2500'
MSA
BT VOR
MSA 2500' all sectors
if DME not available
❶ 2500';
2000' within 23 NM
❷ 2000' within 8 NM

**SPEED RESTRICTION**
MAX 250 KT below FL100.
At or above FL100 speed may
be increased without further
ATC clearance.

EVREUX
112.4 EVX
N49 01.9 E001 13.3
(TACAN not co-located)
N49 01.7 E001 12.8
(PGS R-274/D55.5)

117.05 PGS
N49 00.0 E002 37.4

108.8 BT
N48 58.5 E002 27.3

At 620'

At 1000'
but not later than
BT 3.4 DME

R108°

MAX 185 KT

D13 BT
PB093
N48 57.1
E002 46.9

EVX 1J, 1M

288°
R091°
74
LGL 1J, 1M
271°
KELUD
N48 46.1 E002 23.7
(PGS R-216/D15)

L'AIGLE
115.0 LGL
N48 47.4 E000 31.8
(PGS R-263/D83.8)

NOT TO SCALE

These SIDs require a minimum climb gradient
of 334' per NM (5.5%) up to FL150 for ATC
purposes.

| Gnd speed-KT | 75 | 100 | 150 | 200 | 250 | 300 |
|---|---|---|---|---|---|---|
| 334' per NM | 418 | 557 | 835 | 1114 | 1392 | 1671 |
| 608' per NM | 760 | 1013 | 1519 | 2025 | 2532 | 3038 |

If unable to comply advise ATC upon first
contact or as soon as possible during climb.

**HIGH PERFORMANCE PROCEDURES**
Aircraft able to maintain a climb
gradient of about 608' per NM
(10%) up to FL150 may be granted
shorter departure routes with radar
guidance by DE-GAULLE Departure.

DO NOT USE FOR NAVIGATION

**RNAV SID**
**EVREUX, L'AIGLE**
**RWYS 07, 09, 21 RNAV DEPARTURES**
RNAV (GNSS OR DME/DME OR VOR/DME BT-PGS)

*Question 1:*
*Is this a P-RNAV or B-RNAV route, it's not explicit on the chart?*
*(see next page)*

*Garmin GNS530W procedure selection page*

DEP
LGL1J
RUNWAY
RW09
TRANS
LGL
Load?
150%

RUNWAY
RW07
RW09
RW21

*Note that multiple runways share the same departure procedures, hence the runway field has 3 options available in the procedure selection page*

*Question 2:*
*What is the difference between the "J" and "M" designators?*
*(see next page)*

*Note that PB093 is a Fly-Over waypoint. These are only used in RNAV procedures when turn anticipation is undesirable; in this case, the large track change would result in a very early turn, especially for fast aircraft, if it were a Fly-By waypoint*

*Note that ICAO identifiers are only printed on the route plan depiction on this particular chart, not at the top of the page, as is more common*

*Garmin GNS530W flight plan waypoint list*

Departure LGL1J

| | | | |
|---|---|---|---|
| Runway ID | RW09 | | |
| Bearing/ Distance CNFs | D097C | 086° 4.0° | 4.0° |
| | PB093 | 097° 10.4° | 14.4° |
| 5LNC | KELUD | 241° 17.8° | 32.2° |
| VOR ident | LGL | 271° 74.0° | 106° |

**CNF comment**

*Note that the bearing/distance CNF identifier "D097C" is referenced from the BT VOR to the northeast of the Le Bourget. The path-terminator data correctly identifies the track to this waypoint as 086 degrees after take-off. The along-track distance is coded as 4nm from the start of the take-off roll. The turning point for the 097 degrees track to "PB093" is published on the chart as 2.6nm DME distance from the BT VOR. This, rather than the CNF, should be used for primary guidance. Note "PB093" is a tactical RNAV waypoint identifier, not a CNF.*

• Page 30-3 of the LFPB charts has departure instructions that are helpful for interpreting the individual SID pages
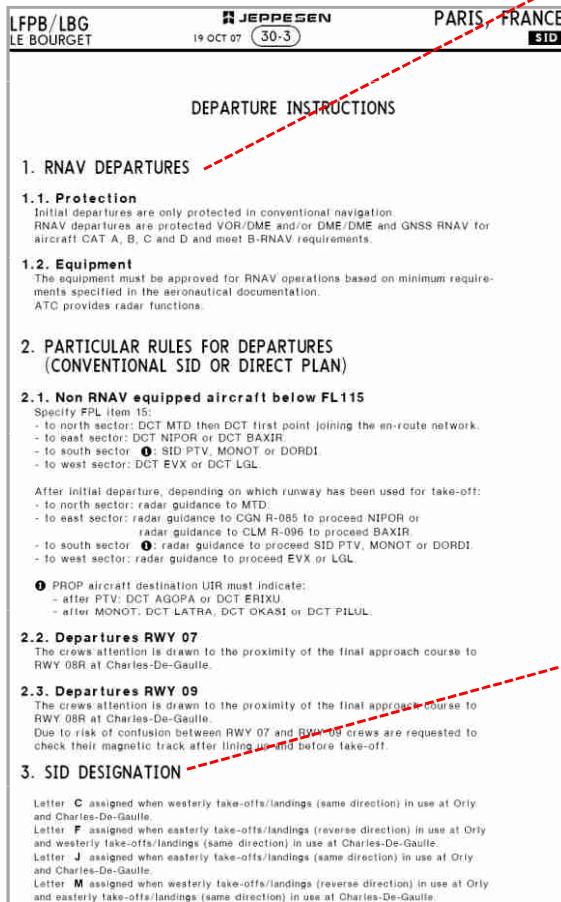
**Question 1:** (referring to previous page)
**Is this a P-RNAV or B-RNAV route, it's not explicit on the chart?**

## 1. RNAV DEPARTURES

### 1.1. Protection

Initial departures are only protected in conventional navigation. RNAV departures are protected VOR/DME and/or DME/DME and GNSS RNAV for aircraft CAT A, B, C and D and meet B-RNAV requirements.

### 1.2. Equipment

The equipment must be approved for RNAV operations based on minimum requirements specified in the aeronautical documentation. ATC provides radar functions.

• Paragraph 1.1 describes how the procedures are designed to protection criteria suitable for B-RNAV GPS, however 1.2 specifies that AIC/AIP sources must be checked for the minimum requirements; which are B-RNAV approval in this case. A P-RNAV 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?**

## 3. SID DESIGNATION

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

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

Letter **M** 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.

• The final letter of the procedure identifier, in the case of LFPB, does not specify a particular departure runway but the departure direction (W or E) and whether Orly departures are in the same or reverse direction. This relates to the proximity of the 3 large Paris airports

# Example of a SID with a published RNAV Overlay



Note that the routes and ICAO identifiers are the same

The overlay chart depicts RNAV waypoints instead of radio fixes

Since the procedure identifiers are the same, there is only one database coded procedure for each conventional route and its overlay version. The published RNAV tactical waypoint names are used, and not CNF identifiers created by Jeppesen
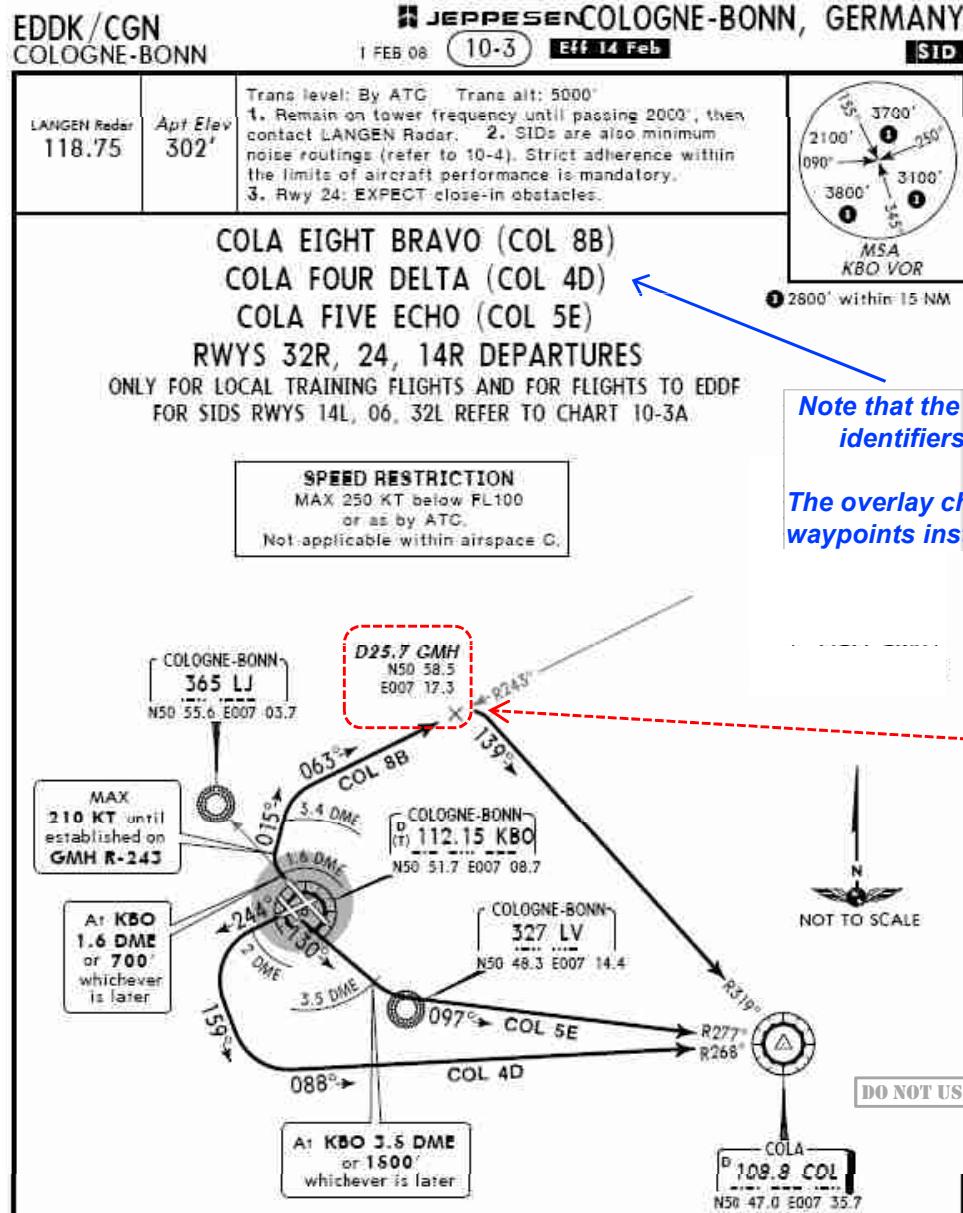
Note: State AIP charts often publish SIDs for the same runway on the same chart. In this case, the RNAV overlay is only detailed in the in the German AIP text page following the 32R SID chart

# 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



**SID**

LSGG/GVA GENEVA — JEPPESEN GENEVA, SWITZERLAND — 13 APR 07 (10-3G1) SID

GENEVA Departure (R) 119.52 — Apt Elev 1411' — Trans level: By ATC   Trans alt: 7000'
1. Contact GENEVA Departure when instructed.   2. SIDs are also minimum noise routings. Strict adherence within the limits of aircraft performance is mandatory.   3. To expedite traffic, expect line-up clearances at intersections unless operations require full runway length.

KONIL FOUR CHARLIE (KONIL 4C) [KONI4C]
KONIL TWO DELTA (KONIL 2D) [KONI2D]

waypoint  digit  letter    (ICAO designator)    [database identifier]

- **The SIDs have the usual ICAO designators and are coded in the database with appropriate identifiers**

**TRANSITION**

LSGG/GVA GENEVA — JEPPESEN GENEVA, SWITZERLAND — 6 JUL 07 (10-3N) TRANSITION

GENEVA Departure (R) 119.52 — Apt Elev 1411' — Trans level: By ATC   Trans alt: 7000'

TRANSITION ROUTES AFTER KONIL

DO NOT USE FOR NAVIGATION

[database identifier]

No other transition available

Garmin GNS530W

DO NOT USE FOR NAVIGATION

- **The transitions are B-RNAV ATS routes, published in the paper chart but, in this example, without ICAO designators and they are not coded as routes in the GPS database**

- **(An airline's customised database may include such routes)**

# Example of a SID which is not coded in RNAV databases

**_EICK Cork_**
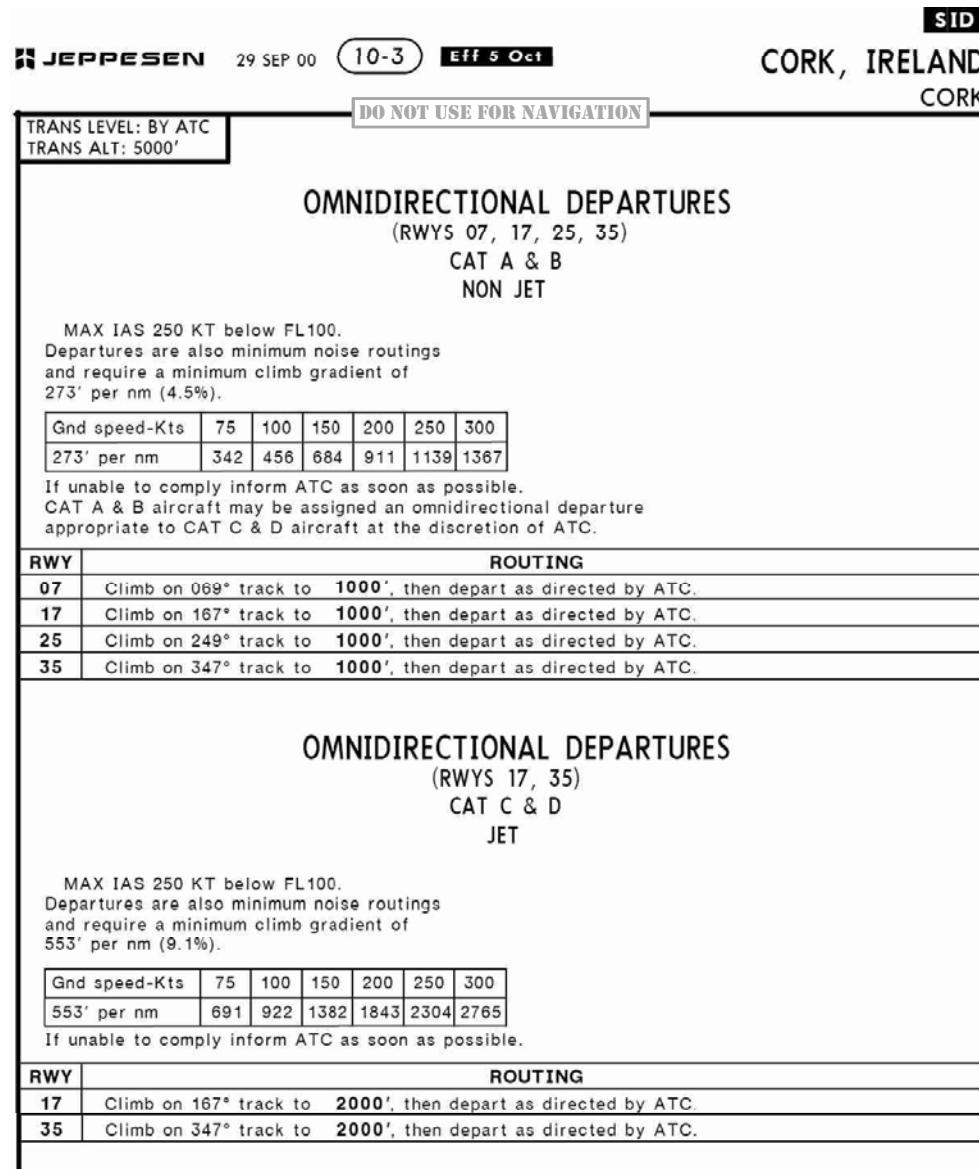


- Although this chart has a SID title, the omnidirectional departures do not have a route structure, so they are not coded as a departure procedures in the database

*(illustrative example, route-based SIDs were introduced at EICK in Feb 2008)*

# Structure of Arrival and Approach procedures
## 1. The ICAO model

**The ICAO arrival and approach procedure model:**



Enroute a — Arrival transition segments — common route segment

$IAF_1$ — Approach transitions

Enroute b

IF    FAF    MAP

$IAF_2$

Enroute c — $IAF_3$

Arrival route | Initial segment | Intermediate segment | Final segment | Missed approach segment

The 5 segments of an instrument procedure

**Mapping of the model to Jeppesen charts:**

STAR chart    Approach chart

**Mapping of the chart structure to GPS database procedure records**

Transition ID a
Transition ID b
Transition ID c

*In Europe, arrival procedures usually have a unique starting point rather than multiple transitions*

*Instrument approaches are generally coded with more than one IAF starting point selection available within the Approach Transition field of the procedure record*

Transition ID 1

| Transition ID (=initial waypoint ) & Arrival Designator | Transition ID 2 | Approach ID |
|---|---|---|
| | Transition ID 3 | |

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

STAR chart — JERSEY, UK

Approach chart — JERSEY, UK

DO NOT USE FOR NAVIGATION

RWY 27 ARRIVALS FROM NORTH

1. STAR routes begin at enroute fixes

2. They end at the Initial Approach Fix (IAF)

3. The IAF is then used as the track and course reversal navigation reference for Approach procedures

RWY 27 ARRIVALS FROM SOUTH

VOR ILS DME Rwy 27

VOR DME Rwy 27

NDB DME Rwy 27

Note: the JW NDB is the IAF in this case

| | Enroute | | IAF | IF | FAF or FAP | MAP |
|---|---|---|---|---|---|---|
| | | *Arrival route* | *Initial segment* | *Intermed. seg.* | *Final segment* | *Miss. app.* |

*Jeppesen charts*
*GPS database*

**The typical arrival structure, described on prior pages**

| STAR (or RNAV STAR) | Approach |
|---|---|
| Transition ID & <u>Arrival</u> Designator | Transition ID | Approach ID |

**Example 1: a published non-STAR arrival, not coded in the database**

| ARRIVAL (or RNAV Arrival) | Approach |
|---|---|
| unnamed procedure, not coded | Transition ID | Approach ID |

**Example 2: STAR followed by an Arrival continuation chart, whose route is coded as part of the <u>Approach</u> procedure (transition)**

| STAR (or RNAV STAR) | ARRIVAL (or RNAV Arrival) | Approach |
|---|---|---|
| Transition & <u>Arrival</u> Designator | Transition ID | Approach ID |

**Example 3: P-RNAV can also be implemented with a conventional STAR followed by a "more efficient" P-RNAV Initial Approach to the FAP/FAF <u>or</u>….**

| STAR (or RNAV STAR) | INITIAL APPROACH | Approach |
|---|---|---|
| Transition & <u>Arrival</u> Designator | Transition ID | Approach ID |

**Example 4: ….as a single "long" procedure that terminates at the FAP/FAF: In this case, the database procedure may be coded as an Arrival <u>or</u> an Approach Transition**

| TRANSITION (or RNAV Transition) | Approach |
|---|---|
| Transition ID & <u>Arrival</u> Designator | Trans'n ID | Approach ID |

**or**

| Transition ID | Approach ID |
|---|---|

➤ · **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 | standard IFR procedures |
|---|---|---|
| **Traditional** | ARRIVAL | STAR<br>ARRIVAL<br>TRANSITION<br>INITIAL APPROACH |
| **RNAV** | RNAV ARRIVAL<br>(not used at present) | RNAV STAR<br>RNAV ARRIVAL<br>RNAV TRANSITION<br>RNAV INITIAL APPROACH |

➡ · Note that an "Arrival" chart may be a 'general' route (not coded in the RNAV database), <u>or</u> a continuation route coded within the transition selections for an approach

· The examples that follow illustrate each of the procedure types

# Procedure titles and names

## 5. Arrival procedure designators

**_Example: STAR designator_**

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

EGJJ/JER JERSEY — JEPPESEN 9 MAR 07 (10-2A) Eff 15 Mar — JERSEY, UK STAR

| *ATIS 112.2 | Apt Elev. 277' | Alt Set: hPa Trans level: By ATC Trans alt: 3000' |
|---|---|---|

JERSEY 1A [JSY1A], JERSEY 2B [JSY2B]
JERSEY 1E [JSY1E], JERSEY 1F [JSY1F]
JERSEY 2P [JSY2P], JERSEY 1W [JSY1W]

JERSEY 1N, JERSEY 2Q
BY ATC, NOT TO BE USED FOR FLIGHT PLANNING

RWY 27 ARRIVALS
FROM NORTH

1900'
MSA JSY VOR

**_waypoint name_**   **_1 digit_**   **_1 letter_**   *[database identifier]*

**_Example:_**   # JERSEY 1W [JSY1W]

- *In the UK, usually the full name of the waypoint or fix at the <u>end</u> of the procedure (as in this example, the Jersey VOR )*
- *Other than in the UK, usually the name of the waypoint or fix at the <u>start</u> of the procedure*

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

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

- *the database identifier is printed in [square brackets]*
- *If the ICAO designator is a 5LNC, it will drop the last character*
- *If the ICAO name is a VOR, it will use the 3 letter ident of the VOR*
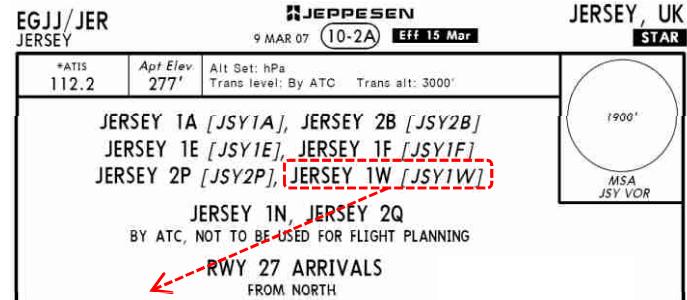
➡ · **Terminal procedure database identifiers are always in the format** `a a a n a` **or** `a a a a n a`

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

EGLL/LHR HEATHROW — JEPPESEN — LONDON, UK — 14 SEP 07 — 10-2F — INITIAL APPROACH
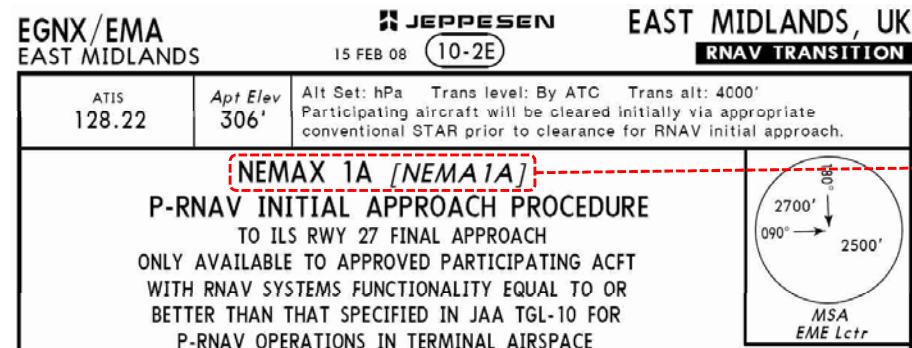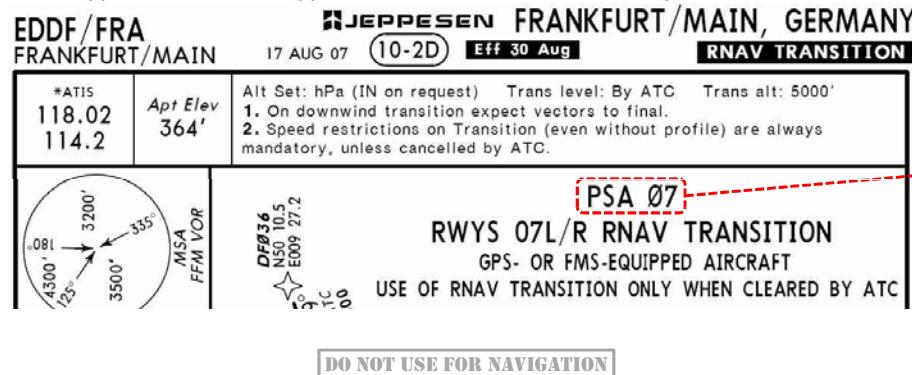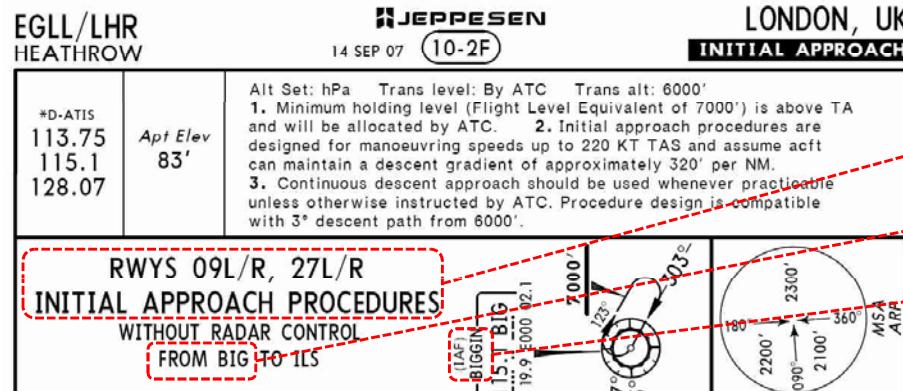
| STAR | | INITIAL APPROACH | Approach |
|---|---|---|---|
| Transition & Arrival Designator | | Transn ID | Approach ID |

1. No route designator…

2. but the route starts at "BIG" VOR

3. and BIG is also labelled as the IAF, and various EGLL STARs terminate at BIG

4. hence it is an Approach procedure record

5. with "BIG" available as the Approach transition

*Note that both the EGLL and EDDF examples, although coded in the database as Approach transitions, appear in the STAR section of their respective State AIPs*



EDDF/FRA FRANKFURT/MAIN — JEPPESEN — FRANKFURT/MAIN, GERMANY — 17 AUG 07 — 10-2D — Eff 30 Aug — RNAV TRANSITION

| RNAV TRANSITION | Approach |
|---|---|
| Transition ID | Approach ID |

1. The route name is not a procedure identifier

The route starts at "PSA" VOR and is for Runway 07 approaches, thus the route name used is "PSA 07"

2. hence it is an Approach procedure record

3. with "PSA" available as the Approach transition

DO NOT USE FOR NAVIGATION



EGNX/EMA EAST MIDLANDS — JEPPESEN — EAST MIDLANDS, UK — 15 FEB 08 — 10-2E — RNAV TRANSITION
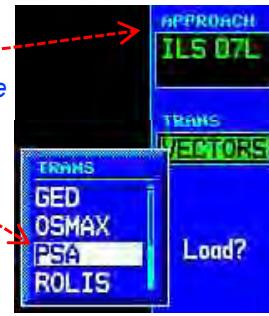
| RNAV TRANSITION | Approach |
|---|---|
| Transition ID & Arrival Designator | Approach ID |

1. The chart has an ICAO procedure designator (and a database procedure identifier)

2. hence it is an Arrival procedure record

3. with "NEMA1A" as the identifier

4. The route starts at "VELAG", which is the only available transition in the database

# Example of a 'general' Arrival



EGHH/BOH BOURNEMOUTH — JEPPESEN 24 AUG 07 (10-2B) — BOURNEMOUTH, UK ARRIVAL

*Note that, since these procedures are not STARs and do not have an ICAO identifier or published route name, ATC will include the arrival route as part of the overall clearance, eg. "G-ABCD, route direct Westcott PEPIS SAM…"*
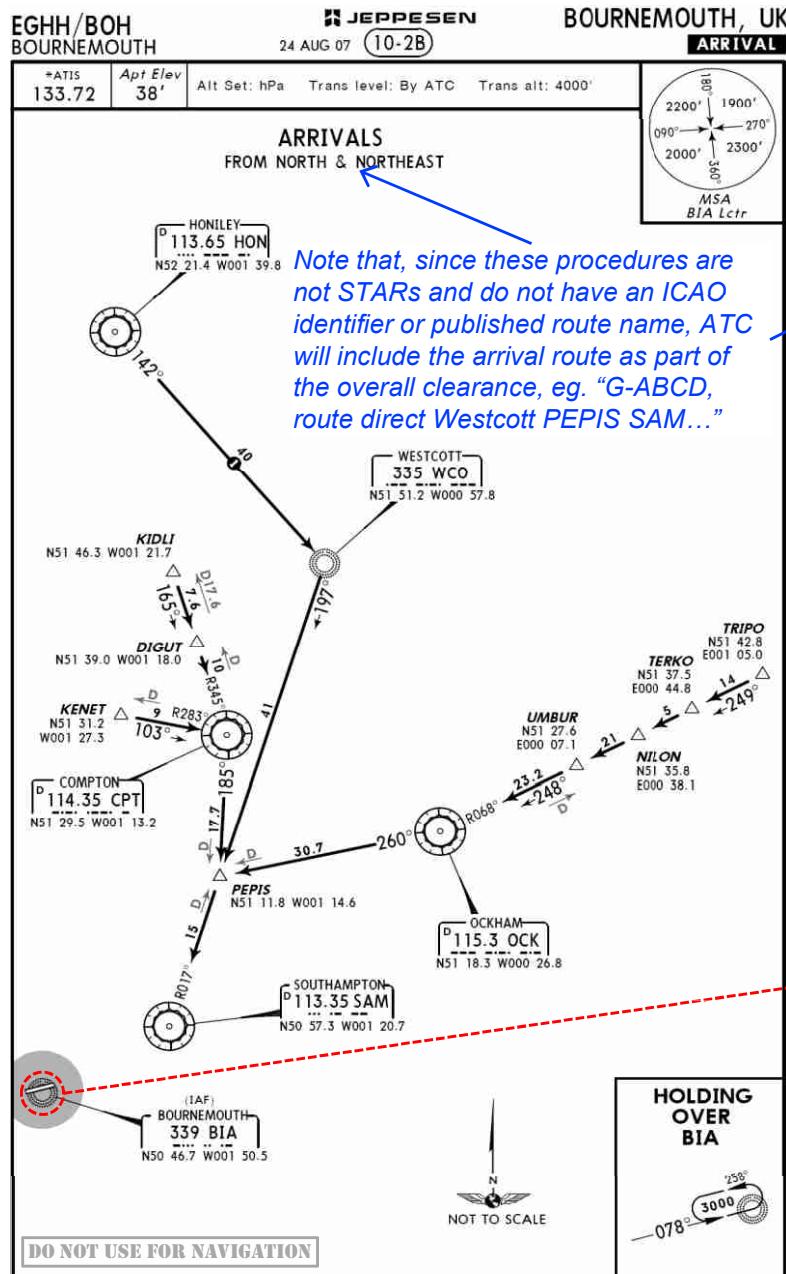
*The Arrival record selection includes all of the published STARs for EGHH, which are coded in the normal way, but not any routes called "North" or "Northeast" - they are not coded in the database*

*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
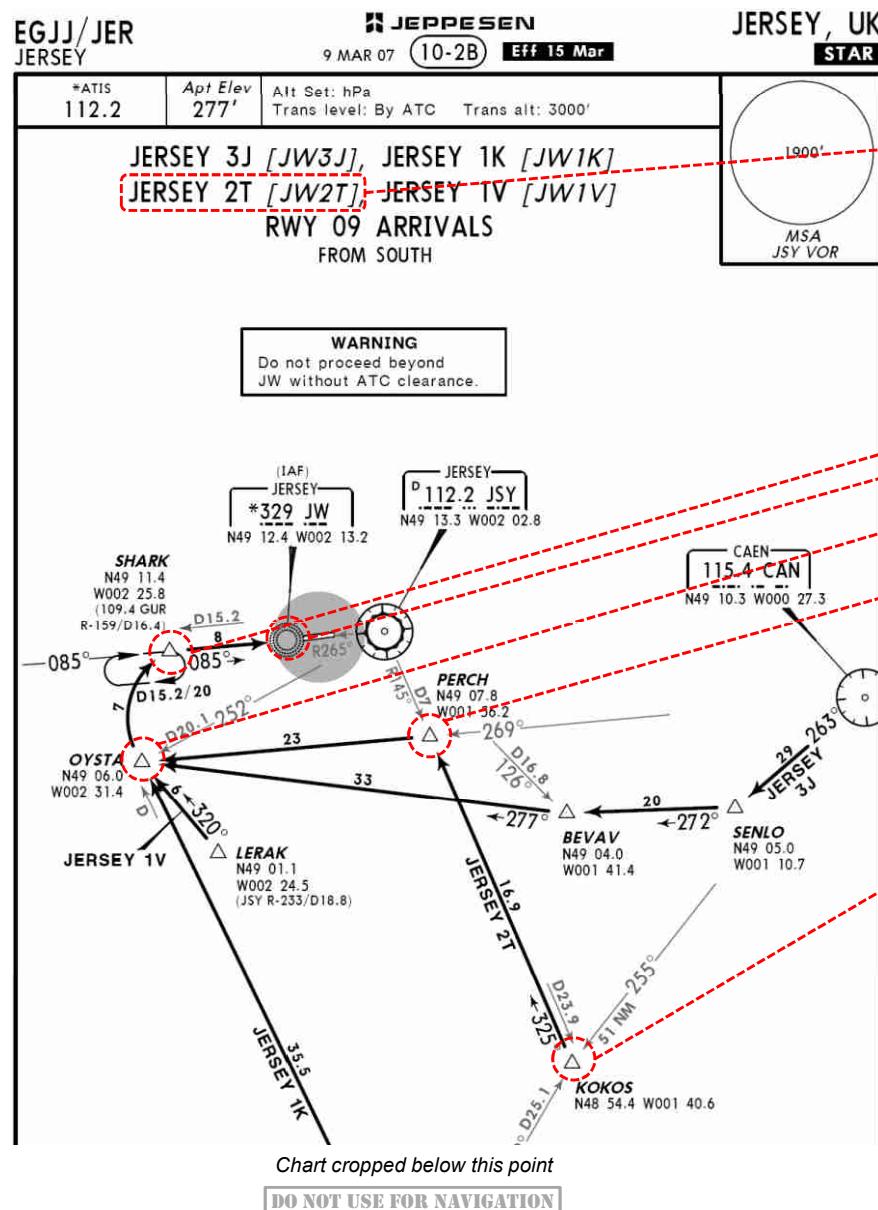


Garmin GNS530W procedure selection page

OYSTA
(name cropped on screen edge)
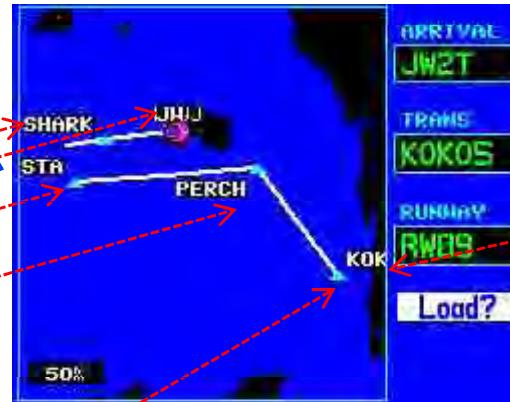
KOKOS
(name cropped on screen edge)

5LNCs

NDB ident

Garmin GNS530W flight plan waypoint list

Chart cropped below this point

DO NOT USE FOR NAVIGATION

# Example of an RNAV STAR to the IAF
## (but see next page)



LFPB/LBG
LE BOURGET

JEPPESEN
27 JAN 06 (30-2J)

PARIS, FRANCE
RNAV STAR

*ATIS 120.0 | Apt Elev 218' | Alt Set: hPa — Trans level: By ATC — Trans alt: 4000' — For additional holding information refer to page 30-2A.

DIEPPE 4P (DPE 4P)
RWYS 25, 27 RNAV ARRIVAL
FROM NORTH TO MERUE & MOKNO

MSA BT VOR

MSA 2500' all sectors if DME not available
❶ 2500'; 2000' within 23 NM
❷ 2000' within 8 NM

DIEPPE 115.8 DPE
N49 55.5 E001 10.2

At FL180
MAX 280 KT

D46 CRL
At FL100

D43 CRL
At FL80

(IAF by APP)
MOKNO
N49 26.5 E001 37.1

At FL60
MAX 250 KT

CREIL
109.2 CRL
N49 15.3 E002 30.9
(TACAN Not Co-located)
N49 15.4 E002 31.0

ROUEN 116.8 ROU
N49 27.9 E001 16.8

(IAF) MERUE
N49 18.4 E001 51.5

KOROM 098° D26 R278°
N49 19.0 E001 43.8

❸ Usable only if holding at IAF MERUE planned.

108.8 BT
N48 58.5 E002 27.3

DO NOT USE FOR NAVIGATION

**RNAV STAR**

**DIEPPE 4P (DPE 4P)**

**STARs are published RNAV and are available in B-RNAV**

*Is this a P-RNAV or B-RNAV route? Page 30-2 of the LFPB charts has overall information on arrivals and includes the comment*

*Garmin GNS530W procedure selection page*

ARRIVAL DPE4P
TRANS DPE
RUNWAY ALL
Load?

*The runway field is "All" if the same route is used for more than one runway. In this case, the procedure is for 2 of the 6 runways at LFPB*

*Garmin GNS530W flight plan waypoint list*

Arrival DPE4P

VOR ident — DPE
VOR/Distance CNFs — CRL46 150° 22.5; CRL43 148° 3.6
5LNC — MOKNO 151° 7.8

*The charted procedure seems to end at MERUE but in the GPS database DPE4P ends at MONKO?*

*Note the comment that the route segment to MERUE is only if holding there. (The AIP chart is clearer and shows a dotted line for the MONKO to MEURE segment)*

**In fact, LFPB is an example of an airport that uses an "RNAV STAR" chart followed by an "RNAV Arrival" continuation chart - see next page**

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



**RNAV STAR**

DIEPPE 4P (DPE 4P)

*Chart from previous page*

**RNAV ARRIVAL**

RWYS 07, 25, 27
RNAV ARRIVAL PROCEDURES
RNAV (GNSS OR DME/DME OR VOR/DME BT)
FROM MERUE & MOKNO
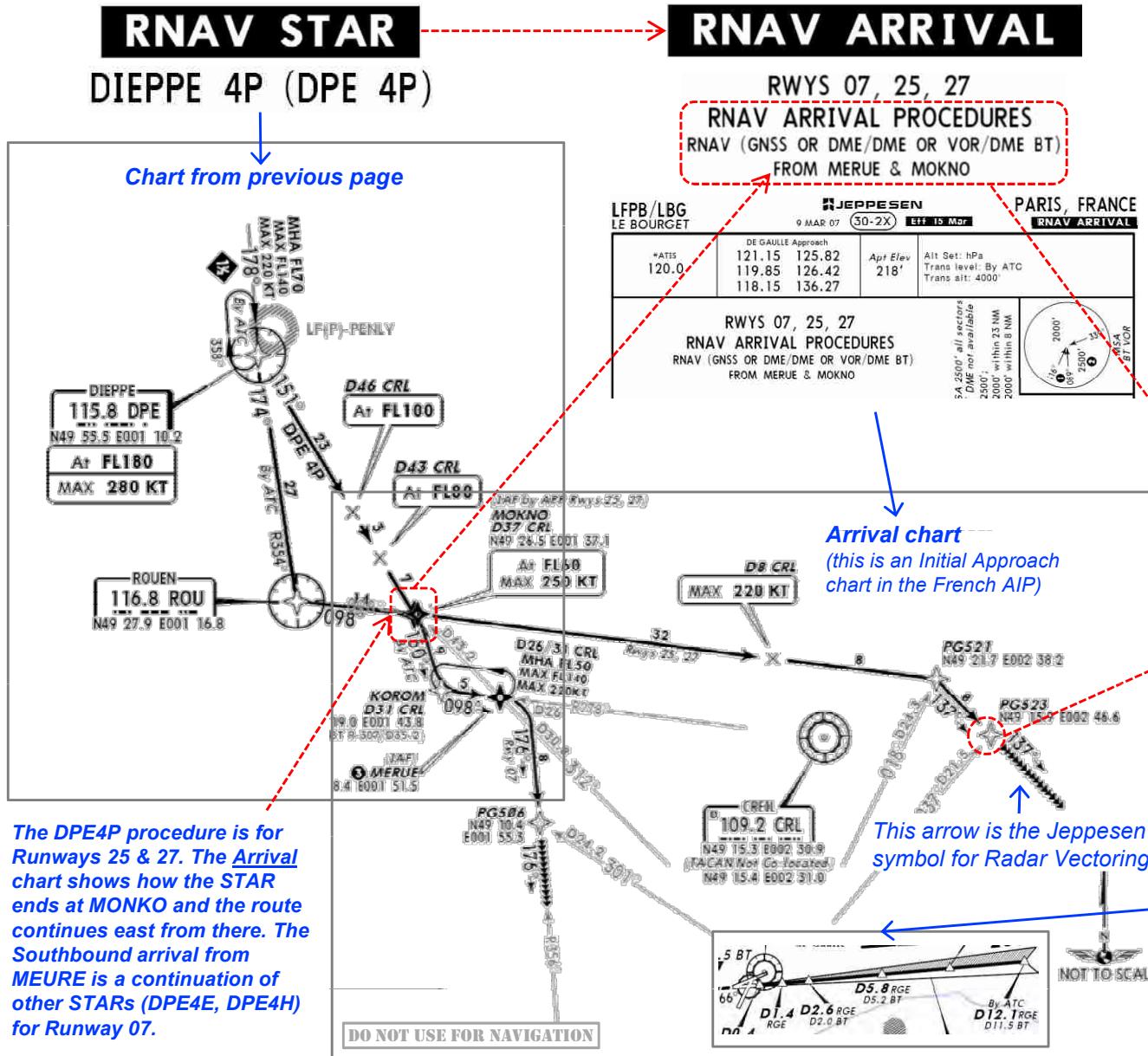
*Selecting (for example) the ILS27 database procedure results in a pop-up list of available transitions that includes MONKO; this is the route on the RNAV ARRIVAL chart*

*RNAV ARRIVAL*

*Arrival chart*
*(this is an Initial Approach chart in the French AIP)*

*ILS27*

*This arrow is the Jeppesen symbol for Radar Vectoring*

*The "man seq" leg name shows that waypoint sequencing is suspended for the Radar Vectoring segment, it is re-engaged in the Garmin 430/530 by pressing the OBS key*

**The DPE4P procedure is for Runways 25 & 27. The _Arrival_ chart shows how the STAR ends at MONKO and the route continues east from there. The Southbound arrival from MEURE is a continuation of other STARs (DPE4E, DPE4H) for Runway 07.**

ILS DME Rwy 27
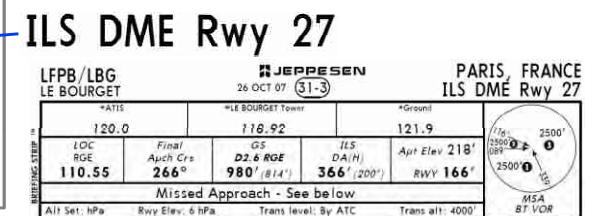
# Example of an RNAV transition to the final approach
## (coded in the database as an <u>Arrival</u> Procedure)

Jeppesen approach chart: EGNX/EMA EAST MIDLANDS, EAST MIDLANDS, UK. 15 FEB 08. 10-2E. RNAV TRANSITION.

ATIS 128.22. Apt Elev 306'. Alt Set: hPa. Trans level: By ATC. Trans alt: 4000'. Participating aircraft will be cleared initially via appropriate conventional STAR prior to clearance for RNAV initial approach.

NEMAX 1A [NEMA1A] P-RNAV INITIAL APPROACH PROCEDURE TO ILS RWY 27 FINAL APPROACH ONLY AVAILABLE TO APPROVED PARTICIPATING ACFT WITH RNAV SYSTEMS FUNCTIONALITY EQUAL TO OR BETTER THAN THAT SPECIFIED IN JAA TGL-10 FOR P-RNAV OPERATIONS IN TERMINAL AIRSPACE.

## RNAV TRANSITION

## NEMAX 1A [NEMA1A]
## P-RNAV INITIAL APPROACH PROCEDURE

*Garmin GNS530W procedure selection page*



*Note QNH setting is based on LNAV reference*

**Set QNH after passing NXS17**

*Note various level, altitude and speed limits at Waypoints*

**FL50**

*Garmin GNS530W flight plan waypoint list*



*(IAF) 5LNC*

*These are tactical RNAV waypoints (not CNFs) – using the "aannn or aaann" convention, in this case "NX" are the last two letters of the EGNX identifier, "S" indicates a Southerly arrival, and the two digits are the along-track distance to touchdown in nm*

*5LNC*

*Airport CNF*

109

# Example of an RNAV transition to the final approach
## (coded in the database as an <u>Approach</u> Transition)

**P**



**JEPPESEN** FRANKFURT/MAIN, GERMANY

EDDF/FRA FRANKFURT/MAIN — 17 AUG 07 — 10-2E — Eff 30 Aug — **RNAV TRANSITION**

*ATIS 118.02 114.2 — Apt Elev 364' — Alt Set: hPa (IN on request)   Trans level: By ATC   Trans alt: 5000'
1. On downwind transition expect vectors to final.
2. Speed restrictions on Transition (even without profile) are always mandatory, unless cancelled by ATC.

ROLIS Ø7 [ROLØ7]
RWYS 07L/R RNAV TRANSITION
GPS- OR FMS-EQUIPPED AIRCRAFT
USE OF RNAV TRANSITION ONLY WHEN CLEARED BY ATC

MSA FFM VOR

HOLDING OVER ROLIS

*Note that some RNAV Transitions often do not specify an IAF and/or IF, only the FAF or FAP*

Clearance limit **ROLIS** N50 26.1 E007 49.5

**ETARU** N50 17.1 E008 06.7 — At **FL110** — Minimum **220 KT**

DFØ93 N50 13.4 E008 19.8

DFØ92 N50 09.1 E008 22.3

DFØ94 N50 04.8 E008 24.7 — At or above **FL80** — **220 KT**

DFØ4Ø N50 02.0 E008 13.1 — At or below **FL90**

DFØ44 N49 56.4 E007 49.9 — At **FL80** — **220 KT**

DFØ96 N50 03.4 E008 18.9

DFØ41 N50 00.6 E008 07.3

DFØ42 N49 59.2 E008 01.5

DFØ43 N49 57.8 E007 55.7

DFØ53 N49 53.6 E007 58.1

DFØ54 N49 52.2 E007 52.3

DFØ52 N49 55.0 E008 03.9 — **220 KT** — At or above **5000'**

DFØ51 N49 56.4 E008 09.7 — At or above **4000'**

DFØØ7 N49 59.5 E008 22.4 — By ATC

DFØØ9 N49 58.6 E008 18.9

(FAF RWY 07R) **ROBSA** D12.6 FRD N49 57.7 E008 15.6

DME FRED **(115.9) FRD** N50 01.8 E008 34.0

FRANKFURT **114.2 FFM** N50 03.2 E008 38.2

(FAF RWY 07L) **LOMPO** D12.5 FRD N49 58.0 E008 15.6 — At or above **4000'**

DO NOT USE FOR NAVIGATION

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## RNAV TRANSITION
### ROLIS Ø7 [ROLØ7]
### RWYS 07L/R RNAV TRANSITION

*Garmin GNS530W procedure selection page*



- **The transition route name on the chart is the name of the waypoint at the start of the procedure plus the runway number (ROLIS 07) and the database identifier in square brackets is an abbreviated version of this (ROL07).**
- **<u>GPS databases do not use this convention</u>. All transitions are waypoint identifiers only (ROLIS in this example)**
- **The GPS procedure must be cross-checked against the paper chart to ensure the ROLIS GPS transition route is the same as the charted ROLIS 07 route**

*Garmin GNS530W flight plan waypoint list*



*5LNCs*

*These tactical RNAV waypoints use the "aannn" convention, in this case "DF" are the last two letters of the EDDF identifier. The last 3 digits are arbitrary and unique within the Frankfurt TMA*

*5LNC*

*Airport CNFs*

# Example of RNAV STAR arrival structure to the IAF
## (compare with the "long" RNAV transitions on the two prior pages)

LEBL/BCN
BARCELONA

**Transition ID**

**RNAV STAR**
**Transition ID & Arrival Designator**

BISBA TWO YANKEE (BISBA 2Y) [BISB2Y]
RWYS 25L/R RNAV ARRIVAL
RNAV (DME/DME)
P-RNAV APPROVAL REQUIRED

**ILS Rwy 25R**
**Approach ID**

DO NOT USE FOR NAVIGATION

*Note the long list of arrivals available at LEBL, with many very similar identifiers*

**Arrival Designator**

**RNAV STAR**
**Transition ID & Arrival Designator**

CASPE TWO YANKEE (CASPE 2Y) [CASP2Y]
MATEX ONE YANKEE (MATEX 1Y) [MATE1Y]
RWYS 25L/R RNAV ARRIVALS
RNAV (DME/DME)
P-RNAV APPROVAL REQUIRED
FROM SOUTHWEST

*Note the somewhat inconsistent coding of the associated runway, all these procedures are for 25L or 25R, the field is "25B" for both in some arrivals and "ALL" in others.*

**RNAV STAR**
**Transition ID & Arrival Designator**

MARTA FOUR YANKEE (MARTA 4Y) [MART4Y]
RWYS 25L/R RNAV ARRIVAL
RNAV (DME/DME)
P-RNAV APPROVAL REQUIRED

| ARRIVAL | ARRIVAL |
|---------|---------|
| ALBE1S | MART1Z |
| ALBE1T | MART2S |
| BISB1S | NART2T |
| BISB1T | MART4Y |
| BISE2V | MATE1S |
| BISB2Y | MATE1T |
| CASP1U | MATE1Y |
| CASP2S | MATE1Z |
| CASP2Y | NEPA2V |
| CASP4T | OSTU1U |
| GRAU1U | OSTU1V |
| GRAU3S | PUMA3S |
| GRAU4T | PUMA3T |
| LOBA1U | VERS1S |
| LOBA3S | VERS1V |
| LOBA3T | VERS1Z |

# Altitude and Speed restriction coding in ARINC 424 database procedures

- ARINC 424 does provide 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 GPS units, or the integrated 'glass cockpits' currently fitted to piston aircraft, except for the altitude terminator of the CA, VA or FA leg types (course, heading and track to altitude respectively)

- A brief description of the coding is provided below, however, any further detail is beyond the scope of this course

| Altitude Restrictions | Speed Restrictions |
|---|---|
| • Altitude restrictions are usually applied at waypoints, although ARINC 424 provides a number of different ways they can be coded. | • 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 |
| • 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. | • 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 |
| • **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 GPS 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** | • Speed restrictions that only apply during specific times are not coded |
| • 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 | |

# Approach Procedures: introduction

|  | 1. "Database Overlays" | 2. "Published Overlays" | 3. RNAV Approaches |
|---|---|---|---|
| **Precision Approaches** | • All ILS approaches are coded as database overlays | • There are currently no RNAV precision approaches in Europe | |
| **Non-Precision Approaches (NPA)** | • All AIS-published route-based NPAs are coded as database overlays (within the coverage limits of the database)<br>• 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 GPS Rwy 27") | • Non-precision GPS approaches are increasingly common in Europe. A variety of names are used (RNAV, GNSS, GPS)<br>• Airport CNFs are usually published on the paper charts |

- This section will review how conventional and RNAV approaches are coded and presented in GPS databases, and the formats used for approach procedure names and database identifiers

- The examples illustrate the RNAV issues relevant to this section, but not every variety of procedure is detailed

- Note that important topics not specific to RNAV (eg. approach minima, circle-to-land procedures, obstacle clearance and MSAs) are not considered

- The detailed description of Database Overlays is not an implicit endorsement of using GPS as primary guidance for conventional approaches: quite the opposite, it illustrates complexities and discrepancies which reinforce why approaches must be flown using the primary navigation method described on the paper chart

- GPS units, other than the modern WAAS-approved models, do not provide guidance for many of the path-terminators used in database approach overlays. A pilot relying on such GPS 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

# Procedure titles and names

## 5. Jeppesen chart index number convention

**EGHH/BOH BOURNEMOUTH** — JEPPESEN — 6 APR 07 — (11-1) — **BOURNEMOUTH, UK** ❶ ILS DME Rwy 08

**Jeppesen chart index example**

(11-1)

**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

**2nd digit: Chart Type**

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*

- 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 many 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 | Rule 2: "or" | Rule 3: Secondary navaid | Rule 4: Chart notes |
|---|---|---|---|
| • The chart title is the primary navaid for the procedure plus "Rwy" and the runway identifier<br>• eg. ILS Rwy 27, NDB Rwy 09L<br>• "ILS" means that <u>both</u> the localiser and glideslope are required<br>• "LOC" is used instead of "LLZ" as the Localiser abbreviation | • If more than one type of procedure is published on the same page, then "or" is used<br>• eg. ILS or LOC Rwy 27<br>      VOR or NDB Rwy 09L | • 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 <u>chart note</u> if DME is required<br>• <u>Some countries continue to include DME in the chart title</u> | • 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 | Rule 6: Offset final approach | Rule 7: RNAV |
|---|---|---|
| • 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"<br>• 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<br>• eg. 'VOR Z Rwy 09L' followed by 'VOR Y Rwy 09L' | • 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<br>• eg. NDB A Rwy 09 | • The current standard is to use the more generic 'GNSS' instead of GPS, but GPS still appears on many current charts<br>• RNAV approaches may specify the equipment type to be used or an RNP value required<br>• eg. GNSS Rwy 07, RNAV (GNSS) Rwy 07, RNAV Rwy 07 |

*Source: ECACNAV Instrument Procedure Design presentation: "Approach Procedure Title Standardization",* Jim Terpstra, 2001. (VB) The "7 Rules" above are my interpretation of this paper.

115

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



'DME required' chart note



DO NOT USE FOR NAVIGATION
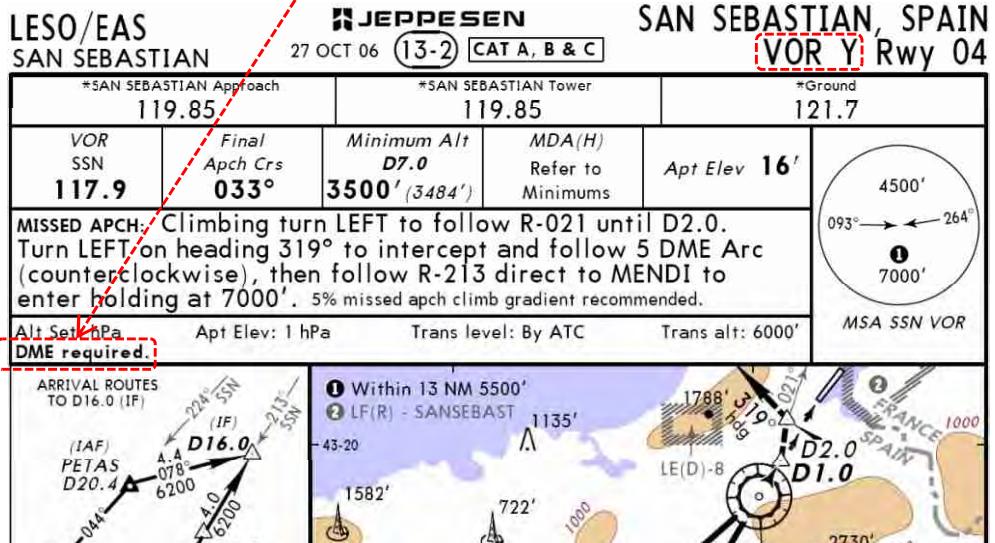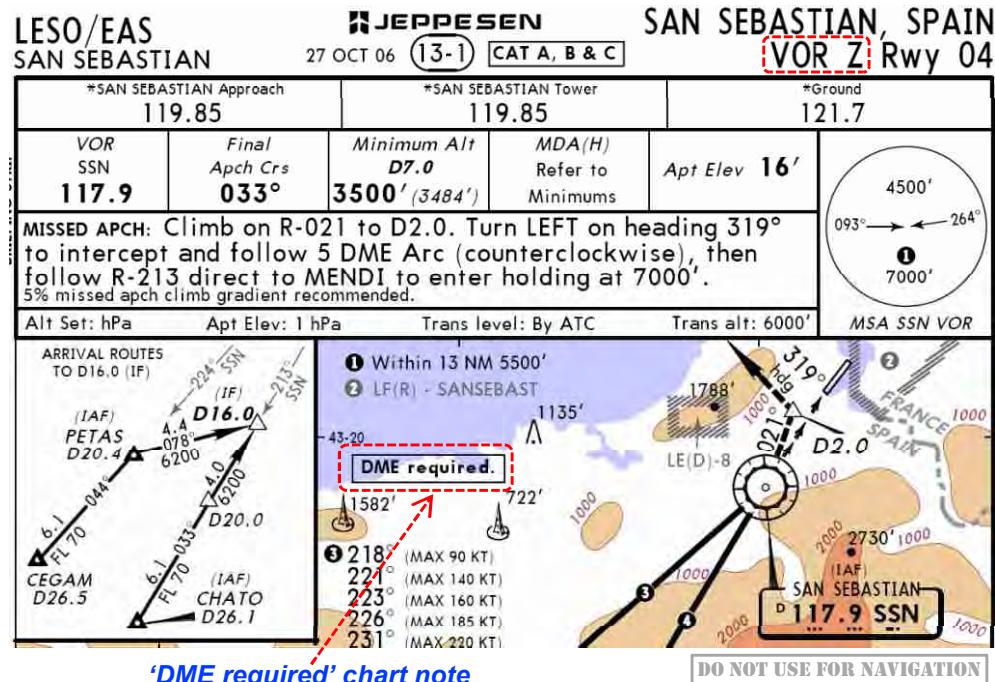


- Example where there are two VOR approach charts to Runway 04, hence the procedure titles 'VOR X' and 'VOR Y'

- 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 GPS database, and the procedure identifier does not include the 'Z' character



*The Garmin 530 database has 2 approach selections available for LESO. Note that the NDB procedure is "CAT A&B" only and thus not coded in the database*

*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*

*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 <u>only one procedure of a given type (eg. VOR) per runway</u> 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
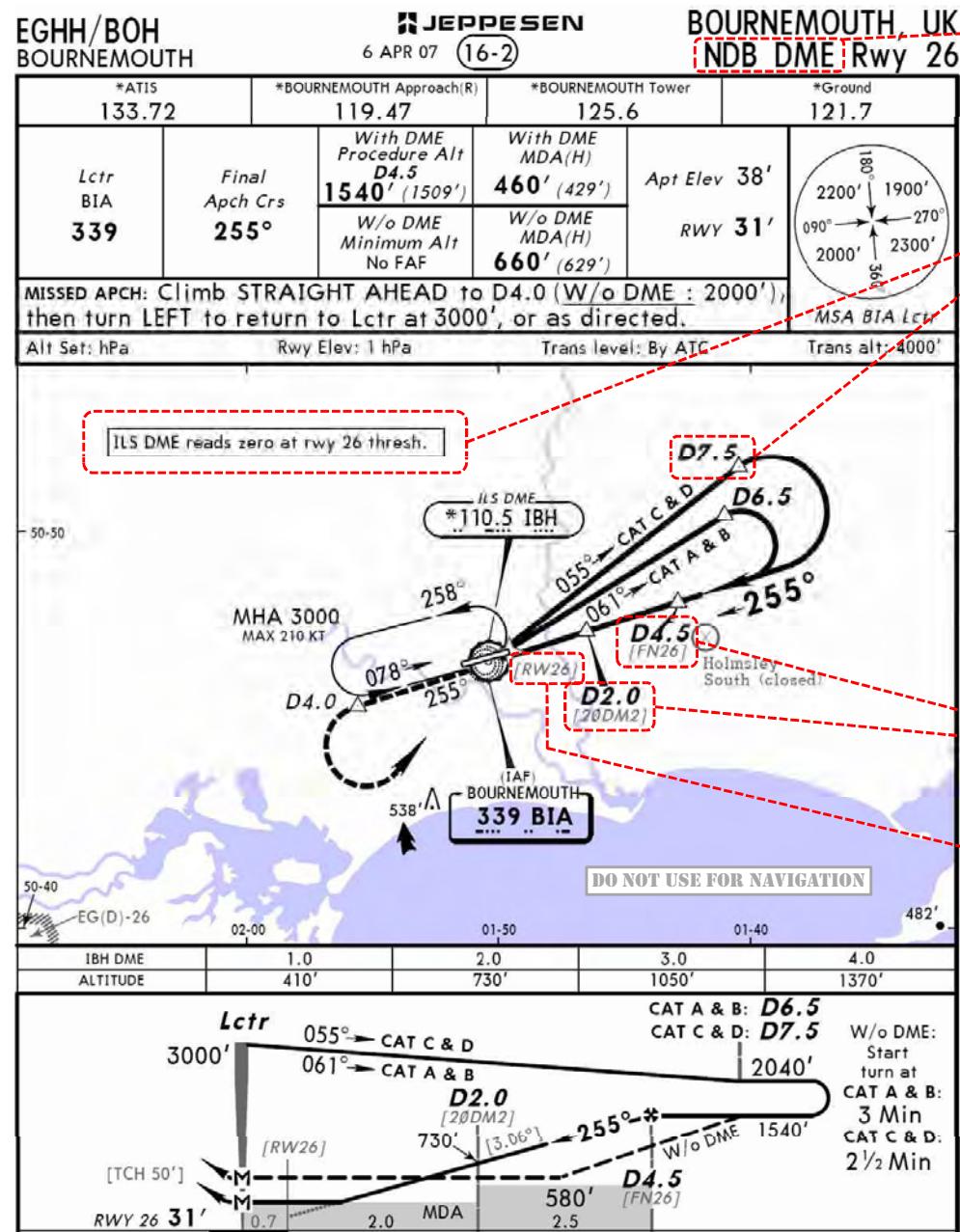
Note: title with secondary navaid (DME) included. This convention is often used in Europe instead of the alternative of noting the DME requirement in the chart text

*Garmin GNS530W procedure selection page*
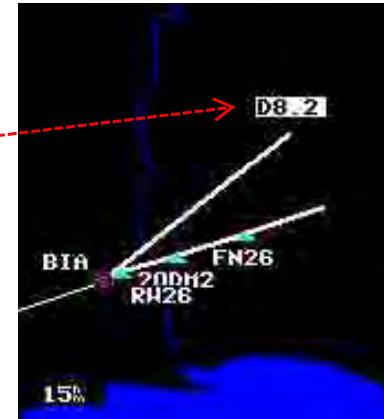
Note that the paper chart depicts distances from the DME, which reads zero at the 26 threshold. The database overlay uses along-track distance between waypoints. Hence "D7.5" on the chart becomes "D8.2" in the database, because its preceding waypoint, the BIA NDB, is 0.7nm SSW of the 26 threshold

*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 after 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

# Example of a VOR approach



Garmin GNS530W procedure selection page
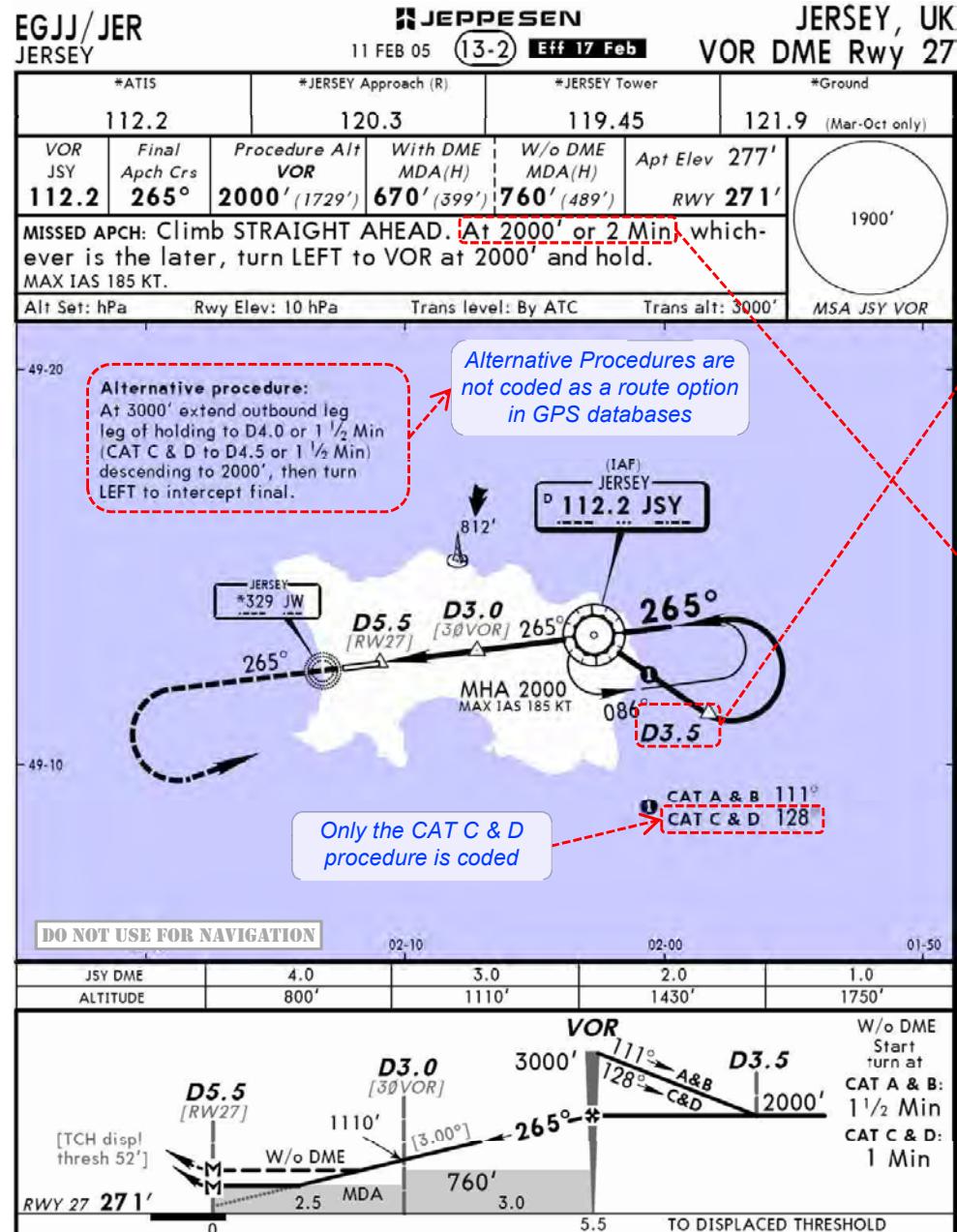


Note the discrepancy that this waypoint has a different name on the map display and the database waypoint list. Both variants are examples of a database identifier for a charted fix name where the bearing/distance convention is not used (which would have been "D128D" in this case). This occurs when an 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

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 GPS unit will not sequence automatically when this waypoint is reached – it is a manual termination leg, so the pilot must press the OBS key (in the Garmin 430/530; varies in other GPS units) to start guidance to the JSY when the 2000'/2min condition has been met.

Garmin GNS530W flight plan waypoint list



Alternative Procedures are not coded as a route option in GPS databases

Only the CAT C & D procedure is coded

# Example of an ILS approach

EDDK/CGN COLOGNE-BONN

JEPPESEN 8 DEC 06 (11-3) Eff 21 Dec

COLOGNE-BONN, GERMANY
ILS or LOC Rwy 32R

| ATIS | COLOGNE-BONN Director (APP) | COLOGNE-BONN Tower (R) | Ground |
|---|---|---|---|
| 112.15    124.2 | 121.05 | 124.97 | 121.72 |

| LOC IKEN 109.7 | Final Apch Crs 317° | GS LOM 1660' (1358') | ILS DA(H) 502' (200') | Apt Elev 302' RWY 302' | MSA KBO VOR |

MISSED APCH: Climb STRAIGHT AHEAD to D3.2 KBO or 2000', whichever is later, then turn RIGHT to COL VOR climbing to 5000'.

Alt Set: hPa (IN on req)   Rwy Elev: 11 hPa   Trans level: By ATC   Trans alt: 5000'
LOC: DME REQUIRED.

| LOC (GS out) | KBO DME | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 |
|---|---|---|---|---|---|---|---|---|
| | ALTITUDE | 1030' | 1340' | 1660' | 1980' | 2300' | 2620' | 2940' |

DO NOT USE FOR NAVIGATION

*Garmin GNS530W procedure selection page*



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

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

Note that RARIX, the charted final approach point, is preceded by a turn from either of the two IAFs. Older FMS units cannot support a final approach fix without a *prior* waypoint on the final approach track. Hence, the database procedure uses RARIX as the final approach 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**

*Garmin GNS530W flight plan waypoint list*

# Example of an RNAV(GPS) approach
## (see also section 4 for more details on GPS approaches)



Jeppesen chart: EDDK/CGN COLOGNE-BONN — COLOGNE-BONN, GERMANY — 8 DEC 06 (12-6) Eff 21 Dec — RNAV (GPS) Rwy 32R

| ATIS | | COLOGNE-BONN Director (APP) | COLOGNE-BONN Tower (R) | Ground |
|---|---|---|---|---|
| 112.15 | 124.2 | 121.05 | 124.97 | 121.72 |

| RNAV | Final Apch Crs 317° | Minimum Alt RARIX 3000' (2698') | MDA(H) 770' (468') | Apt Elev 302' RWY 302' |
|---|---|---|---|---|

MISSED APCH: RNAV: Climb on track 317° to 5000'. When passing DK660 or 2000', whichever is later, turn RIGHT via DK661 on track 122° to COL VOR.
NON-RNAV: Climb STRAIGHT AHEAD to 5000'. When passing D3.2 KBO or 2000', whichever is later, turn RIGHT to COL VOR.

Alt Set: hPa (IN on req)   Rwy Elev: 11 hPa   Trans level: By ATC   Trans alt: 5000'

MSA ARP 3800'

GPS qualification required.

COLOGNE-BONN (T) 112.15 KBO

NOT TO SCALE

(IAF) COLA
D 108.8 COL

(IF) DK655

RARIX

DK605

RW32R

(Dangerous industrial plant)

3.0 NM to RW32R [30TH4]

DO NOT USE FOR NAVIGATION

| DIST to THR | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 |
|---|---|---|---|---|---|---|---|
| ALTITUDE | 990' | 1310' | 1630' | 1950' | 2270' | 2590' | 2900' |

RW32R [TCH 50'] — RWY 32R 302' — 3.0 NM to RW32R [30TH4] — RARIX ✳ 3000' — [3.00°] 1310'

*Garmin GNS530W procedure selection page*



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

*Garmin GNS530W flight plan waypoint list*



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

Note that in this procedure, RARIX is coded as the Final Approach Fix (compare with the previous page)

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

120

# Example of a GPS 'published overlay' approach

LSGG/GVA GENEVA — JEPPESEN — GENEVA, SWITZERLAND (GPS) VOR DME Rwy 23

| ATIS | GENEVA Arrival (APP) | GENEVA Final (APP) | GENEVA Tower | Ground |
|---|---|---|---|---|
| 135.57 | 136.25 | 120.3 | 118.7 | 121.67 |

| VOR GVA 115.75 | Final Apch Crs 226° | Procedure Alt D17.2 GVA 7000' (5635') | MDA(H) 1810' (445') | Apt Elev 1411' RWY 1365' |
|---|---|---|---|---|

MISSED APCH: Climb on R-226 GVA to 4000'. At D4.0 GVA continue climb to 7000'. At D9.5 GVA turn LEFT (MAX 185 KT) to intercept and follow R-040 CBY to SPR VOR. For turns below 5000' MIM bank angle 25°.

Note very small letters next to "23" denoting this is a also a GPS approach

*Garmin GNS530W procedure selection page*

There is no "T crossbar" at the start of this procedure (in part, due to terrain) and SPR is not an IAF. All the IAFs for the procedure are on the STAR charts. VADAR is an example.

*Garmin GNS530W flight plan waypoint list*

Note that all the approach fixes on the chart have published CNF identifiers in faint grey

Note that "D9.5" is also the database identifier, whilst "D4.0" uses the bearing/distance convention to create the identifier "D226D". This is because there is only one "D.9.5" waypoint in the Geneva approach charts. "D4.0" is used several times in reference to different points and thus each instance of "D4.0" requires a unique CNF identifier

121

# Course contents

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. **Error detection and warnings**

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

## 1. The requirement for integrity monitoring

*GPS 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*

**true position of satellite**

**position indicated by erroneous CA code**

*2D representation of 3D range spheres*

**the faulty pseudorange can result in a navigation solution that appears to be valid but is inaccurate**
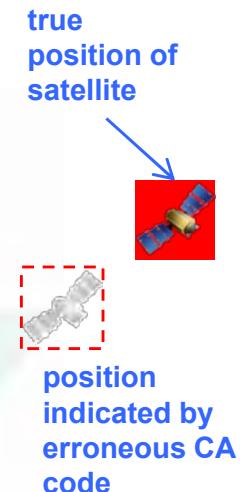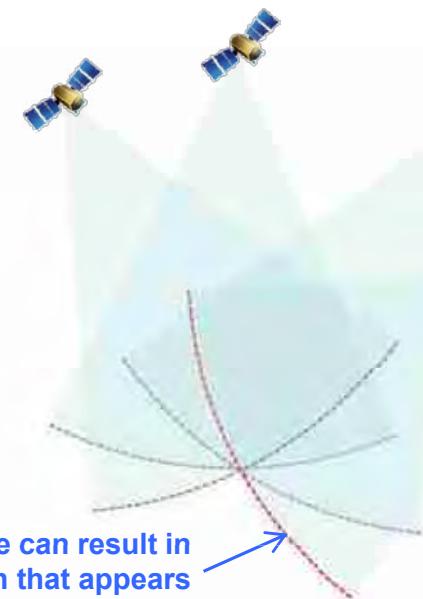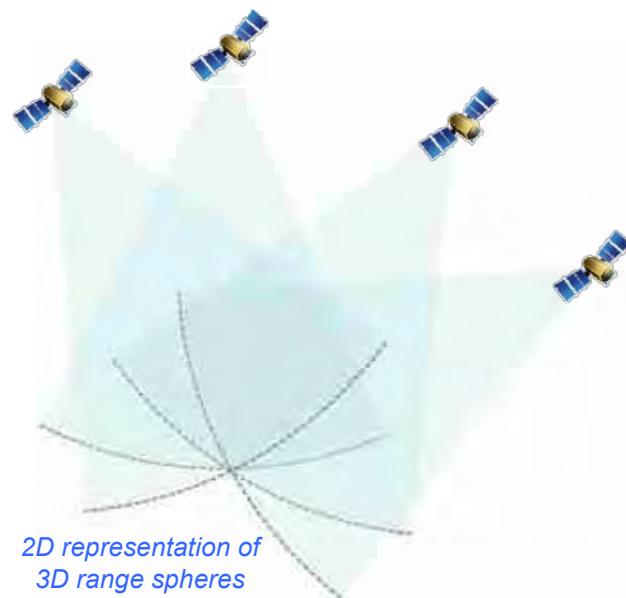
- **The GPS Control Segment ground stations monitor satellites and detect faults**

- **However, the system may take <u>up to 2hrs</u> to detect 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 GPS 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 GPS receiver with the capability for Fault Detection (FD)*
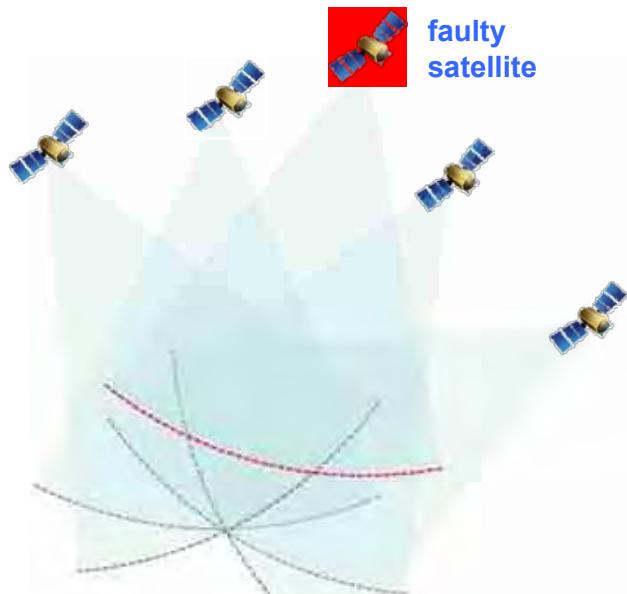
*A 6th satellite provides a GPS receiver with the capability for Fault Detection and Exclusion (FDE)*

**faulty satellite**
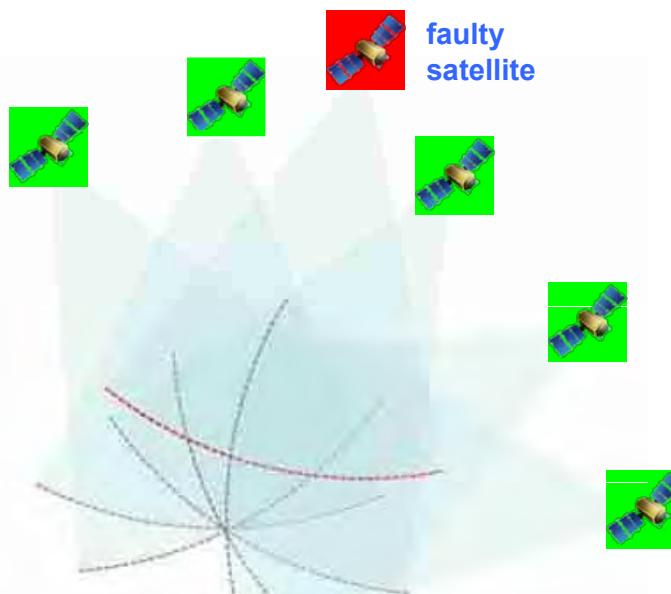
**faulty satellite**

- **The receiver can recognise that a satellite is faulty, because the 5 range spheres don't all intersect at a consistent point; but, because any combination of 4 satellites might provide a valid solution, it can not always identify which satellite is faulty**

- **RAIM (Receiver Autonomous Integrity Monitoring) is synonymous with Fault Detection (FD) and is a feature of all approved IFR GPS receivers**

- **The receiver can identify and isolate the faulty satellite, by finding which combination of 5 satellites will provide a self-consistent and valid navigation solution, and excluding the 6th**

- **Many TSO C129 receivers (eg. Garmin 430/530 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 GPS 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 GPS approaches**

# Principles of RAIM
## 3. RAIM availability and requirements

### Predicted RAIM availability

- Although, in practice, the GPS satellite constellation provides 6 or more visible satellites in almost all circumstances, this is not guaranteed

- On a particular route at a particular time, it may be that the "geometry" of the satellite constellation, or a known satellite failure, means that the minimum of 5 satellites needed for RAIM will not be available

- Such a lack of RAIM availability may be predicted, either by the GPS receiver software using almanac data and the time and route of flight, or by an internet-based RAIM prediction tool

Predicted RAIM availability requirements

### Actual RAIM availability

- RAIM availability can be lost at any point in a flight if the number of visible, serviceable satellites falls below 5

- This may happen when RAIM was predicted to be available, if an unexpected satellite failure takes place

- All IFR GPS receivers will provide the pilot with a prominent alert if RAIM is lost at any point in flight – this does not mean the GPS position is wrong (eg. if 4 accurate satellite signals remain available) but it does mean that the integrity of the position is not assured (ie. one of the 4 signals could be erroneous)

Actual RAIM availability requirements

| B-RNAV | |
| --- | --- |
| RAIM prediction is not required before a B-RNAV route is flown using GPS, but it is advisable | A loss of RAIM availability does not mean that GPS navigation must be discontinued (as long as the GPS receiver is not also warning of a loss of GPS position) but the pilot should maintain a cross-check of position using conventional radio aids |
| **P-RNAV** | |
| RAIM prediction must be conducted before a P-RNAV flight, and 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 | A loss of RAIM availability during a P-RNAV flight means that contingency procedures for the loss of P-RNAV capability must be followed (eg. advising ATC and requesting vectors or a conventional procedure) |
| **RNAV(GPS) Approaches** | |
| Generally, RAIM prediction is required before conduction a flight which will use a GPS approach, eg. for the USA, see AIM Section 1-1-19 h and I, and for the UK, AIP Sup S 11/2008 | A loss of RAIM availability means that the approach must be discontinued and the missed approach procedure flown. IFR GPS receivers will not activate an approach if RAIM is not available between the FAF and MAP |

# 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 GPS is to be used for P-RNAV, the availability of RAIM must be confirmed with account taken of the latest information from the US Coastguard giving details of satellite non-availability"*

### AUGUR NPA (Non-Precision Approach) prediction tool

*Airport ICAO codes entered*

*RAIM prediction displayed graphically over 24hrs*
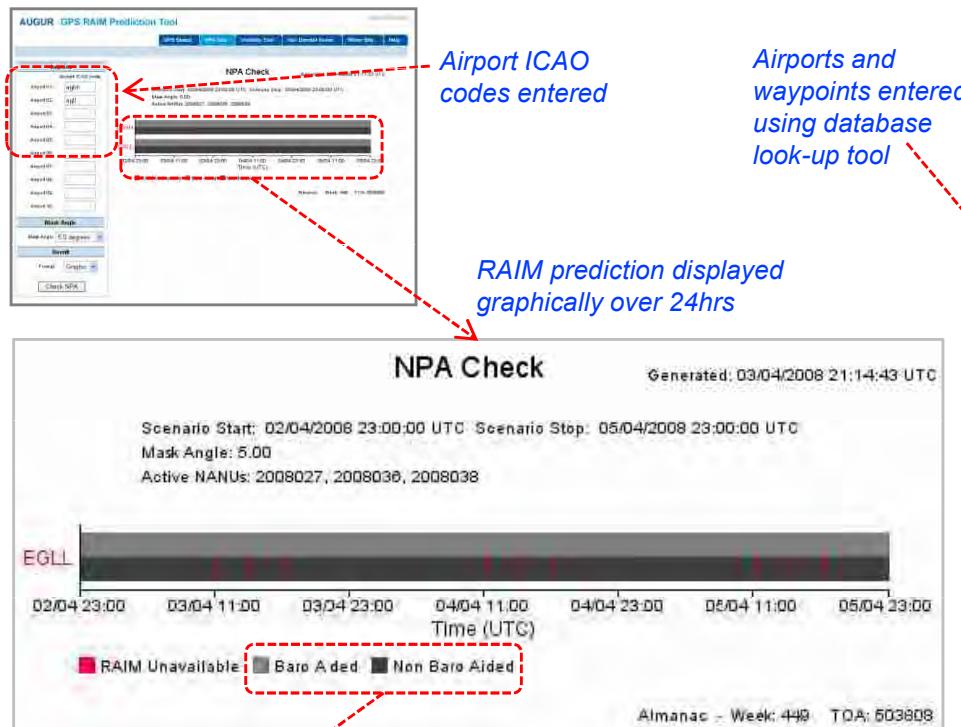
### AUGUR Route prediction tool

*Airports and waypoints entered using database look-up tool*

*The default 5 degree mask angle and FD (Fault Detection) algorithm should be used here*

*Route RAIM report generated for specified time of flight and 5min intervals either side*
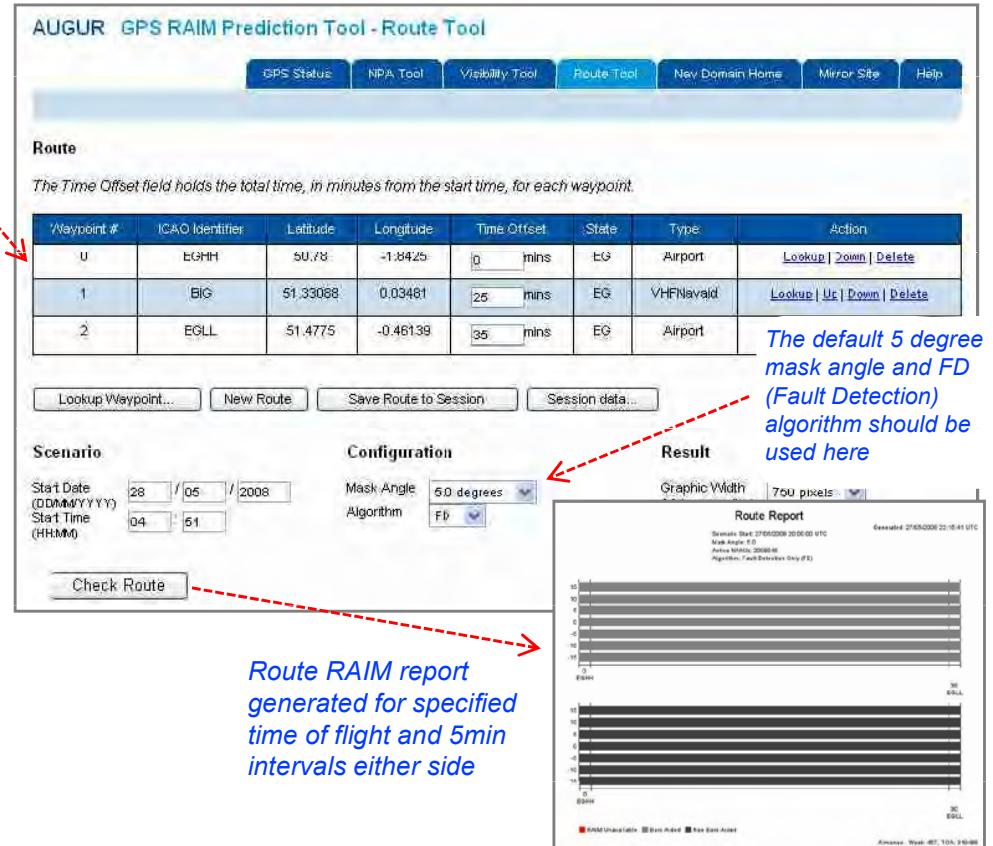
- *"Baro Aiding" in this context means a GPS unit which can use a barometric altitude input as a substitute for a 4th satellite in determining a 3D position fix. Most IFR GPS installations will have such an altitude input as part of their certification requirements, allowing the less demanding (by 1 satellite) "baro-aided" prediction result to be used.*
  - *Note that this is completely different from the concept of baro-aiding in turbine aircraft FMS/GPS units that may use barometric input to provide a synthetic glideslope for baro-aided VNAV approaches.*

- For a technical description of the AUGUR algorithms, see "RAIM Performance: How Algorithms Differ" by P.B. Ober, Delft University
  http://www.integricom.nl/publications/ION%20GPS%201998%20RAIM%20Performance-How%20algorithms%20differ.pdf

• All IFR GPS receivers can use the Almanac data in the Navigation Message to predict whether there will 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:

1) Select 'RAIM Prediction' from the Utility Page, using the steps described at the beginning of this section.

2) 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** Key.)

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 GPS 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 GPS receiver relies on the Almanac broadcast by GPS 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 US Coast Guard website:
  http://www.navcen.uscg.gov/navinfo/Gps/ActiveNanu.aspx
  - this site also provides the GPS equivalent of NOTAMs ("NANU", Notice Advisory to Navstar Users)
  - the USCG information is also available on the "Status" page of the AUGUR website, and is used in the AUGUR prediction tools

- **For this reason, an IFR GPS receiver's built-in RAIM prediction may not comply with the requirements of some RNAV applications and approvals (particularly P-RNAV), and the AUGUR prediction tools must be used instead**

*Note that RAIM prediction refers to the Fault Detection function (FD). RNAV applications requiring a predicted availability of Fault Detection and Exclusion (FDE), eg. GPS 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 P-RNAV procedures (RNP-1) along a given route and time, this does not necessarily mean that it is available for GPS 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*

**AUGUR GPS RAIM Prediction Tool**

| | GPS Status | NPA Tool | Visibility Tool |

A minimum of 31 satellites are available during the query period

B-RNAV en-route predictive RAIM check **not** required
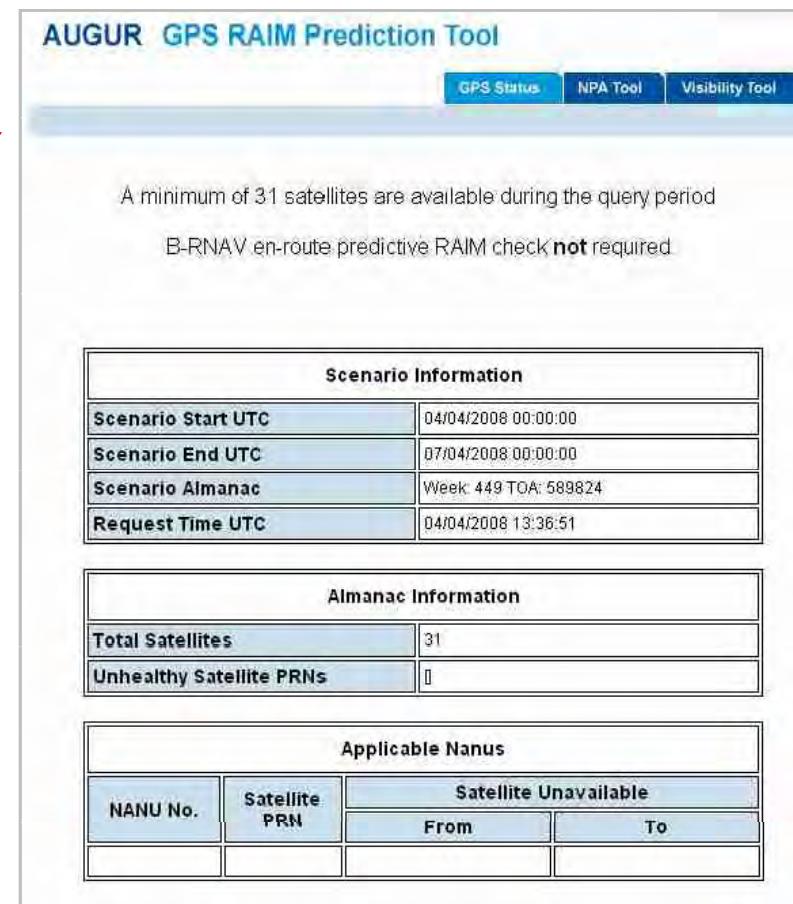
| Scenario Information | |
|---|---|
| Scenario Start UTC | 04/04/2008 00:00:00 |
| Scenario End UTC | 07/04/2008 00:00:00 |
| Scenario Almanac | Week: 449 TOA: 589824 |
| Request Time UTC | 04/04/2008 13:36:51 |

| Almanac Information | |
|---|---|
| Total Satellites | 31 |
| Unhealthy Satellite PRNs | 0 |

| Applicable Nanus | | | |
|---|---|---|---|
| NANU No. | Satellite PRN | Satellite Unavailable | |
| | | From | To |
| | | | |

# GPS position warnings
## 1. The Loss of Integrity alert

- Whilst RAIM is available, the GPS 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 (ie. the RNP-1 limit needed for P-RNAV) and 0.3 nm for GPS approaches

- Example, from the Garmin 530 Pilot's Guide:

  - *The CDI scale in IFR GPS 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 GPS database ensures that the appropriate CDI scale and RAIM protection limits are applied*
  - *In some GPS, units manually selecting a 1nm or 0.3nm CDI scale may not change the RAIM protection limit to the corresponding RNP value (although it does in the Garmin 430/530 series)*

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

- The "Loss of Integrity" (LOI) alert provided by a GPS 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 GPS may not be used as a source of primary guidance**
  - **during a P-RNAV procedure, the pilot must advise ATC of the RAIM failure and request radar vectors or a conventional alternative procedure**
  - **during a GPS approach, the pilot must initiate the missed approach and advise ATC**

- In practice, most instances of LOI are very brief. However, if an 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 GPS unit may provide in the Status or Aux pages (eg. Estimated Position Error, Dilution of Precision and Horizontal Uncertainty Level)*

- IFR GPS 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 GPS 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 GPS unit, and how they are annunciated and accessed



## Example: Garmin GPS 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. Cross-check 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

# Reference: JAA TGL 10

> ### JAA Administrative & Guidance Material
> #### Section One: General Part 3: Temporary Guidance Leaflets
>
> **LEAFLET NO 10 Rev 1:** **AIRWORTHINESS AND OPERATIONAL APPROVAL FOR PRECISION RNAV OPERATIONS IN DESIGNATED EUROPEAN AIRSPACE**
>
> This leaflet provides guidance material for the approval of aircraft and operations in the European region where Precision Area Navigation (P-RNAV) is required. It relates to the implementation of area navigation within the context of the European Air Traffic Management Programme (EATMP) and should be read in conjunction with EUROCONTROL document 003-93 (), Area Navigation Equipment: Operational Requirements and Functional Requirements.

## 10.2 Normal Procedures

### 10.2.1 Pre-flight Planning

. . . . . . . . . .

10.2.1.3 If a stand-alone GPS is to be used for P-RNAV, the availability of RAIM must be confirmed with account taken of the latest information from the US Coastguard giving details of satellite non-availability.

Note: RAIM prediction may be a function of the equipment provided that satellite non-availability data can be entered. In the absence of such a function, an airspace service provider may offer an approved RAIM availability service to users.

**∧ATS** **SUPPLEMENTS TO THE UNITED KINGDOM AIP**

**S 11/2008**

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**NATS Limited**
Aeronautical Information Service
Control Tower Building, London Heathrow Airport
Hounslow, Middlesex TW6 1JJ
Editorial: 020-8745 3457
Fax: 020-8745 3453
Distribution: 0870-8871410
Contact: 020-7453 6518 (CAS)
AFTN: EGGNYNYX
Website: www.ais.org.uk

NOTES:
(a)  All times are UTC.
(b)  References are to the UK AIP.
(c)  Information, where applicable, should also be used to amend appropriate charts.

**UK RNAV (GNSS) INSTRUMENT APPROACH PROCEDURES**

## 10     Pre-Flight Planning

10.1    Aircraft operators shall ensure that the appropriate coverage from GNSS is provided for the intended flight. Receiver Autonomous Integrity Monitor (RAIM) availability prediction should take into account the GPS constellation predicted for the duration of the flight, NOTAM and avionics architecture eg, Baro aiding input. Software tools available on the Internet can be used for this purpose eg AUGUR[4] or through the aircraft navigation system RAIM prediction capability, if provided. In the event of a predicted, continuous loss of appropriate level of fault detection of more than five (5) minutes for any part of the RNAV (GNSS) approach procedure, the flight planning should be revised eg, delaying the departure or planning a different approach procedure.

10.2    RAIM availability prediction software does not guarantee the service; they are tools to assess the expected capability to meet the required navigation performance. Because of failure of some GNSS elements, operators must be aware that RAIM, or GPS navigation altogether, may be lost while airborne which may require reversion to an alternative means of navigation. Therefore, pilots should assess their capability to navigate (potentially to an alternate destination) in case of failure of GPS navigation.
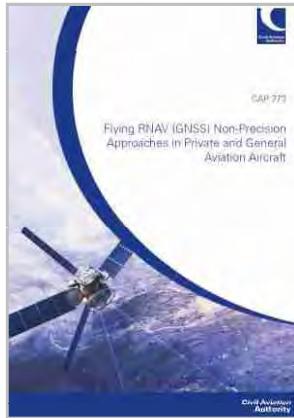
Flying RNAV (GNSS) Non-Precision
Approaches in Private and General
Aviation Aircraft

## RAIM Prediction

During the pre-flight planning phase, the availability of RAIM (or equivalent monitor) at the destination should be verified as closely as possible before take-off, and in any event, not more than 24 hours before take-off (RAIM should be available from 15 minutes before the Estimated Time of Arrival (ETA) until 15 minutes after ETA). This may be established either by an internal function of the receiver (Note 1) or an Air Navigation Service Provider (ANSP) may offer an approved RAIM availability service to users (for example: http://augur.ecacnav.com/npa.html) (Note 2).

**NOTE 1:** 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 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 2:** 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.

# Course contents

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. **P-RNAV requirements and approvals**
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

# Introduction: the "compliance" and "authorisation" models of regulation

- P-RNAV approval differs from the style of regulation most private GA operators are familiar with

- The "compliance model" for private IFR (or VFR) defines individual, independent criteria that must be met for a flight to be legal, for example
  - aircraft certification and equipment
  - pilot qualifications and currency
  - operational requirements (such as fuel reserves and weather minima)

- If these independent criteria are met, a private flight is permissible – they are both a necessary and sufficient condition. For example, any IFR-certified aircraft may be (privately) operated under IFR anywhere in the world by any pilot holding the appropriate pilot qualification and instrument rating

- In the commercial world, a different kind of regulation applies: it is an "authorisation model", rather than a "compliance" one. Commercial operators need specific authorisation for individual aircraft types, routes, operating procedures, weather minima, minimum equipment lists, training programmes etc. which form the "OpSpecs" (Operations Specifications) that the aviation authority of the State regulating the operator is responsible for approving and monitoring

- A small number of IFR applications require operational approval (in the form of a "Letter of Authorisation", LoA) for all operators, not just commercial ones. This is an established principle under ICAO, although, prior to P-RNAV, such applications have not been relevant to piston aircraft. For example, private turbine aircraft flying in RVSM airspace (Reduced Vertical Separation Minima, usually above FL290 up to FL410) require the same kind of RVSM LoA as commercial operators

- The LoA is the responsibility of, and issued by, the State of Registry, which interprets the guidance agreed under ICAO for a particular application (including 'regional' ones, such as P-RNAV) and publishes requirements operators must meet
  - it is necessary, but not sufficient, for an operator to meet these requirements (eg. having an RVSM equipped aircraft, having pilots trained in RVSM procedures, using appropriate checklists). The operator must, in addition, specifically apply for and be granted an LoA

  ➡ **· Approval for P-RNAV operations is analogous to RVSM: private GA operators require a P-RNAV Letter of Authorisation**

Note: this requirement is not specific to any one country, all ICAO states have to follow the LoA method defined by Europe for P-RNAV approval. However, in the USA, RNAV 1 has similar requirements to P-RNAV (see FAA AC 90-100A) but the "compliance model" is used for Part 91 (private) operators

# Introduction to JAA TGL 10

- The JAA's TGL (Temporary Guidance Leaflet) 10 is the basic source of guidance on P-RNAV approval

- 'Revision 1' is the current version, as of April 2008

- Because P-RNAV LoAs are the responsibility of the State of Registry, each national aviation authority implements an LoA process based on TGL10

**JAA TGL10**

*An overall guide to RNAV approvals, refers applicants to TGL10*

*Application form for P-RNAV LoAs and other RNAV approvals*

*UK operators send these to the CAA Safety Regulation Group's Flight Operations Policy (Admin) team*

***For example:***

**FAA's AC90-96A**

**UK CAA's FODCOM 04/2008**     **and CA4045**

*Describes LoA requirements based on TGL10*

*For US-registered aircraft based in Europe, the New York International Field Office of the FAA is responsible for P-RNAV LoAs*

➡ **· Although individual States are responsible for issuing P-RNAV LoAs, all the national requirements are essentially those of JAA TGL10**

# Overview of the JAA TGL10 document

- TGL10 is a relatively concise and accessible document. There is a significant amount of material which describes operational requirements for commercial aircraft and the features older Flight Management Systems need to comply with P-RNAV; this does not concern the private GA operator. The only essential requirements for a single-pilot light aircraft are a compliant IFR GPS installation and appropriate pilot training and operating procedures

| Section | Comment |
|---|---|
| 1. Purpose | Introductory paragraph. Importantly, it emphasises that TGL10 is <u>not compulsory</u>: an LoA applicant may elect to use an alternative means of compliance that meets the objectives of TGL10 and satisfies the authority of the State of Registry |
| 2. Scope | Describes what is covered in TGL10, and what P-RNAV means in operational terms |
| 3. Reference Documents | Lists many regulatory and technical documents relating to P-RNAV from ICAO, the JAA, the FAA and Eurocontrol |
| 4. Assumptions | Describes various navigation, airspace and operational principles that P-RNAV depends upon: eg. design criteria for procedures, performance of the GPS system, availability of alternative procedures |
| 5. System Description | Lists the various kinds of navigation sensors that may be used in P-RNAV (eg. GPS, DME/DME, IRS) |
| 6. Airworthiness Objectives | Describes the accuracy, integrity and continuity performance needed for an avionics installation to be TGL10-compliant |
| 7. Functional Criteria | **Lists the 21 avionics system functions required for P-RNAV, and 6 recommended functions** |
| 8. Acceptable Means of Airworthiness Compliance | Describes the various means by which an aircraft avionics installation may be demonstrated to be compliant with TGL10 (eg. manufacturer certification for new OEM installations vs. operator's compliance statement for retrofit equipment). Also refers to GPS TSO requirements and database integrity standards |
| 9. Aircraft Flight Manual | States that either the aircraft Flight Manual or an operator's compliance statement must identify the avionics installation as having RNP-1 or better capability |
| 10. Operational Criteria | **Provides guidelines for P-RNAV operating procedures and pilot training** |

➡ · **Sections 7 and 10 are particularly relevant for GA pilots: they detail the avionics features, pilot training and operating procedures needed for P-RNAV**

# JAA TGL10: summary of requirements

- TGL10 and the appropriate National Aviation Authority (NAA) guidance material (eg. FAA AC90-96A, CAA FODCOM 04/2008) need to be studied in detail by any P-RNAV LoA applicant. However, the key P-RNAV requirements for a private operator of a non-FMS equipped aircraft may be summarised as follows:

| 1. Avionics installation | 2. Pilot knowledge and training | 3. Operations manual |
|---|---|---|
| • TGL10 section 8.3.1 states *"The use of GPS to perform P-RNAV operations is limited to equipment approved under FAA TSO-145 and TSO-146, and JTSO-C129a/TSO C129 in the equipment classes A1, B1, C1, B3 and C3 and which support the minimum system functions specified in Section 7"*<br>• The TSO/JTSOs requirement is met by most modern panel-mount IFR GPS units (eg. the Garmin 400,500,1000 series and B/K KLN94)<br>• The section 7 functional requirements are typically met by an IFR-approved installation with a flight manual entry approving the use of the GPS for terminal procedures. A coupled HSI is probably required, an autoslewing (E)HSI is not.<br>• An autopilot is not required<br>• If the installation (including annunciators and nav indicators) is approved for the more demanding RNP-0.3 of GPS approaches, it is likely to be suitable for P-RNAV<br>• A database supplier with a Type 2 LoA or equivalent is also required (see section 2b)<br>• However, the ultimate decision on P-RNAV airworthiness approval rests with the NAA | **Ground training**<br>• TGL10 section 10.5 states that pilots must receive appropriate training in<br> – the P-RNAV operating guidelines in sections 10.2 and 10.3<br> – the Theory subjects in table 3 section 10.5<br>• Section 3b of this manual details how it can be used to comply with these ground training requirements<br><br>**Flight/Simulator training**<br>• TGL10 section 10.5 only states that *"where practicable standard training events (simulator checks/proficiency checks) should include departures and arrivals using the RNAV based procedures"*<br>• NAAs define their own training requirements. For example, in an FAA LoA application, the operator needs to report the training methods proposed. Appendix C of FODCOM 04/2008 details the training the UK CAA requires for P-RNAV<br>• Section 6 of this manual includes a syllabus intended to meet such NAA requirements | • TGL10 section 10.7 states that *"the aircraft Operations Manual….and checklists must be revised to take account of…the operating procedures in paragraphs 10.2 (Normal Procedures) and 10.3 (Contingency procedures)"*<br>• In the author's interpretation of TGL10, 3 methods of compliance should be acceptable<br> – amending an existing operations manual to comply with 10.7<br> – writing an "extended checklist" for the aircraft to comply with 10.7<br> – writing a flight manual supplement to cover P-RNAV operations, as per TGL10 section 9.2, which states that this is acceptable for an aircraft without an operations manual<br>• PPL/IR Europe recommends that an "extended checklist" form of operations manual, with appropriate standard operating procedures, is used for private, single-pilot IFR. A template for such manuals is available to members at the www.pplir.org website. Modifying such a checklist/manual to include the P-RNAV items of TGL10 sections 10.2 and 10.3 is our suggested method of compliance<br>• If the aircraft is operated with a Minimum Equipment List (MEL) this must be amended to refer to P-RNAV requirements |

➡ **· Sections 3b of this manual details how it may be used to meet the pilot knowledge and training requirements of TGL10, and section 3c provides guidelines for developing a compliant P-RNAV "extended checklist"**

# An informal guide to getting a P-RNAV LoA

*Example for an aircraft with an IFR approved Garmin 430, 530 or 1000 installation (OEM or retrofit)*

| | 1. Avionics installation | 2. Pilot knowledge and training | 3. Operations manual | 4. Application process |
|---|---|---|---|---|
| **FAA** | • Compile documents demonstrating IFR approval status for Terminal Procedures<br>– Flight Manual pages for OEM installations<br>– Flight Manual Supplement and Form 337 (if appropriate) for retrofits<br>– Garmin's TGL10 compliance statement; see http://www.ecacnav.com/content.asp?CatID=208 | • Document the training that has/will be used for pilots operating under the LoA to acquire and maintain currency in the requirements detailed in AC90-96A Appendix 1.3 and Appendix 2.3 and 2.4 (essentially those of TGL sections 10.2,10.3 and 10.5)<br>• A statement that this Manual has been studied, and describing the pilots' IFR GPS initial and recurrent training may suffice. A CFII or DPE endorsement of both should suffice | • Prepare an "extended checklist" or operations manual, consistent with the aircraft Flight Manual, to comply with AC90-96A Appendix 2.3<br>• The guidelines in Section 3c of this manual should be adequate for this purpose | • For operators based in Europe, submit items 1-3 to the FAA's New York International Field Office<br>• For operators based in the USA, submit these to the local FAA Flight Standards District Office (FSDO) |
| **UK CAA** | • Engage with Avionics Maintenance organisation to obtain a P-RNAV airworthiness compliance statement acceptable to the CAA<br>• Prepare a description of the avionics system and navigation indicators used for P-RNAV<br>• Document database supplier compliance<br>• Document MEL references to P-RNAV, if appropriate | • Document the training that has/will be used for pilots operating under the LoA to acquire and maintain currency in the requirements detailed in pages 9 and 11 of CAA FODCOM 04/2008<br>• PPL/IR Europe will be seeking approval that this Manual and the training syllabus in Section 6 meet these requirements if undertaken by an Instrument Rating instructor or examiner | • Prepare an "extended checklist" or operations manual, consistent with the aircraft Flight Manual, to comply with CAA form CA4045 "Notes for Completion of Section II paragraph 3" and TGL10.2 and 10.3<br>• The guidelines in Section 3c of this manual should be adequate for this purpose | • Complete CAA Form CA4045, prepare the attachments required by this form, and submit these to the CAA address on page 5 of CA4045 |

➡ • **P-RNAV approval is in its "infancy" for private single-pilot aircraft operators, so this summary is only an informal guide. The definitive sources are the appropriate JAA and NAA documents, which may have changed since this manual was written. NAAs have full and final discretion on issuing LoAs, and no third party document, such as this one, can give any assurance on the requirements that will be applied**

http://www.ecacnav.com/content.asp?CatID=208

*Many useful resources and documents, well worth browsing*

*Garmin 400, 500 and 1000 series compliance statements*

# A P-RNAV LoA is issued to an "operator". What does this mean in practice?

- For the purposes of private general aviation, an "operator" is the person, organisation or business that exercises operational control over an aircraft

- This "operational control" is distinct from the duties of the pilot in command. For example, the operator may control the circumstances in which the aircraft is flown, whilst the pilot is responsible for executing the flight

- The operator is not necessarily the legal owner of the aircraft, since the aircraft may be leased or hired by the operator, or it may be owned by a trust on behalf of the operator

**Examples of some possible 'combinations' of owner, operator and pilot:**

| Owner | Operator | Pilot |
|---|---|---|
| • A private aircraft is owned by a person who is also the operator and pilot | | |
| • A private aircraft is owned by a person, organisation or business who is also the operator | | • A pilot hires or borrows an aircraft from the operator<br>• The operator hires or otherwise engages a pilot |
| • A private aircraft is owned by a person, organisation or business who is not the operator | • A person is the operator of the aircraft under an arrangement with the owner, that person is also the pilot of the aircraft | |
| | • A person, organisation or business is the operator of the aircraft under an arrangement with the owner | • A pilot hires or borrows an aircraft from the operator<br>• The operator hires or otherwise engages a pilot |

- An LoA identifies a "Responsible Person", or equivalent, who is responsible for ensuring that the terms of the LoA are complied with. That person may authorise pilots to operate under the LoA as long as they meet the conditions specified

- The LoA is also specific to <u>individual</u> aircraft listed by serial number and registration. An aircraft may have multiple operators, each with their own LoA

- In the simple example of a private aircraft owner (or trust beneficiary), who is also the operator and pilot, he or she will apply for an LoA for their aircraft naming themselves as the Responsible Person. The LoA will permit them to authorise other pilots to fly the aircraft under P-RNAV, subject to the training and operating requirements specified

- In the case of a Company, Group or Club aircraft, the organisation will be the operator and nominate a responsible person. It would be possible in principle, although perhaps impractical, for a pilot to apply for an LoA, in their personal capacity, for a 3rd party aircraft they have access to

> - **Although the "Responsible Person" authorises pilots to operate under the LoA, a pilot in command <u>is also responsible</u> for ensuring that they are personally qualified and that an aircraft is suitably equipped, operated and authorised for any flight they undertake**

# Course contents

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. **P-RNAV training topics**
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

# Summary of P-RNAV pilot training requirements
## Complies with JAA TGL10, FAA AC90-96A and UK CAA FODCOM 04/2008

P

- The table below is a synthesis of training topics in the JAA, FAA and CAA source documents and should comply with all 3
- The rest of this section includes P-RNAV topics that do not fit elsewhere in the manual

*T: Theory training requiring study of this manual*
*A: Avionics training, supported by sections 2 and 5 of this manual*
*F: Flight and/or Simulator training, see syllabus in section 6*

| T | A | F | Topic | Comment |
|---|---|---|-------|---------|
| ✔ | | | General RNAV theory<br>- differences between B-RNAV, P-RNAV and RNP-RNAV<br>- meaning of RNP/ANP<br>- limitations of RNAV<br>- GPS concepts and limitations | Topics are fully covered by this manual<br>- see section 1<br>- see section 1<br>- see sections 1 and 2<br>- see section 2a and 2b |
| ✔ | | | P-RNAV theory<br>- RNP-1 definition as it relates to P-RNAV requirements<br>- airspace where P-RNAV is required<br>- changes to charting and documents to reflect P-RNAV<br>- required navigation equipment for flight in P-RNAV airspace | Topics are fully covered by this manual<br>- see section 1<br>- see section 3b (this section)<br>- see section 3b (this section)<br>- see section 3a |
| ✔ | | | Charting, database and avionics topics<br>- RNAV path terminator concepts<br>- Waypoint naming concepts<br>- the 'CF' path terminator<br>- the 'TF' path terminator<br>- fly-by and fly-over waypoints | Topics are fully covered by this manual<br>- see section 1<br>- see section 2b<br>- see section 1<br>- see section 1<br>- see section 1 |
| ✔ | | ✔ | Operational procedures and practices<br>- Normal procedures (TGL10.2)<br>- Contingency procedures (TGL10.3) | Topics are fully covered by this manual<br>- see section 3c<br>- see section 3c |
| ✔ | ✔ | ✔ | Use of RNAV Equipment<br>- retrieving a procedure from the database<br>- briefing the procedure, comparing it with the charted procedure<br>- action to be taken if discrepancies are noted<br>- sensor management<br>- tactically modifying the flight plan | Topics are covered but not in full, refer to GPS receiver User Manual<br>- see section 2c and sections 5 & 6<br>- see sections 2 and 3c<br>- see sections 2 and 3c<br>- see section 2<br>- see sections 5 & 6 |
| | | ✔ | Flying P-RNAV procedures<br>- LNAV and associated lateral control techniques,<br>- VNAV and vertical control techniques,<br>- use of automatic pilot and flight director<br>- implications of system malfunctions not RNAV related | See section 6 for a recommended syllabus for flight/simulator training to meet these requirements |

# Additional P-RNAV theory topics
## 1. Airspace where P-RNAV is required

- P-RNAV applies to the airspace of the 42 countries which are members of the European Civil Aviation Conference (ECAC)
- The implementation of P-RNAV has been underway since 2004; the process has accelerated recently and many countries will have some P-RNAV procedures by the end of 2008
- P-RNAV applies to terminal procedures, although this scope may be extended (eg. the current proposals for P-RNAV transit routes in the London TMA). Currently, there are always conventional alternatives available for aircraft that are not P-RNAV compliant, although such aircraft may experience delays and restrictions within busy TMAs
- In the future, some TMAs may become only accessible to P-RNAV approved aircraft (eg. London)

**The 42 countries of the ECAC**
http://www.ecac-ceac.org
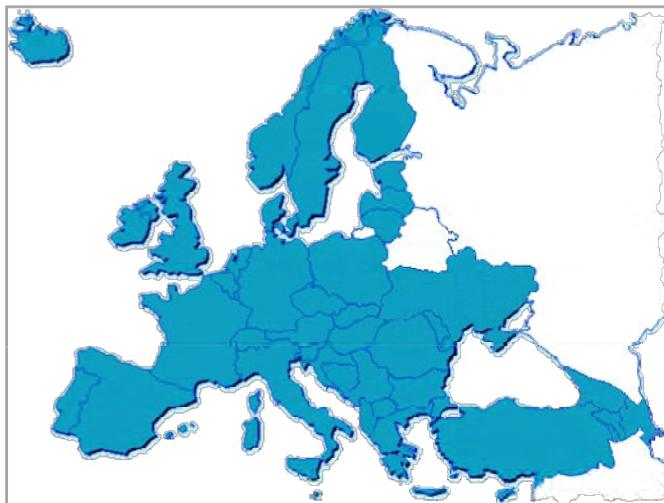
Albania, Armenia, Austria, Azerbaijan, Belgium, Bosnia, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Monaco, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Macedonia, Turkey, Ukraine, UK

**AICs relating to the planning and implementation status of P-RNAV are available in the ECACNAV website**
http://www.ecacnav.com/content.asp?CatID=207

**Example: current AIC list (last updated 4 September 2007)**

| | |
|---|---|
| AUSTRIA AIC A9/03 | LITHUANIA AIC09/06 |
| BELGIUM AIC Nr.05/2006 | MALTA AIC A05/03 |
| CROATIA AIC A01/07 | NORWAY AIC 01/04 |
| CYPRUS AIC A05/06 | THE NETHERLANDS AIC-A 05/06 |
| CZECH REPUBLIC AIC A8/06 | POLAND AIC A02/07 |
| DENMARK A20/03 | PORTUGAL AIC 001-2007 |
| DENMARK SUPPLEMENT AIC | ROMANIA AIC A01/05 |
| ESTONIA AIC A5/06 | SERBIA & MONTENEGRO AIC A6/07 |
| FINLAND AIC A16/2001 | SLOVAK REPUBLIC AIC A-9-2003 |
| FRANCE AIC A19/07 | SLOVENIA AIC A02/2006 |
| GERMANY AIC IFR 3 | SPAIN AIP GEN 1.5-1 |
| GREECE AIC A2/06 | SWEDEN AIC A 9/2006 |
| HUNGARY AIC 04/07 | SWITZERLAND AIC A019/07 |
| IRELAND AIC Nr.01/07 | TURKEY AIC 05/03 |
| ITALY AIC A 3/2004 | UNITED KINGDOM AIC 125/2006 |
| LATVIA AIC A01/04 | |

# P-RNAV AIC example

**Extract, full document available at http://www.ecacnav.com/content.asp?CatID=207**

**OPERATION OF PRECISION RNAV (P-RNAV) AIRBORNE EQUIPMENT
IN THE TERMINAL AIRSPACE OF GERMANY**

### 3. TERMINAL AREA NAVIGATION APPLICATION PLANNING FOR P-RNAV

*Note that current RNAV procedures will be 'upgraded' to require P-RNAV. The only change to the procedure chart may be a small "P-RNAV Approval Required" note*

3.1 In line with the ECAC-wide agreement, Germany will introduce P-RNAV approval requirements in termin-al airspace after successful completion of a safety assessment in the third quarter of 2007. P-RNAV procedures will be implemented in two steps.

**3.1.1 Step 1**

RNAV terminal area procedures which are published as GPS/FMS RNAV transition to final approach (over-lay to radar vector pattern) will, after a new publication, require P-RNAV approval.

**3.1.2 Step 2**

Standard instrument departure routes using B-RNAV route segments will, after a new publication, require P-RNAV approval.

*Note the availability of non-RNAV alternatives, but also the caveat on delays & routing*

3.2 Aircraft operation on such P-RNAV terminal area procedures shall be approved in accordance with the relevant JAA Temporary Guidance Leaflet No. 10 (TGL 10 Rev. 1): "Airworthiness and Operational Approval for Precision RNAV Operations in Designated European Airspace", or equivalent.

3.3 Some means of accessing airspace/airports served by P-RNAV designated procedures will continue to be provided by the retention of a limited number of conventional procedures, supplemented by the use of radar vectors. This provision will allow non-approved aircraft to continue to operate routinely into and out of the affected airports. However, such non-P-RNAV aircraft operations may incur delays and/or ex-tended routings during peak periods.

3.4 RNAV (GNSS) non-precision approach procedures based on JAA TGL 3 REV. 1 remain unchanged, since JAA TGL 10 REV. 1 excludes the final approach phase.

- P-RNAV requirements are published in AIS documents, and in products from commercial suppliers like Jeppesen

- The ATC section of the Jeppesen Airway Manual describes current P-RNAV requirements and status:
  - in the "Air Traffic Control Europe" sub-section, for Europe overall
  - in the "State Rules and Procedures" sub-sections, for individual countries

- "RNAV" is a generic label used in procedure chart titles and names. Specific RNAV requirements, such as P-RNAV, are noted in the chart text

**P-RNAV requirement noted in small chart text**

**Chart otherwise uses 'generic' RNAV titles**

LEBL/BCN BARCELONA — 16 NOV 07 (10-2) Eff 22 Nov — **JEPPESEN** — BARCELONA, SPAIN — **RNAV STAR**

ATIS 118.65 | Apt Elev 14' | Alt Set: hPa — Trans level: By ATC — Trans alt: 6000'

BISBA TWO YANKEE (BISBA 2Y) [BISB2Y]
RWYS 25L/R RNAV ARRIVAL
RNAV (DME/DME)
P-RNAV APPROVAL REQUIRED

MSA BCN/PRA VOR — 131° 5700' — 253° — 5100' 075° — 3200'
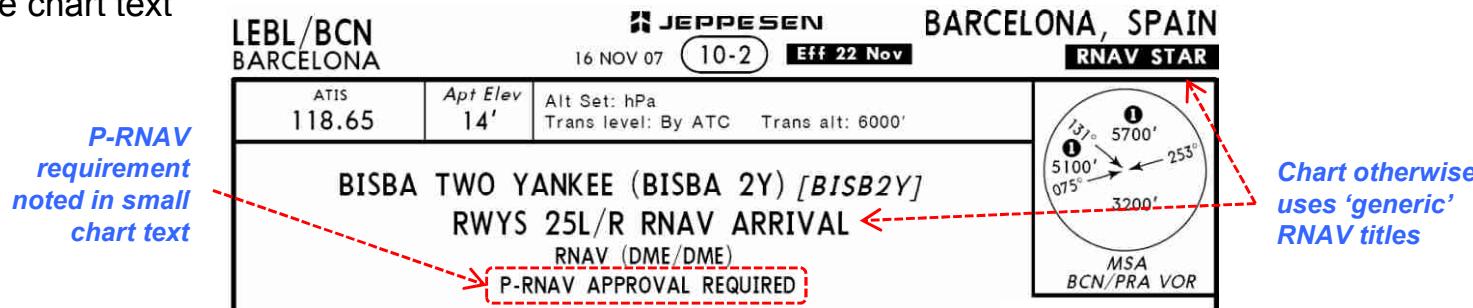
- A pilot needs to study the Jepp manual text pages in detail to be sure of all the conditions for RNAV operations. In the example below, EHAM Schipol's RNAV procedure charts note a B-RNAV requirement, but the Arrival text pages also describe conditions under which P-RNAV is required

**Charts note a B-RNAV requirement**
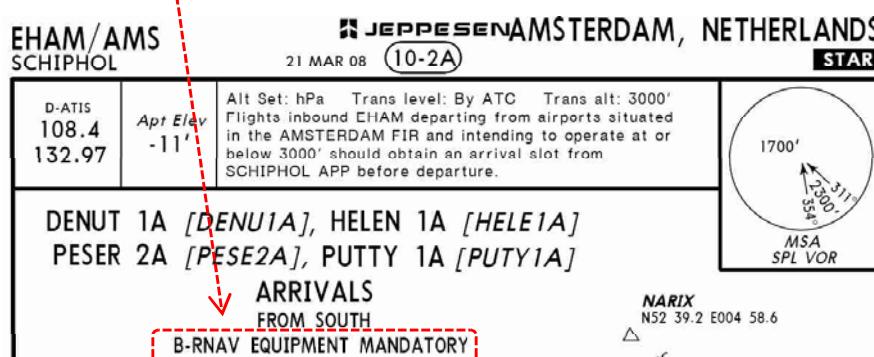
**Text pages note a P-RNAV requirement for night arrivals**

EHAM/AMS SCHIPHOL — 21 MAR 08 (10-2A) — **JEPPESEN** AMSTERDAM, NETHERLANDS — **STAR**

D-ATIS 108.4 132.97 | Apt Elev -11' | Alt Set: hPa — Trans level: By ATC — Trans alt: 3000'
Flights inbound EHAM departing from airports situated in the AMSTERDAM FIR and intending to operate at or below 3000' should obtain an arrival slot from SCHIPHOL APP before departure.

DENUT 1A [DENU1A], HELEN 1A [HELE1A]
PESER 2A [PESE2A], PUTTY 1A [PUTY1A]
ARRIVALS
FROM SOUTH
B-RNAV EQUIPMENT MANDATORY

MSA SPL VOR — 1700' — 311° 354° 2300'

NARIX N52 39.2 E004 58.6

EHAM/AMS SCHIPHOL — 29 FEB 08 (10-1P4) Eff 13 Mar — **JEPPESEN** AMSTERDAM, NETHERLANDS — **AIRPORT BRIEFING**

**2. ARRIVAL**

2.1.4. RNAV PROCEDURES

2.1.4.1. DURING NIGHT

In order to enable their pilots to accept the RNAV transitions, operators of ACFT arriving during NIGHT must hold a P-RNAV operations approval issued by their state, or a temporary exemption issued by CAA Netherlands.

# Additional P-RNAV theory topics
## 3. Flight Plan filing and RNAV

- Within ECAC airspace, the rules for Flight Plan filing relating to an aircraft's RNAV capability differ slightly from the ICAO standard

- The ECAC rules for item 10 (Equipment) of the ICAO FPL form are:
    - that B-RNAV equipment shall form part of the standard equipment, indicated through the use of the letter S in item 10
    - the letter R is also inserted in item 10, in conjunction with the letter S, to indicate B-RNAV compliance
    - the letter P is also inserted in item 10, in conjunction with the letters R and S, to indicate P-RNAV compliance

**B-RNAV compliant aircraft, with Mode S transponder**

```
10 EQUIPMENT
   Equipement
        SR        /S
```

**P-RNAV compliant aircraft, with Mode S transponder**

```
10 EQUIPMENT
   Equipement
       PSR        /S
```
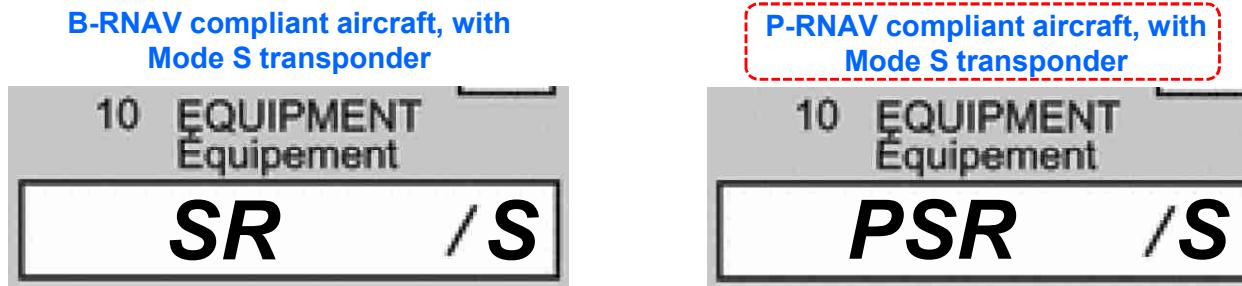
- An aircraft operating under an exemption from RNAV requirements shall indicate this in Item 18 of the FPL with the entry "STS/NONRNAV". These are usually only State aircraft
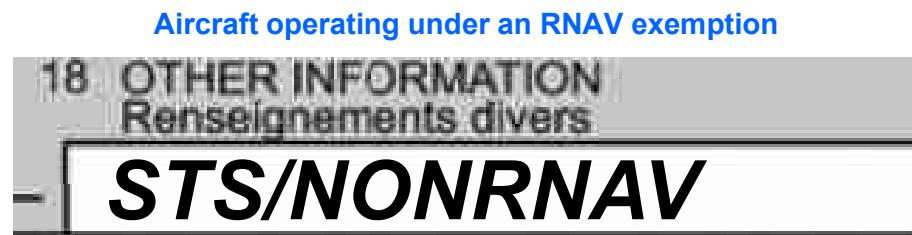
**Aircraft operating under an RNAV exemption**

```
18 OTHER INFORMATION
   Renseignements divers
 -   STS/NONRNAV
```

# Course contents

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. **P-RNAV operations**

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

# P-RNAV Operating Procedures

- TGL 10 Section 10 has guidelines for P-RNAV operating procedures that pilots should be trained in and which should be included in the operations manual or "extended checklist" submitted as part of a P-RNAV LoA application

- The FAA and UK CAA P-RNAV requirements are based on these TGL10 guidelines and ICAO's European RNAV guidance document

**JAA TGL10**
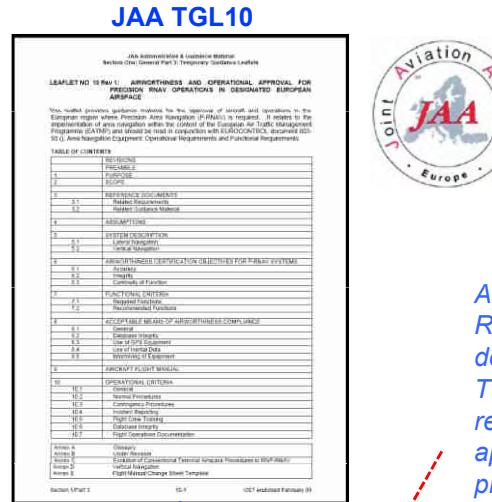


*An overall guide to RNAV approvals, it does not detail the TGL10 guidelines but refers to the need for approved operating procedures*

*Application requires submission of an "Operations Manuals, to include normal procedures, contingency procedures, incident reporting and flight crew training"*

**FAA's AC90-96A**

**UK CAA's FODCOM 04/2008**    **and CA4045**

*P-RNAV operating procedures are detailed in Appendix 2 Section 3. This is similar to TGL10 section 10, with some additional detail and notes*

➡ · **The 4 'guideline' pages that follow are a synthesis of the TGL10 and AC90-96A material, omitting items that are not relevant to a single-pilot aircraft. LoA applicants should also refer to the original documents**

# P-RNAV Operating Procedure guidelines (1)
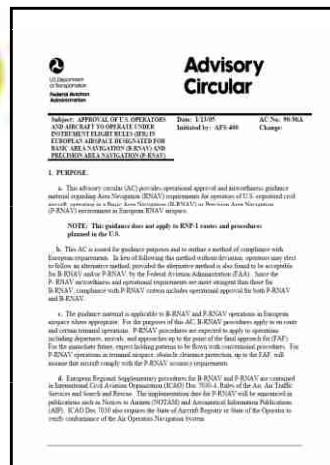
## Pre-flight Planning

1. Check charts and NOTAMS to confirm availability of the navigation infrastructure as required for the flight, including any non-RNAV contingencies

2. Check that the aircraft navigation equipment needed for the route to be flown is compliant and serviceable, including AIP information on whether dual P-RNAV systems are required

3. Check the GPS database coverage and validity is suitable for the intended flight and, in particular, that the terminal procedures for the departure, arrival and alternate airfields are available

4. Check that RAIM is predicted to be available for the route and time of flight using the AUGUR tool (http://www.augur.ecacnav.com) up to 24hrs in advance of the flight

5. Note that some P-RNAV procedures require minimum speeds that some piston aircraft can not comply with. Check procedure charts and be prepared to advise ATC of non-compliance and best speed attainable

## Prior to Departure

1. Confirm the navigation database is current

2. Receive ATC clearance, including P-RNAV SID designator

3. Load the SID procedure into the GPS flight plan, and complete the enroute flight plan

4. Check the GPS SID procedure against the paper chart, using the map display (as a minimum) or by confirming the waypoint sequence, track angles, distances and fly-by vs fly-over waypoints. A procedure shall not be used if any discrepancy is found

5. Prior to commencing take off, verify the aircraft's GPS position is available and accurate

6. During the procedure, monitor the GPS navigation by crosschecking with conventional navigation aids

*Note that the manual entry of waypoints or modification of a P-RNAV procedure is not permitted. However, the pilot must be able to react promptly to ATC route modifications in the form of 'direct to' clearances, by inserting of waypoints into the flight plan from the database if required*

## Arrival

1. Prior to the start of the procedure, verify that the correct terminal procedure has been loaded

2. Check the loaded procedure against the paper chart, using the map display (as a minimum) or by confirming the waypoint sequence, track angles, distances and fly-by vs fly-over waypoints. A procedure shall not be used if any discrepancy is found

3. Prepare to revert to a conventional arrival procedure if required as a contingency

4. Monitor the GPS navigation by crosschecking with conventional navigation aids, particularly the gross error check with respect to a published VOR/DME fix at the start of a procedure, if available

*Notes:*

*If a GPS integrity alarm is received, a conventional procedure must be flown*

*The manual entry of waypoints or modification of a P-RNAV procedure is not permitted. However, the pilot must be able to react promptly to ATC route modifications in the form of 'direct to' clearances, by inserting of waypoints into the flight plan from the database if required*

*All published altitude and speed constraints must be observed*

**Contingency Procedures**

*The operator will need to develop contingency procedures to address cautions and warnings for the following conditions:*

• Failure of the RNAV system components including, those affecting flight technical error (e.g. failures of the flight director or automatic pilot)

• Failure of the navigation sensors or the loss of RAIM, which constitutes a loss of GPS P-RNAV capability

*The pilot must notify ATC of any loss of the P-RNAV capability, together with the proposed course of action*

*The pilot should continue with the P-RNAV procedure in accordance with the published lost communication procedure in the event of communications failure*

*The pilot should navigate using an alternative means of navigation which doesn't need to be RNAV*

**Incident Reporting**

Report significant incidents associated with the operation of the aircraft which affect or could affect the safety of P-RNAV operations. Specific examples may include:

• GPS system malfunctions during P-RNAV operations

• Significant navigation errors attributed to incorrect data or a navigation database coding error

*Errors or discrepancies with Jeppesen database products should be reported to the contact address at http://www.jeppesen.com …Customer Support…Navigation Data Support*

# P-RNAV Operating Procedure guidelines (4)

**Extracts from the ICAO European RNAV Guidance Material, 5th edition available at http://www.ecacnav.com/Document_Library**
*(with bold emphasis added)*

*A synthesis of the items from this document is available in the Jeppesen Airway Manual ATC section, 'Procedures For Area Navigation (RNAV) Operations – Europe' sub-section*
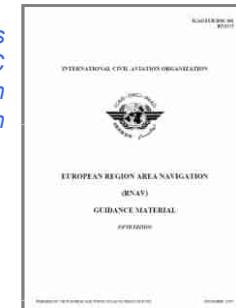
## Radio Communications and ATC Procedures

The RNAV contingency procedures related to the carriage and operation of B-RNAV equipment, is equally applied to the failure and degradations, in flight, of P-RNAV systems. The following provisions refer

**"When an aircraft cannot meet the requirements for either P-RNAV or B-RNAV, as required by the RNAV ATS route or procedure, as a result of a failure or degradation of the RNAV system, a revised clearance shall be requested by the pilot."**

The RNAV contingency RTF Phraseology is as follows: **"Unable RNAV due equipment"**

---

With respect to the degradation/failure in flight, of an RNAV system, while the aircraft is operating on a terminal area procedure requiring the use of RNAV, the following applies:

a) the aircraft should be provided with radar vectors, until the aircraft is capable of resuming its own navigation; or

b) the aircraft should be routed by conventional navigation aids, i.e. VOR/DME

The use of radar vectors is considered as a means best suited to resolve such issues in a tactical TMA environment.

---

Terrain Clearance

The use of RNAV does not affect existing ICAO provisions describing responsibilities with respect to avoidance of terrain. Specifically, unless an IFR aircraft is receiving navigation guidance in the form of radar vectors from ATC, **the pilot remains responsible for avoidance of terrain**.

# Developing a P-RNAV "extended checklist" or operations manual

A P-RNAV Operations Manual or 'extended checklist' should include 3 elements:

1. The normal checklist items, consistent with the aircraft flight manual
2. The operations manual content for single-pilot IFR
3. The additional content required for P-RNAV

The members' forum at www.pplir.org, in the "Documents and Tools" section, has 2 editable templates for such a manual

*An FAA Part 91 Operations Manual for a P-RNAV approved Cessna 421C*
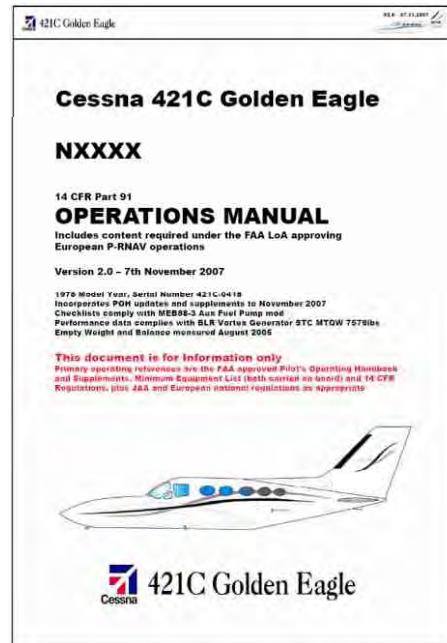
*A template for a Piper Seneca manual, based on a UK CAA approved AOC-style manual used for Instrument Rating training*

➡ · **The next 3 pages illustrate the P-RNAV contents and checklist structure used for a Cessna 421 operating under an FAA P-RNAV LoA**

# P-RNAV extended checklist example: items added to an 'normal' IFR checklist to comply with P-RNAV requirements

## Pre-Flight Planning

1. Check AUGUR for RAIM availability, and NOTAMs
2. Check currency and coverage of GNS480 database
3. Check if dual P-RNAV systems are required, and note contingencies in the event of a GNS480 failure

## Prior to Departure

1. Verify P-RNAV LoA copies are on board (tech log)
2. Check GNS480 self-test, data currency & coverage (# 1&2)
3. Enter Flight Plan and select Departure Procedure
4. Crosscheck Procedure map display with Jepp paper charts
5. Verify initialisation complete and GPS position available
6. Check RAIM Prediction

## GNS480 RAIM Prediction (see Pilot's Guide p19)

1. Highlight Destination waypoint in Flight Plan screen
2. Press INFO key, then RAIM smart key
3. if required, press the CRSR knob to change the ETA
4. Press MENU/ENTER to compute the RAIM prediction

## Departure

1. Perform GPS position check on runway
2. Monitor tracking accuracy on CDI scale (1nm)
3. Crosscheck PRNAV guidance with conventional aids

## Arrival

1. Select and load the Arrival Procedure in GNS480 #1
2. Crosscheck Procedure map display with Jepp paper charts
3. Prepare and brief the alternative non-PRNAV procedure
4. Complete gross error check using radio navaids
5. Monitor GNS480 for Loss of Integrity annunciation
6. Monitor tracking accuracy on CDI scale (1nm)

## P-RNAV Capability Failure (eg. LOI alert)

**Total failure of one GNS480**
1. Revert to the working GNS480
2. Notify ATC

*In the event of an LOI alert, monitor the GNS480s for 1 minute, then initiate the procedures below*

**LOI alert or other loss of P-RNAV capability in GNS480#1**
1. Cancel cross-link function in GNS480#2 from Flight Plan screen menu
2. If in a procedure requiring dual P-RNAV systems, advise ATC & revert to the alternative procedure
3. Cancel GPS Roll Steer mode if selected
4. Select GNS480#2 as nav source for the MX20 and KMD540 MFDs on the avionics switch panel

**LOI alert or other loss of P-RNAV capability in GNS480#2**
1. Continue with GNS480#1 as primary nav source
2. If in a procedure requiring dual P-RNAV systems, advise ATC & revert to the alternative procedure

**LOI alert or other loss of P-RNAV in both GNS480s**
1. Select radio navigation aids and CDI source
2. Advise ATC and continue with non-PRNAV procedure or as directed
3. Cancel GPS Roll Steer mode if selected

## ICAO Flight Plan Form – Item 10

The ICAO flight plan Item 10 (Equipment) entry for Nxxxx is "PRS/S" designating P-RNAV (and B-RNAV) approval and Mode S

## Database Integrity

The GNS480 database is certified by Garmin as conforming to Do200a and ED76. Hence, navigation database integrity checks are not required beyond the validity & cross-check procedures above

# Illustration of extended checklist structure (1)

**PPL/IR EUROPE**

*Blue boxes are both P-RNAV and 'conventional' IFR checks*

*Black header boxes indicate where aircraft-specific normal checklist sections should be inserted*

## P-RNAV Pre-Flight Planning

1. Check AUGUR for RAIM availability, and NOTAMs
2. Check currency and coverage of GNS480 database
3. Check if dual P-RNAV systems are required, and note contingencies in the event of a GNS480 failure

## Before Starting Engines

## Prior to P-RNAV Departure

1. Verify P-RNAV LoA copies are on board (tech log)
2. Check GNS480 self-test, data currency & coverage (# 1&2)
3. Enter Flight Plan and select Departure Procedure
4. Crosscheck Procedure map display with Jepp paper charts
5. Verify initialisation complete and GPS position available
6. Check RAIM Prediction

## GNS480 RAIM Prediction (see Pilot's Guide p19)

1. Highlight Destination waypoint in Flight Plan screen
2. Press INFO key, then RAIM smart key
3. if required, press the CRSR knob to change the ETA
4. Press MENU/ENTER to compute the RAIM prediction

## Starting Engines

## Before Taxiing

## Before Take-Off

## IFR Departure Checks (See PRNAV checks if applicable)

1. Departure Clearance…..RECEIVE
2. Avionics………………... SET, check GPS data & RAIM
3. Autopilot switches……...Panel ON but AP Console OFF
4. HSI OBS and HDG…...   OBS set, HDG to Runway heading
5. Departing into IMC with OAT <10C
   Pitot & Stall heat, Prop Deice…ON
   Windshield Deice………………LOW (HIGH if OAT<-10C)

Departure Brief
   Climb runway HDG…   to xxxx ft or x DME
   Turn…………………    Left/right to HDG xxx
   Intercept……………..    track X @ facility Y
   Continue climb to…...   xxxx ft

Engine Failure after take-off Brief
   Decision point, Accel Stop/Go performance
   Failure in IMC: "step on the bug", feather dead leg

## P-RNAV Departure and After Departure

1. Perform GPS position check on runway
2. Monitor tracking accuracy on CDI scale (1nm)
3. Crosscheck PRNAV guidance with conventional aids

## Takeoff

# Illustration of extended checklist structure (2)

*Black header boxes indicate where aircraft-specific normal checklist sections should be inserted*

*Blue boxes are both P-RNAV and 'conventional' IFR checks*

**Climb**

**Establishing Cruise**

**Enroute Checks**

**Flight in Icing Conditions**

**Descent**

**IFR Arrival Checks** (See PRNAV checks if applicable)

1. Radios and GPS…........ SET
2. Altitude…………….......... SET QNH, check cleared level
3. Mixtures…………………… CHECK
4. Fuel……………………….. CHECK MAINS & QUANTITY
5. Ice………………………… CHECK
6. Seats and belts……….. CHECK

**P-RNAV Arrival**

1. Select and load the Arrival Procedure in GNS480 #1
2. Crosscheck Procedure map display with Jepp paper charts
3. Prepare and brief the alternative non-PRNAV procedure
4. Complete gross error check using radio navaids
5. Monitor GNS480 for Loss of Integrity annunciation
6. Monitor tracking accuracy on CDI scale (1nm)

**IFR Initial Approach Checks**

1. Lights………………………… AS REQD
2. Aux Fuel Pumps………...LOW
3. Cabin Pressure………..... DIFFERENTIAL NEARING ZERO
4. Yaw Damp.................... OFF
5. Throttles…………………22"
5. Flaps…………………… 15$^O$, below 176 KIAS

**IFR Final Approach Checks**

1. Gear……………………..DOWN
2. Flaps…………………… 30$^O$ if AP off and below 146 KIAS
3. Ice………………………..CHECK

**IFR 1000' Checks**

1. Gear……………………..3 GREENS
2. Props…………………….1800rpm, MAX IF REQD
3. Mixtures…………………..FULL RICH
4. Cabin Pressure…………ZERO DIFFERENTIAL
5. Ice………………………..CHECK

**VFR Approach and Landing**

**Go-Around**

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
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   e. RNAV and RNP applications

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   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. **GPS procedure types**
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

# Introduction: ICAO 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 glidepath | Based on a navigation system that does not meet the precision approach standards of ICAO Annex 10 but which does provide course <u>and</u> glidepath deviation.<br>Procedures have a DA rather than an MDA. | Based on a navigation system that provides course and glidepath deviation which meets the precision standards of ICAO Annex 10 |

Examples based on traditional radio aids and radar:

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

Examples based on RNAV:

| | | |
|---|---|---|
| **RNAV(GPS) or RNAV(GNSS)**<br>"Published overlay" or "stand-alone" GPS non-precision approaches, which use LNAV minima | **LNAV/VNAV**<br>Vertical guidance provided by SBAS-GPS (eg. WAAS) or Baro-VNAV (through approved FMS)<br>**LPV**<br>Vertical guidance provided by SBAS-GPS (eg.WAAS). Procedure may 'downgrade' to LNAV/VNAV minima if satellite signal or runway environment/lighting does not meet LPV criteria | **GLS**<br>GNSS Landing System: precision approach based on GPS with GBAS (eg. LAAS)<br>Currently, CAT I procedures have been deployed in limited numbers. CAT II and III applications are being developed. |

➡ · **This manual will only address Non-Precision GPS approaches, since there are currently no procedures with GPS vertical guidance available in Europe**

# Typical structure of a conventional NPA

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

Initial approach fix is an NDB or VOR
*(NDB in this example)*

Intermediate fix is a DME distance or outbound time

**IAF**

**Initial segment**

**IF**

**Intermediate segment**

**Missed Approach segment**

**MAP**

**Final segment**

**FAF**

Racetrack pattern at the IAF permits arrivals from any direction

Missed approach point is usually the same beacon as the IAF, if this is located at the airport

Final approach fix is a DME distance, or (in a non-DME procedure) upon establishing the final approach track

*Lctr*

3000'

2000'

Missed approach point is always depicted on an NPA profile view with a letter M

Represents Minimum descent altitude

M

1250'

*Actual MDA value available from the table below the profile view on a Jeppesen chart*

Final approach fix is always depicted on an NPA profile view by this 'Maltese cross' symbol

Step-down fix altitudes are usually minima that must be observed but chart notes may indicate they are advisory or mandatory (ie. exact required altitudes)

DO NOT USE FOR NAVIGATION

*Source: Jeppesen*

# Typical structure of a GPS NPA: the "T-shaped" procedure

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

**IAF**

There are 3 Initial Approach Fixes available in the characteristic "T-shaped" GPS procedure. This allows for arrivals from any direction to proceed to the Final Approach Fix using only turns with a track change of no more than 90 degrees

**Initial segment**

*Missed approach point is an RNAV waypoint (often Fly-Over) at the runway threshold*

Typically, both the initial and intermediate legs are 5nm

*Dual purpose fix: IAF and IF*

**MAP**

**Missed Approach segment**

**Final segment**   **FAF**   **Intermediate segment**

**IF/IAF**

*In this example, the missed approach consists of a Track-to-Fix (TF) leg from the MAP followed by a Direct-to-Fix (DF) leg back to the MAP.*

**Initial segment**

Step-down altitudes on the vertical profile are minima which must be observed unless explicitly labelled 'Mandatory' or 'Maximum', or unless the chart notes that they are advisory only

FAF identifier: aa are the last two letters of the airport's ICAO designator, nn is the runway number, "F" is the code letter for the Final Approach Fix

**IAF**

*Missed approach waypoint name and database identifier*

***RWYnn***
*[RWYnn]*

*[identifier]*

***aannF***

"aann" as per the FAF identifier, "I" is the code letter for the IF

***aannI***

2500'

**IF/IAF**

The final approach is depicted as a continuous descent profile. This is not mandatory, but the chart will note any minimum descent restrictions and, often, depict minimum obstacle clearing altitudes on the profile view

1000'

2000'

Numbers 'above the line' are distances (in nm) between waypoints, as shown in the GPS distance to next waypoint display

Numbers 'below the line' are distance (in nm) to the threshold, equivalent to the DME distance display in an ILS procedure, but often not displayed by the GPS

**M**

3.0     3.0     5.0

6.0     11.0

In this example, the basic T-shape is modified with an IAF and intermediate segment extending beyond the cross-bar of the T

❶ For MANDATORY alt on descent profile see table above.

Note that in this case, there are mandatory altitudes on the vertical profile (ie. not just minima, but an exact required altitude)
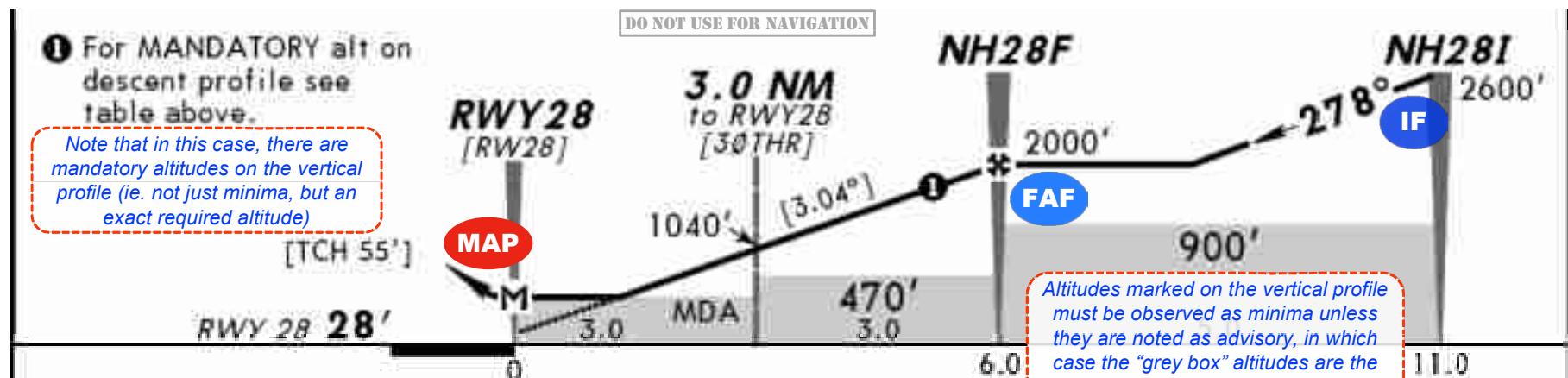
Altitudes marked on the vertical profile must be observed as minima unless they are noted as advisory, in which case the "grey box" altitudes are the required minima by segment

Source: Jeppesen

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

- When approaching the procedure area, the aircraft's arrival track (or magnetic bearing) to the IF determines which IAF should be used

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

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

**"Right Base Area"**

**"Straight-In Area"**

**"Left Base Area"**

**Initial segment**

IAF

IF/IAF

FAF

Intermediate segment

Final segment

Missed Approach segment

MAP

*Jeppesen charts depict a Minimum Sector Altitude for each arrival area*

090°

2500'

25

360°

*Radius in nm from the IAF within which the MSA applies*

*MSA*

# GPS NPA notes (2)
## The "T" structure is not used in all GPS NPAs

| LFBZ (Biarritz) RNAV(GNSS) Rwy 09 | EDDK (Cologne-Bonn) RNAV(GPS) 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 IAF's conform to the structure of standard arrival routes within the TMA rather than a T-shaped GPS NPA*



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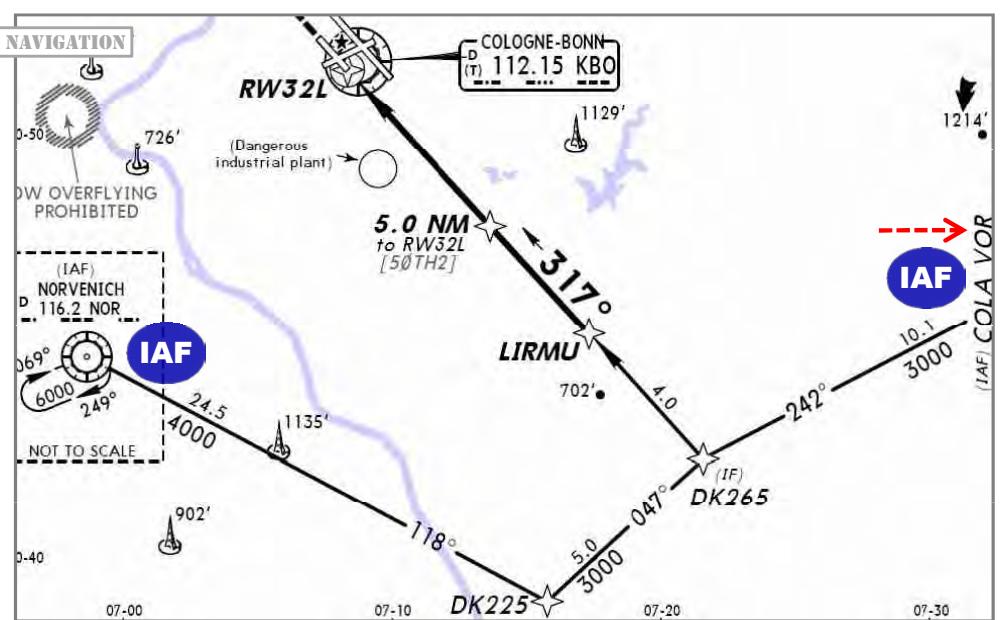
*At a larger airport like Cologne, pilots may expect a STAR terminating at one of the IAFs (eg. NORVENICH or COLA), or radar vectors to the GPS final approach or to an intermediate waypoint on the GPS NPA*

*Source: Jeppesen*

**Example:**



LONDON, UK
RNAV (GNSS) Rwy 27L
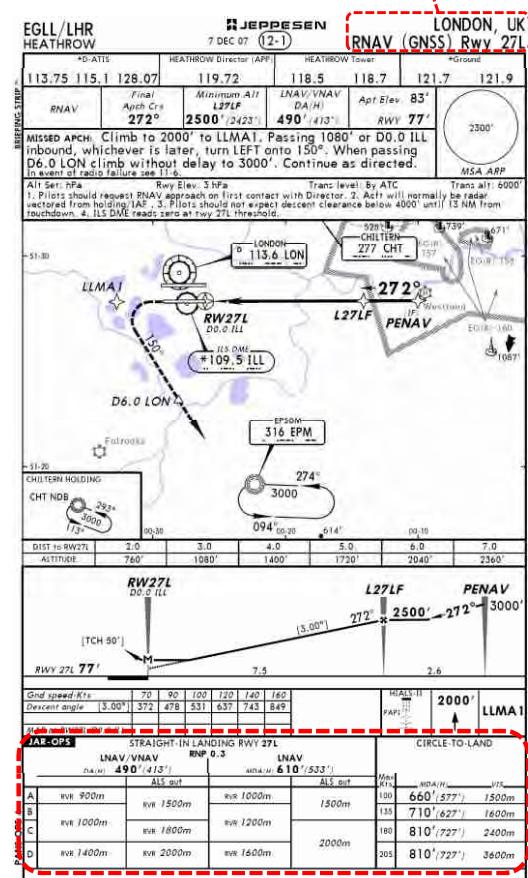


*LNAV/VNAV minima apply to an APV procedure (Approach with Vertical guidance) which uses either Baro-Aided VNAV or SBAS (WAAS or EGNOS). Light aircraft avionics do not support Baro-aiding of this kind and EGNOS is not yet available for aviation uses in Europe, hence these minima will not apply to light GA operators*

*The "LNAV" minima are the correct ones for a GPS Non-Precision Approach*
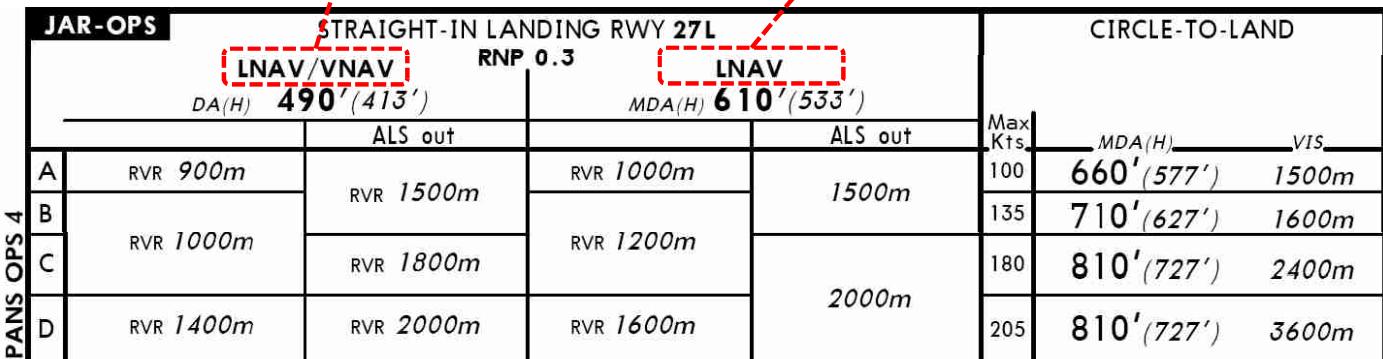


| JAR-OPS | STRAIGHT-IN LANDING RWY 27L | | | | | | CIRCLE-TO-LAND | | |
|---|---|---|---|---|---|---|---|---|---|
| | LNAV/VNAV | | RNP 0.3 | | LNAV | | | | |
| | DA(H) 490'(413') | | | | MDA(H) 610'(533') | | Max Kts | MDA(H) | VIS |
| | | ALS out | | | | ALS out | | | |
| A | RVR 900m | | RVR 1500m | | RVR 1000m | 1500m | 100 | 660'(577') | 1500m |
| B | RVR 1000m | | | | RVR 1200m | | 135 | 710'(627') | 1600m |
| C | | | RVR 1800m | | | 2000m | 180 | 810'(727') | 2400m |
| D | RVR 1400m | | RVR 2000m | | RVR 1600m | | 205 | 810'(727') | 3600m |

*Source: Jeppesen*

*GPS units like the Garmin 430/530 use baro-aiding to improve a position fix when fewer satellites are visible, and can provide advisory VNAV information based on user-defined altitude targets. This should not be confused with the Baro-aided VNAV needed for an APV. In Europe, suitable WAAS-approved GPS installations will be able to provide the synthetic glideslope guidance for APV and LPV procedures when EGNOS is fully operational*

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. **GPS approach requirements and approvals**
   c. GPS approach operations

5. Avionics training

6. Simulator and/or Flight training

# UK and US requirements for private aircraft and GPS NPAs

- In general, for private GA operators, GPS Non-Precision Approaches are an additional type of IFR procedure that does not require special authorisation or additional pilot qualifications

| | 1. Avionics approval | 2. Pilot knowledge and training | 3. Operations |
|---|---|---|---|
| **FAA** | • Based on aircraft original equipment:<br>– Flight Manual section on GPS equipment must specify that the installation is approved for IFR and GPS approaches<br>• Based on retrofit equipment:<br>– Installation must be IFR approved as per AC20-138A<br>– Flight Manual supplement must specify that installation is approved for GPS approaches | • A current FAA Instrument Rating qualifies a pilot to fly GPS NPAs without a requirement for further formal ground or flight training<br>• The FAA recommends that pilots should be familiar with at least the 12 areas of GPS operation listed in AIM section 1-1-19-P, either through training or by practicing in VMC conditions | • 14 CFR Part 91 regulations govern IFR flight for private operators<br>• The Aeronautical Information Manual (AIM) Section 1-1-19 details the requirements for using GPS as a navigation aid in NPAs and other IFR applications<br>• AIM Section 5-4-5 "Instrument Procedure Charts" describes the design of GPS NPAs and the related aircraft and ATC procedures |
| **UK CAA** | • Based on aircraft original equipment:<br>– Flight Manual section on GPS equipment must specify that the installation is approved for IFR and GPS approaches<br>• Based on retrofit equipment:<br>– Installation must be an EASA approved modification and the corresponding Flight Manual supplement must specify that installation is approved for GPS approaches | • A current UK CAA or JAA Instrument rating (or UK IMC Rating) qualifies a pilot to fly GPS NPAs without a requirement for further formal ground or flight training<br>• However, the UK CAA recommends that all pilots undergo training before flying GPS NPAs<br>• CAP773, available at www.caa.co.uk, provides a detailed guide for pilots, instructors and FTOs on suitable training | • AIP Supplement S 11/2008 describes the basic operating requirements for GPS NPAs in UK airspace<br>• CAP 773 has further detail on recommended operating practices specific to GPS NPAs<br>• Although private operators do not need approval for GPS NPAs, the CAA RNAV Approval guidance document, FODCOM 04/2008, is a useful additional source of information |

➤ · **The key requirement for both N- and G- registered aircraft is that the Flight Manual (or equivalent) permits the GPS installation to be used for standalone GPS NPAs**

· **Section 4c of this document details the required and/or recommended operating procedures for GPS NPAs**

# Training requirements outside of the UK and USA

- Some countries <u>do require</u> general aviation pilots to have completed formal training in GPS NPAs, and this requirement may also apply to foreign-registered aircraft operators

- Note that holders of JAA Instrument Ratings are not exempt from any additional national regulations of other JAA countries they fly in

- These national regulations are available in State AIS publications, and are usefully summarised in the Jeppesen Airway Manual ATC Section, under "State Rules and Procedures"

Example: extract from Jeppesen Airway Manual, ATC Section, State Rules and Procedures: Germany

> **GENERAL REQUIREMENTS FOR PILOT QUALIFICATION**
> *Pilots wishing to carry out GPS stand alone non-precision approaches must have familiarized themselves sufficiently with the basic principles, special features and restrictions of GPS, as well as the handling of the GPS equipment on board the aircraft.*
>
> *Pilot qualification for the use of the GPS procedures and GPS receivers must be proved. Such proof may be provided, for example, in the form of certificates issued by the equipment manufacturers, IFR flight training centres as well as by flight instructors, authorized trainers and technical experts in possession of an IFR rating, respectively. Proof may be entered in the pilot's logbook.*

Example: extract from Jeppesen Airway Manual, ATC Section, State Rules and Procedures: Denmark

> **Qualification requirements for non-commercial pilots**
> *Pilots wishing to carry out GPS non-precision approaches shall have sufficient theoretical and practical knowledge about the use of navigational equipment based on GPS before this equipment is used.*
> *Documentation for pilot qualification training is to be presented on request and shall be entered in the pilot's logbook or the like.*

➡ - **PPL/IR Europe recommends that all private pilots complete a suitable course of training before flying GPS Non-Precision Approaches**

- **A logbook endorsement from an instructor or FTO, that this training has been completed, should also qualify the pilot for GPS NPAs in the countries where such training is required**

# Summary of GPS NPA pilot training recommendations

• The table below is a synthesis of recommended training topics based on FAA and CAA source documents

*T: Theory training requiring study of this manual*
*A: Avionics training, supported by sections 2 and 5 of this manual*
*F: Flight and/or Simulator training, see syllabus in section 6*

| T | A | F | Topic | Comment |
|---|---|---|-------|---------|
| ✓ | | | General RNAV theory<br>- definition and meaning of RNAV and RNP<br>- limitations of RNAV<br>- GPS concepts and limitations<br>- RAIM | Topics are fully covered by this manual<br>- see section 1<br>- see sections 1 and 2<br>- see section 2a and 2b<br>- see section 2d |
| ✓ | | | GPS NPA Theory<br>- GPS NPA procedure design<br>- GPS NPA procedure charts, limitations and minima<br>- required navigation equipment for GPS NPAs | Topics are fully covered by this manual<br>- see section 4a<br>- see section 4a<br>- see section 4b (this section) |
| ✓ | | | Charting, database and avionics topics<br>- RNAV path terminator concepts<br>- fly-by and fly-over waypoints<br>- waypoint naming concepts<br>- coding of GPS overlays and standalone NPAs<br>- use of only current databases & coded procedures; cross-checking | Topics are fully covered by this manual<br>- see section 1<br>- see section 1<br>- see section 2b<br>- see section 2c<br>- see section 2b |
| ✓ | | ✓ | Operational procedures and practices<br>- Normal procedures<br>- Contingency procedures | Topics are fully covered by this manual<br>- see section 4c<br>- see section 4c |
| ✓ | ✓ | ✓ | Use of RNAV Equipment<br>- retrieving a procedure from the database<br>- briefing the procedure, comparing it with the charted procedure<br>- action to be taken if discrepancies are noted<br>- sensor management<br>- tactically modifying the flight plan | Topics are covered but not in full, refer to GPS receiver User Manual<br>- see section 2c and sections 5 & 6<br>- see sections 2 and 3c<br>- see sections 2 and 3c<br>- see section 2<br>- see sections 5 & 6 |
| | | ✓ | Flying GPS NPA procedures<br>- LNAV, VNAV and associated control techniques,<br>- use of automatic pilot and flight director<br>- missed approach and contingency procedures (eg. loss of RAIM)<br>- ATC procedures | See section 6 for a recommended syllabus for flight/simulator training to meet these requirements |

| | SUPPLEMENTS TO THE UNITED KINGDOM AIP | S 11/2008 Publication Date: 24 April | Civil Aviation Authority |
|---|---|---|---|
| NATS | | | |

**2 General**

2.1 Notified RNAV (GNSS) Instrument Approach Procedures will be available for use by all Instrument and IMC Rated pilots of UK and foreign registered aircraft. Aircraft must have suitably approved equipment.

**3 Aircraft Navigation System**

3.1 The aircraft navigation system shall include at least one GPS receiver. The navigation system must be approved to conduct:

   (a) RNAV (GNSS) stand-alone approaches1 or;
   (b) approaches of RNP 0.3 or RNP-RNAV 0.3 type2.

3.2 All approved installations must have the appropriate approval for RNAV (GNSS) approach operations entered in the Aircraft Flight Manual (AFM), Pilot Operating Handbook (POH) or equivalent. The navigation system can be as a minimum:

   (a) A system only based on GNSS having at least one GPS receiver qualified to TSO-C129a / ETSO-C129a Class A1 or TSO-C146()3 / ETSO-C146() Class Gamma and operational class 1, 2 or 3 or;
   (b) a multi-sensor system (eg, Flight Management System) having at least one GPS receiver qualified to TSO-C129() / ETSO -C129() Class B1, C1, B3 or C3 or TSO-C145() / ETSO-C145() class 1, 2 or 3 (with equivalent integration guidance).

3.3 Any operating limitations mentioned in the AFM, concerning use of the navigation system on RNAV (GNSS) approach procedures must be observed.

3.4 Pilots must be able to determine that the on-board aeronautical database and software version in use for the navigation system is valid for the time of flight. The entire approach procedure must be loadable, by name, from the navigation database. **Manually entered and overlay procedures must not be used as the primary reference on any approach, at any time.**

**4 Pilot Training and Licensing**

……

4.2 CAP 773, Flying RNAV (GNSS) Approaches in General Aviation Aircraft provides guidance to pilots and instructors in the use of GPS for approach operations. This CAP contains technical information on the function of GPS together with equipment requirements, human factors considerations, training and practical guidance for the use of GPS during RNAV (GNSS) approach operations. It also contains guidance for instructors, Flight Training Organisations (FTOs) and Registered Facilities on appropriate training for RNAV (GNSS) approaches. CAP 773 is available on the CAA website and then by following the links Publications; General Aviation.

4.3 A CAA Personnel Licensing Department policy statement entitled, Flight Training and Testing for RNAV (GNSS) Non-Precision Instrument Approaches is available on the CAA website and then by following the links Safety Regulation; Personnel Licensing; What's New?

4.4 CAA Safety Sense Leaflet No.25 (Use of GPS) has been updated to include safety related guidance and information on the use of GPS in IMC and on instrument approaches. The leaflet may be found on the CAA website and then by following the links, Safety Regulation; General Aviation; Safety Sense Leaflets.

**AIM Chapter 1: Air Navigation; Section 1: Navigation Aids; Sub-section 19: GPS**

**d. General Requirements**

**1. Authorization to conduct any GPS operation under IFR requires that:**

(a) GPS navigation equipment used must be approved in accordance with the requirements specified in Technical Standard Order (TSO) TSO-C129, or equivalent, and the installation must be done in accordance with Advisory Circular AC 20-138, Airworthiness Approval of Global Positioning System (GPS) Navigation Equipment for Use as a VFR and IFR Supplemental Navigation System, or Advisory Circular AC 20-130A, Airworthiness Approval of Navigation or Flight Management Systems Integrating Multiple Navigation Sensors, or equivalent. Equipment approved in accordance with TSO-C115a does not meet the requirements of TSO-C129. Visual flight rules (VFR) and hand-held GPS systems are not authorized for IFR navigation, instrument approaches, or as a principal instrument flight reference. During IFR operations they may be considered only an aid to situational awareness.

(b) Aircraft using GPS navigation equipment under IFR must be equipped with an approved and operational alternate means of navigation appropriate to the flight. Active monitoring of alternative navigation equipment is not required if the GPS receiver uses RAIM for integrity monitoring. Active monitoring of an alternate means of navigation is required when the RAIM capability of the GPS equipment is lost.

(c) Procedures must be established for use in the event that the loss of RAIM capability is predicted to occur. In situations where this is encountered, the flight must rely on other approved equipment, delay departure, or cancel the flight.

(d) The GPS operation must be conducted in accordance with the FAA-approved aircraft flight manual (AFM) or flight manual supplement. Flight crew members must be thoroughly familiar with the particular GPS equipment installed in the aircraft, the receiver operation manual, and the AFM or flight manual supplement. Unlike ILS and VOR, the basic operation, receiver presentation to the pilot, and some capabilities of the equipment can vary greatly. Due to these differences, operation of different brands, or even models of the same brand, of GPS receiver under IFR should not be attempted without thorough study of the operation of that particular receiver and installation. Most receivers have a built-in simulator mode which will allow the pilot to become familiar with operation prior to attempting operation in the aircraft. Using the equipment in flight under VFR conditions prior to attempting IFR operation will allow further familiarization.

(e) Aircraft navigating by IFR approved GPS are considered to be area navigation (RNAV) aircraft and have special equipment suffixes. File the appropriate equipment suffix in accordance with TBL 5-1-2, on the ATC flight plan. If GPS avionics become inoperative, the pilot should advise ATC and amend the equipment suffix.

(f) Prior to any GPS IFR operation, the pilot must review appropriate NOTAMs and aeronautical information. (See GPS NOTAMs/Aeronautical Information.)

(g) Air carrier and commercial operators must meet the appropriate provisions of their approved operations specifications.

**AIM Chapter 1: Air Navigation; Section 1: Navigation Aids; Sub-section 19: GPS**

## p. GPS Familiarization

Pilots should practice GPS approaches under visual meteorological conditions (VMC) until thoroughly proficient with all aspects of their equipment (receiver and installation) prior to attempting flight by IFR in instrument meteorological conditions (IMC). Some of the areas which the pilot should practice are:

1. Utilizing the receiver autonomous integrity monitoring (RAIM) prediction function;

2. Inserting a DP into the flight plan, including setting terminal CDI sensitivity, if required, and the conditions under which terminal RAIM is available for departure (some receivers are not DP or STAR capable);

3. Programming the destination airport;

4. Programming and flying the overlay approaches (especially procedure turns and arcs);

5. Changing to another approach after selecting an approach;

6. Programming and flying "direct" missed approaches;

7. Programming and flying "routed" missed approaches;

8. Entering, flying, and exiting holding patterns, particularly on overlay approaches with a second waypoint in the holding pattern;

9. Programming and flying a "route" from a holding pattern;

10. Programming and flying an approach with radar vectors to the intermediate segment;

11. Indication of the actions required for RAIM failure both before and after the FAWP; and

12. Programming a radial and distance from a VOR (often used in departure instructions).

# Course contents

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. **GPS approach operations**

5. Avionics training

6. Simulator and/or Flight training

# Summary of GPS NPA operating procedures

• The table below is a synthesis of operating procedures for GPS NPAs based on FAA and CAA source documents

| 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 GPS and alternative navigation equipment<br>• Availability of GPS NPA and alternative conventional procedures<br>• Weather forecasts for destination and alternate. GPS NPA and alternate minima<br>• RAIM prediction<br>• NOTAM check |
| **2. Pre-Flight Checks** | • GPS database currency and coverage<br>• Check coding of expected GPS NPA procedure against paper charts<br>• GPS receiver self-test, user selectable settings, LOI monitoring<br>• Flight plan entry and RAIM prediction<br>• Requirement to use a database coded procedure for GPS NPAs, without user entry or amendment |
| **3. Pre-Arrival** | • Selecting and checking the Approach procedure<br>• Determining the appropriate IAF<br>• Activation of the procedure and CDI scaling |
| **4. Flying the GPS NPA procedure** | • Gross error check approaching the IAF, and check that the GPS is in TERM mode with CDI scaling at 1nm<br>• GPS and Navigation instrument mode selection<br>• Use of the GPS receiver if a hold or vectors to an intermediate waypoint on the NPA are required<br>• Check activation of APP mode and CDI scaling to 0.3nm prior to the FAF |
| **5. Flying the Missed Approach** | • Activation of the Missed Approach procedure and the need to manually re-initiate waypoint sequencing<br>• Mode selection and pilot actions in non-RNAV missed approach segments |
| **6. ATC communications** | • Communications during normal procedures<br>• Communications in the event of a GPS navigation failure |
| **7. Contingencies in the event of a GPS navigation failure** | • Immediate actions<br>• Reverting to alternative procedures |

➡ •**Each of these procedures is detailed in the following pages**

   • *This section includes only the key elements needed for GPS NPAs in addition to conventional IFR operating procedures and checks*

| Operating Procedure | Notes and comments |
|---|---|
| **IFR approval and serviceability of GPS and conventional navigation equipment** | • The pilot is responsible for ensuring that the GPS installation is approved for IFR and GPS approaches<br>  - the aircraft flight manual (or equivalent) is the primary source of this information<br>• *The operator must ensure that the flight manual and installation is kept current: the GPS manufacturer may, at times, require mandatory software and hardware upgrades, or issue updates to the flight manual*<br><br>• Unless a VFR alternate is available, the pilot must also ensure that appropriate conventional navigation equipment is serviceable and IFR-approved |
| **Availability of GPS NPA and alternative non-GPS procedures** | • The pilot should review and brief both the GPS and conventional procedures available at the destination and alternate. This is useful even though a GPS satellite system failure is unlikely:<br>  - conventional navaids may be used for gross error checks and monitoring of GPS guidance<br>  - ATC may require a non-GPS procedure to be flown for operational reasons<br>  - IFR workload, particularly in demanding weather and traffic conditions, may not allow much time for a pilot to troubleshoot or reprogram a GPS; 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. GPS NPA and alternate minima** | • The normal IFR planning requirements apply to GPS NPAs<br>• Note that the appropriate minima for GPS NPAs are "LNAV" ones; RNAV approach charts may also include minima for "LNAV/VNAV" or other procedures<br>• If the destination weather is such that an alternate airport is required, the alternate *must have a non-GPS 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** | • GPS 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.<br>• In Europe, http://augur.ecacnav.com/ may be used for RAIM prediction, and is preferable to using the GPS Receiver's built-in prediction software |
| **NOTAM check** | • The pilot's review of applicable pre-flight NOTAMs should include a check of the availability of GPS, conventional and missed approach procedures and of radio aids<br>• Note that, whilst GPS NPAs are relatively immature in Europe, published GPS procedures may <u>not</u> be available for prolonged periods, or at short notice; for example, due to ATC staff training requirements |

# GPS NPA operations (2) Pre-Flight Checks

| Operating Procedure | Notes and comments |
|---|---|
| **GPS database currency and coverage** | • The GPS receiver must use a current database, supplied from a source approved by the manufacturer<br>• 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*  <br><br>Cycle 0711<br>Effective 25-OCT-07<br>Expires 22-NOV-07 |
| **Check coding of expected GPS NPA 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<br>• This review may be done pre-flight, and it is useful to check all of the potential GPS NPAs and transition identifier selections at this point, in order to minimise in-flight workload<br>• Whilst coding errors are rare, it is common for GPS 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) |
| **GPS receiver self-test, user selectable settings, LOI monitoring** | • When the GPS unit is powered-up, the pilot should verify that the self-test procedure is successful<br>• After a position fix has been acquired, the pilot should monitor the GPS for Loss of Integrity alerts at all times<br>• UK CAA CAP773 (see Part 2 and Appendix 2) recommends that the status of all the user-definable GPS 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** | • The enroute flight plan may be entered at this point and a GPS RAIM prediction performed, either in lieu of or to update a prediction from an internet site such as AUGUR<br>• The RAIM prediction should be repeated whenever the destination ETA changes by more than ~15 minutes |
| **Requirement to use a database coded procedure for GPS NPAs** | • 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 GPS database<br>• *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* |

| Operating Procedure | Notes and comments |
|---|---|
| **Selecting and checking the Approach procedure**<br><br>**Determining the appropriate IAF** | • When cleared by ATC for a GPS NPA (ideally, >30nm from the destination), the procedure should be selected from the database but not (subject to the GPS unit logic) 'activated', 'loaded' into the active flight plan, or 'armed'<br>• 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 section 4a). This IAF should be selected from the transition identifier list in the procedure record<br>• ATC clearances should be read back carefully; some TMAs have a large number of similar sounding RNAV waypoints<br>• At this point, a final cross-check of the selected procedure should be performed<br>    - firstly, checking that the correct Airport, Procedure, Transition and Runway identifiers have been selected<br>    - secondly, checking that the database waypoints correspond to the published chart |
| **Activation of the procedure and CDI scaling** | • If the GPS procedure is satisfactory, it may be activated in the active flight plan<br>• "GPS" (rather than "VLOC") mode should be selected for the receiver CDI output, and the correct annunciator display should be verified<br>• Within 30mn of the destination, the CDI should scale to 1nm (max deflection) and "TERM" mode (or equivalent) should be displayed<br><br>*Example: Garmin 530 mode annunciation*<br>*CDI sensitivity 1nm in Terminal mode*<br>*CDI output toggled from VLOC to GPS* |

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



**MAPR** — Missed App. mode: CDI scale is 1nm

**APR** — Approach mode: CDI scale is 0.3nm

FAF — 2nm prior to FAF

**TERM** — Terminal mode: CDI scale is 1nm

30nm prior to destination (or start of terminal procedure)

1 min prior to 30nm boundary

**ENR** — Enroute mode: CDI scale is 5nm

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

Missed Approach segment — MAP — Final segment — FAF — Intermediate segment — IF

# GPS NPA operations (4) Flying the GPS NPA

| 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-GPS navigation if possible)<br>• Recheck that the procedure is active and the GPS is in TERM mode with CDI scaling of 1.0nm<br>• *The GPS 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*<br>• 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 GPS failure (or determine a safe course of action if a non-RNAV MAP is not available) |
| **GPS 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 GPS Map or Nav page settings are suitable for guidance during the procedure<br>• The pilot should establish a "mini checklist" for each procedure segment, for example:<br>   *- approaching a waypoint, self-brief on the next track, distance and level*<br>   *- when the GPS announces 10s to next waypoint, set the HSI to the next track*<br>   *- monitor the GPS receiver (not the HSI) during the 10s countdown, and be prepared to promptly establish a Rate 1 turn as soon as the GPS display says "Turn now to XXX$^{O}$"*<br>• In particular, note that most GPS receivers display only <u>distance to the next waypoint</u> during a procedure, not DME-style distance to the runway threshold |
| **Use of the GPS receiver if a hold or vectors to an intermediate waypoint on the NPA are required** | • *The operating logic of most GPS receivers makes it relatively easy to learn how to load and activate a procedure and follow the guidance from waypoint to waypoint*<br>• *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)*<br>• *A pilot must be trained in managing such tactical changes to the GPS 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 GPS APR (Approach) mode is active</u> – this is a critical check which also ensures that the CDI scaling is adjusting correctly and that RAIM is predicted to be available for the approach. Descent on the final approach must not commence unless "APR" mode is active<br>• After the FAF, if RAIM or position integrity is lost, the GPS will continue to provide track guidance for 5 minutes, but, despite this, the pilot must initiate the Missed Approach immediately |

• **In addition to this brief summary, any private pilot intending to fly GPS NPAs should study the appropriate official guidance material: FAA AIM Section 1-1-19-n and/or CAP773 Part 2 & Appendix 2**

| Procedure | Notes and comments |
|---|---|
| **Activation of the Missed Approach procedure and the need to manually re-initiate waypoint sequencing** | • GPS database procedures are coded such that the Runway Threshold waypoint is <u>always</u> the Missed Approach Point. 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 <u>after</u> a CNF at the runway threshold. This CNF is encoded as the missed approach procedure transition point in the database; see section 2c of this manual) |
| | • A strict logic applies in all IFR-certified GPS 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. In the Garmin 430/530 series, a "SUSP" annunciation indicates that sequencing is suspended, and the "OBS" key must be pressed to recommence sequencing |
| | • 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** |
| **Mode selection and pilot actions in non-RNAV missed approach segments** | • During the missed approach, the GPS will always provide track guidance and waypoint sequencing for "RNAV friendly" path-terminators such as a TF (Track to Fix) segments |
| | • However, even standalone RNAV Approaches often need to use path-terminators that are not fully supported by GPS receivers. Such procedure segments will be listed in the flight plan, but some combination of the following is possible <br> – automatic waypoint sequencing is suspended (for example, the GPS may not "know" when a conditional terminator, such as "2000' or 4DME - whichever is earlier", is reached) <br> – track guidance through the CDI is not provided, neither is autopilot LNAV guidance available <br> – the GPS Map may not display a 'magenta line' for the segment |
| | • Path-terminator support is specific to individual GPS models (and sometimes different software versions for the same receiver). A pilot must be familiar with the GPS user manual instructions on waypoint sequencing and path-terminator support, and prepared to fly the missed approach procedure using conventional navigation techniques (except for the "pure" RNAV legs where this is not possible, and full GPS guidance will be provided by any IFR-approved receiver) |

| Operating Procedure | Transcripts from UK CAA CAP773 Appendix 3 |
|---|---|
| **Communications during normal procedures** | Pilots should request clearance to fly the procedure using the phraseology:<br>*'(Aircraft c/s), request RNAV approach, via (Initial Approach Fix Designator), runway xx'*<br><br>Where traffic conditions permit, air traffic controllers shall clear the pilot to follow the procedure using the following phraseology:<br>*'(Aircraft c/s), cleared RNAV approach, runway xx, (report at [Initial Approach Fix designator])'*<br><br>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:<br>*'(Aircraft c/s), report established on final approach track'*<br>*'(Aircraft c/s), report 2 miles from final approach fix'*<br><br>Air Traffic Controllers shall instruct the pilot to report at the final approach fix, using the phraseology:<br>*'(Aircraft c/s), report final approach fix'*<br><br>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 GPS navigation failure** | When Air Traffic Control is aware of problems with the GNSS system, the following phraseology shall be used:<br>*'(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)]'*<br>*'(Aircraft c/s), GNSS unavailable for (specify operation) [from (time) to(time) (or until further notice])'*<br><br>Following a RAIM indication, pilots shall inform the controller of the event and subsequent intentions.<br>*'(Aircraft c/s) GNSS unavailable (due to [reason eg Loss of RAIM OR RAIM alert]) (intentions)'*<br>*'(Aircraft c/s) Loss of RAIM or RAIM alert (intentions)'* |

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

- Before a GPS NPA has commenced, there are three additional contingencies a pilot should plan for in addition to the conventional IFR approach contingencies
  - a GPS Loss of Integrity alert <u>or</u> a GPS position alarm, warning that the aircraft has deviated beyond the required lateral protection limit
  - A failure of the GPS to automatically sequence to 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 GPS guidance or mode status, excessive deviation from the vertical profile

| | Illustration of contingency procedures |
|---|---|
| **Immediate actions** | <u>Aviate</u>: stop any descent and configure the aircraft appropriately<br><br><u>Navigate (if prior to the Intermediate fix)</u> continue on current heading if able to immediately contact ATC and request vectors to an alternative procedure, otherwise turn to the MAP<br><u>Navigate (if after the Intermediate fix)</u> 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<br><br><u>Communicate</u>: advise ATC *"(Aircraft c/s), Unable RNAV due equipment"* and/or as appropriate |
| **Reverting to alternative procedures** | The "default" contingency in the event of an RNAV 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<br><br>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 GPS User Manual forms part of the aircraft Flight Manual in an IFR approved installation, and the pilot must follow any limitations or contingency procedures it specifies**

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

2. GPS Navigators and their application to RNAV
   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. **Avionics training**

6. Simulator and/or Flight training

- When private pilots use GPS as a supplementary navigation aid, or as a primary aid in less-demanding enroute applications, they generally do not have to complete any formal training. Such GPS skills can often be achieved by studying a user manual and practising in good VFR conditions

- Formal GPS training is always required for P-RNAV (see section 3) and always recommended, sometimes required, for GPS NPAs (see section 4)

- 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 GPS 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 GPS. The operating logic of receiver models is sufficiently varied that an expert user may struggle with the specialised IFR features in an unfamiliar model of GPS, even if they are able to use the basic navigation functions quite easily

- **Assuming basic "enroute" IFR GPS 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

# GPS training for P-RNAV and/or NPA operations
## 2. RNAV training topics (specific to individual models of GPS receiver)

PPL/IR EUROPE

P A

| Topic | Training objectives |
|---|---|
| 1. Loading, briefing and activating procedures | • Familiarity with terminal and approach procedure selection and briefing<br>  – selecting and verifying Transition, Procedure, Runway and Airport identifiers<br>  – displaying waypoints prior to activating the procedure, in order to cross-check against paper charts<br>  – loading, activating or arming the procedure (terminology and logic varies by GPS model)<br>  – changing or deleting the selected procedure before and after activation/arming<br>  – 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<br>  – is the waypoint ETE the time to the start of the turn, or the time to notionally cross the waypoint?<br>  – roughly how many seconds prior to a waypoint do turns begin, based on track change and ground speed?<br>  – when is the next track after a waypoint annunciated?<br>  – when is the turn countdown annunciated? Is the countdown displayed continuously?<br>  – when and how is the turn command annunciated?<br>• Understanding turn guidance through Fly-By waypoints<br>  – does the GPS map provide any curved track guidance through the turn?<br>  – does the GPS CDI 'flip' from one track to the next in mid-turn, or does it provide deviation information relative to the calculated turn path?<br>  – does the coupled HSI CDI provide the same information?<br>  – does the GPS provide the correct turn guidance to a Flight Director and/or Autopilot in NAV mode, and in GPSS mode if available?<br>  – 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<br>  – how is the new procedure activated? What if the aircraft has passed some of the initial waypoints?<br>• Selecting "Vectors-to-final" at the start of or during a procedure<br>  – how do you restore procedure guidance if ATC cancel vectoring and direct you to rejoin the procedure?<br>• Following ATC instructions<br>  – 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?<br>  – if instructed to hold at a waypoint, what GPS guidance is available? How is the procedure re-engaged at the end of a hold?<br>• Using the Missed Approach procedure<br>  – proficiency in re-initiating waypoint sequencing after the MAP, and in the guidance available for non-TF path terminators found in Missed Approach procedures<br>  – activating the Missed Approach procedure before the MAP. Does the GPS mode change from "APP" to "MAPR" immediately? What guidance is provided to the MAP from a waypoint before the FAF? |
| 4. Refresher of GPS basics | • GPS validation on start-up: Database currency and coverage. Self-test. Settings. RAIM prediction<br>• GPS essentials during RNAV operation: forms of LOI alert and other position and integrity messages. CDI scaling and mode annunciation. Recovering the flight plan if the GPS is powered down and restarted. |

- GPS user manuals and other training products for private pilots tend to describe only the basics of how to load and fly a database procedure and the key RNAV operating functions (eg. RAIM prediction, LOI alerts, CDI and mode activation)

- Proficiency to the level of depth described on the previous page is <u>probably best acquired, initially, by using the manufacturer's GPS simulator software</u>, or the actual GPS unit in Simulator mode if the software is not available (see reference page that follows for Garmin software downloads)

- Because actual procedures and airspace may not be easily available for the flight training required, RNAV training will often be conducted in a synthetic training device with a suitable panel-mount GPS (eg. a JAA FNPT2 or an FAA approved FTD, these are not, strictly speaking, "simulators" but will be referred to as such)

- However, this training will be more efficient and cost-effective if the pilot is already proficient in the GPS topics described on the previous page

- Our recommendation is that, prior to formal simulator or flight training, a pilot should
  - re-read the GPS user manual with particular emphasis on the RNAV operating features and functions highlighted in this manual (see example at the end of this section)
  - spend at least 2-3 hours practising with the GPS simulator software: firstly creating scenarios with suitable RNAV 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 GPS RNAV ground, simulator and flight training

# Introductory/Basic GPS training syllabus example

**GARMIN.**

## Garmin GNS 530/430

### Sample Training Syllabus and Flight Lessons for Use by Flight Schools & Flying Clubs

**TABLE OF CONTENTS**

# Garmin 430/530 free Simulator software download
## http://www8.garmin.com/include/SimulatorPopup.html
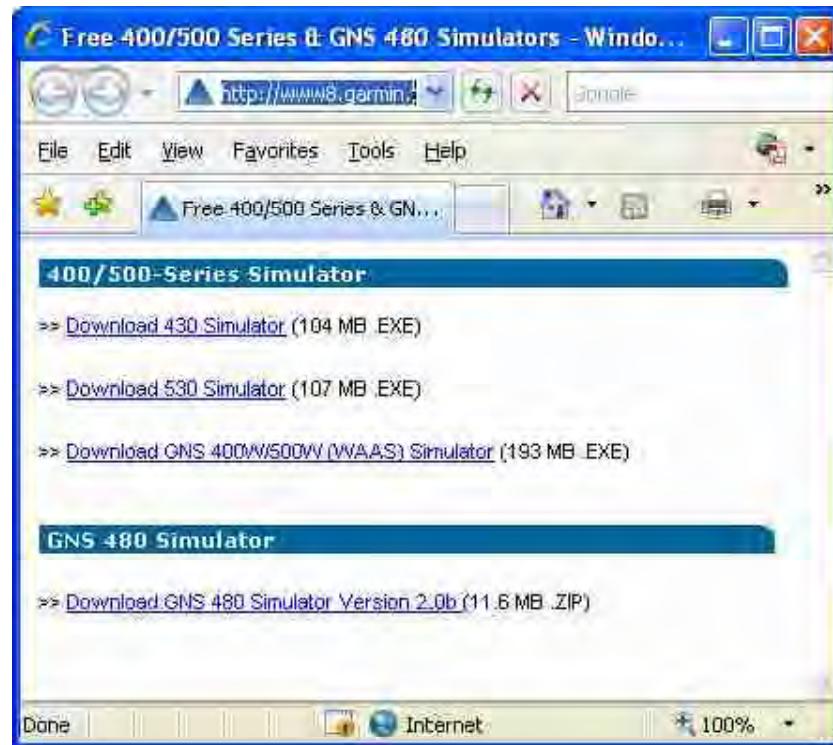
### APPENDIX C
### MAP DATUMS

## 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:

1) A waypoint alert ('NEXT DTK ###°') flashes in the lower right corner of the screen 10 seconds before the turn point (Figure C-6).

2) 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.

3) 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.

*Example: GNS530 simulator screenshots during a Fly-By turn*
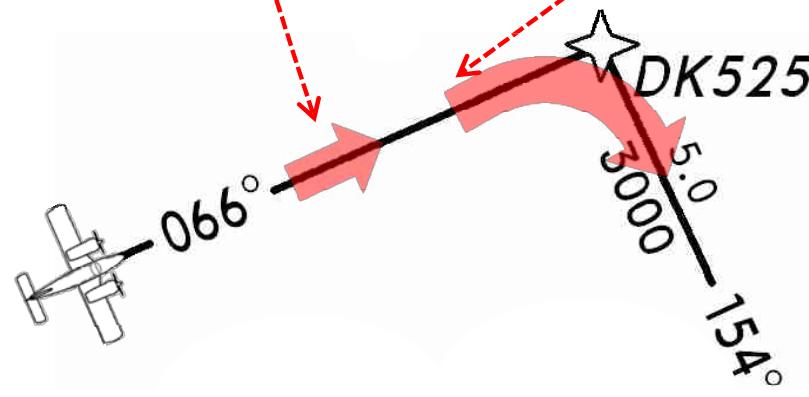
# Course contents

1. RNAV and RNP theory
   a. Introduction
   b. The Path-Terminator
   c. RNAV procedure design
   d. RNP principles
   e. RNAV and RNP applications

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   a. The GPS system
   b. Databases and Coding
   c. Procedures
   d. Error detection and warnings

3. P-RNAV Terminal Procedures
   a. P-RNAV requirements and approvals
   b. P-RNAV training topics
   c. P-RNAV operations

4. RNAV(GPS) Approach Procedures
   a. GPS procedure types
   b. GPS approach requirements and approvals
   c. GPS approach operations

5. Avionics training

6. **Simulator and/or Flight training**

# P-RNAV simulator and/or flight training
## Training course objectives and structure

- The training and operating requirements for P-RNAV are detailed in Section 3 of this manual and summarised in the table below. Our recommendation is that a P-RNAV training course should have the following three parts:

| Theory Training objectives (key points) |
|---|
| **General RNAV theory**<br> - differences between B-RNAV, P-RNAV and RNP-RNAV<br> - meaning of RNP/ANP, limitations of RNAV, GPS concepts |
| **P-RNAV theory**<br> - RNP-1 definition as it relates to P-RNAV requirements<br> - airspace where P-RNAV is required<br> - changes to charting and documents to reflect P-RNAV<br> - required navigation equipment for flight in P-RNAV airspace |
| **Charting, database and avionics topics**<br> - Waypoint naming concepts<br> - the 'TF' and 'CF' path terminators<br> - fly-by and fly-over waypoints |

| Simulator and/or Flight Training objectives |
|---|
| **Operational procedures and practices**<br> - Normal procedures (TGL10.2)<br> - Contingency procedures (TGL10.3) |
| **Use of RNAV Equipment**<br> - retrieving a procedure from the database<br> - briefing the procedure, comparing it with the charted procedure<br> - action to be taken if discrepancies are noted<br> - sensor management<br> - tactically modifying the flight plan |
| **Flying P-RNAV procedures**<br> - LNAV and associated lateral control techniques,<br> - VNAV and vertical control techniques,<br> - use of automatic pilot and flight director<br> -  implications of system malfunctions not RNAV related |

**PART 1: GROUND THEORY**
**Self-study method:**
A pilot may use this manual to self-study P-RNAV theory; the required pages are marked with a **P** in the top right corner. 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 P-RNAV 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 RNAV Equipment**
Covering the four avionics topics detailed in Section 5 of this manual
**RNAV Operational procedures**
Covering section 3c 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 P-RNAV operations**
**2. P-RNAV contingencies**

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

➡ · **Our recommend content for these flight lessons is detailed in the next two pages**

# P-RNAV Lesson 1: Normal Operations

| Element of Lesson | Content recommendations |
|---|---|
| **1. Pre-flight preparation** | • Briefing of route and procedure charts. Availability of non-PRNAV procedures<br>• RAIM check using AUGUR (requires internet access) and the GPS unit's built-in prediction tool<br>• Briefing on power, pitch and configuration for a high speed arrival<br>• Other items in accordance with the P-RNAV checklist or ops manual |
| **2. P-RNAV SID #1 (manually flown)** | • A normal IFR departure, flying the P-RNAV SID to its terminating point<br>*note the path-terminators at the start of the procedure which may not be supported by the GPS, and the transition to GPS LNAV guidance* |
| **3. Short cruise segment** | • A cruise segment to the start of the arrival procedure, using an enroute GPS flight plan<br>*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. P-RNAV STAR#1 (manually flown)** | • A normal P-RNAV STAR, transitioning to an ILS low approach and go-around<br>*although the approach is not required as part of P-RNAV training, practising the transition from GPS guidance to the ILS or other radio approach aids should be included where practical* |
| | *Repositioning as required* |
| 5. P-RNAV SID #2 (autopilot) | • A normal IFR departure, flown using the autopilot, to the SID airways terminating point<br>*note the point on the procedure at which autopilot LNAV may be engaged, and the use of available VNAV features* |
| **6. Short cruise segment** | |
| **7. P-RNAV STAR#2 (autopilot ) with continuous descent at required or maximum performance** | • A P-RNAV STAR, transitioning to an ILS low approach and go-around, flown using the autopilot in LNAV and coupled ILS modes<br>• 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<br>• The P-RNAV star should offer a continuous descent profile (most do, but some older procedures have a stepped arrival)<br>*A pilot's instrument training will have been conducted at the aircraft's normal arrival/approach speeds, and it useful for the P-RNAV 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 ILS glideslope 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 RNAV procedure, and a direct-to clearance to an intermediate waypoint |

# P-RNAV Lesson 2: Contingencies

| Element of Lesson | Content recommendations |
|---|---|
| **1. Pre-flight preparation** | • Briefing of route and procedure charts. Availability of non-PRNAV procedures<br>• Review of RNAV and other contingency procedures in the check list or ops manual |
| **2. Non-RNAV contingencies:**<br><br>P-RNAV SID (optional)<br>Short cruise (optional)<br>**P-RNAV STAR#3** | • To include at least one P-RNAV STAR (flown manually or using the autopilot) in which RNAV performance is normal, but other simulated failures or contingencies are introduced which the pilot must manage whilst flying the full procedure<br>• *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*<br>• *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*<br><br>• This element of Lesson 2 should include at least one tactical change (unplanned hold, change of RNAV procedure, vectors) |
| | *Repositioning as required* |
| **3. RNAV contingencies:**<br><br>P-RNAV SID (optional)<br>Short cruise (optional)<br>**P-RNAV STAR#4** | • As a minimum, this should include one P-RNAV procedure in which a simulated loss of RNAV capability takes place (eg. a failure of the GPS or a RAIM Loss of Integrity) in which the pilot must follow the checklist contingency procedures and then fly a conventional or radar-vectored arrival<br>• If a simulator is used which permits other RNAV failures, these may be included (eg. a discrepancy in a cross-check between GPS position and radio aids) |

## P-RNAV 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 GPS to be used for P-RNAV 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-PRNAV procedures*<br>• *RAIM check using the GPS unit's built-in prediction tool*<br>• *Briefing on power, pitch and configuration for a high speed arrival*<br>• *Review of P-RNAV normal and contingency procedures in the check list or ops manual* |
| ***2. Normal RNAV procedure*** | • *To include at least one RNAV procedure (SID, STAR or Approach) and at least one tactical change (unplanned hold, change of RNAV procedure, vectors)* |

- The training and operating requirements for GPS NPAs are detailed in Section 4 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 RNAV theory<br>- meaning of RNP/ANP, limitations of RNAV, GPS concepts |
| GPS NPA theory<br>- GPS procedure designs and coding<br>- GPS NPA procedure charts, limitations and minima<br>- requirement for current database and database procedures only<br>- required navigation equipment for GPS NPAs |
| Charting, database and avionics topics<br>- Waypoint naming concepts<br>- the 'TF' and 'CF' path terminators<br>- fly-by and fly-over waypoints |

| Simulator and/or Flight Training objectives |
| --- |
| Operational procedures and practices<br>- Normal procedures<br>- Contingency procedures |
| Use of RNAV Equipment<br>- retrieving a procedure from the database<br>- briefing the procedure, comparing it with the charted procedure<br>- action to be taken if discrepancies are noted<br>- sensor management<br>- tactically modifying the flight plan |
| Flying GPS NPA procedures<br>- LNAV, VNAV and associated control techniques,<br>- use of automatic pilot and flight director<br>- missed approach and contingency procedures (eg. loss of RAIM)<br>- ATC procedures |

**PART 1: GROUND THEORY**
**Self-study method:**
A pilot may use this manual to self-study GPS NPA theory; the required pages are marked with a (A) in the top right corner. 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 GPS NPA 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 RNAV Equipment**
Covering the four avionics topics detailed in Section 5 of this manual
**RNAV Operational procedures**
Covering section 4c 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 GPS NPA operations**
**2. GPS NPA 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 GPS NPAs. The minimum time this will require is probably 2hrs for a candidate who is current in IFR and GPS operations.

- **Our recommend content for these flight lessons is detailed in the next two pages**
- **See also the syllabus in UK CAA CAP773 Appendix 1**

# GPS NPA 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<br>• RAIM check using AUGUR (requires internet access) and the GPS unit's built-in prediction tool<br>• Briefing of GPS and 'normal' IFR checklist items<br>• Entering a GPS 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 GPS, as appropriate, for supplementary or primary guidance |
| **3. GPS Non-Precision Approach #1 (manually flown)** | **Pre-Arrival**<br>• Selecting and checking the Approach procedure<br>• Determining the appropriate IAF<br>• Activation of the procedure and CDI scaling<br><br>**Flying the GPS NPA procedure**<br>• Gross error check approaching the IAF, and check that the GPS is in TERM mode with CDI scaling at 1nm<br>• GPS and Navigation instrument mode selection<br>• Check activation of APP mode and CDI scaling to 0.3nm prior to the FAF<br><br>**Flying the Missed Approach**<br>• Activation of the Missed Approach procedure and the need to manually re-initiate waypoint sequencing<br>• Mode selection and pilot actions in non-RNAV missed approach segments |
| | *Repositioning as required* |
| **4. GPS Non-Precision Approach #2 and #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:<br>• An unplanned hold at the IAF<br>• During the hold, a change of runway requiring a new procedure to be loaded<br>• A direct-to clearance to the IAF<br>• 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 GPS with SID and STAR procedures prior to the NPA, emphasising that radio aids must be used as primary guidance for non-RNAV procedures* |

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| Element of Lesson | Content recommendations |
|---|---|
| **1. Pre-flight preparation** | • Briefing of route and procedure charts.<br>• Review of RNAV and other contingency procedures in the checklist |
| **2. Non-RNAV contingencies:**<br><br>**GPS Non-Precision Approach #4** | • To include at least one GPS NPA(flown manually or using the autopilot) in which RNAV performance is normal, but other simulated failures or contingencies are introduced which the pilot must manage whilst flying the approach<br>• *The failures may be specific to the aircraft type, but may include instrument, electrical, engine and fuel system problems*<br>• *In a multiengine trainer or aircraft, an engine failure should be simulated during the arrival*<br>• *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*<br><br>• This element of Lesson 2 may also include tactical changes if appropriate (unplanned hold, change of RNAV procedure, vectors) |
| | *Repositioning as required* |
| **3. RNAV contingencies:**<br><br>**GPS Non-Precision Approach #5** | • As a minimum, this should include one GPS NPA in which a simulated loss of RNAV capability takes place (eg. failure of the GPS or a RAIM Loss of Integrity) during the procedure, such that the pilot must initiate the missed approach prior to the MAP.<br>• The instructor should judge the training value of then flying to an alternate airport with a conventional procedure versus simulating a restoration of GPS capability and completing the NPA on a second attempt<br>• If a simulator is used which permits other RNAV failures, these may be included (eg. a discrepancy in a cross-check between GPS position and radio aids) |

## GPS NPA 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 GPS to be used, 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-PRNAV procedures*<br>• *RAIM check using the GPS unit's built-in prediction tool*<br>• *Review of RNAV normal and contingency checklist procedures* |
| *2. Normal RNAV procedure* | • *To include at least one approach procedure (RNAV, or conventional using the GPS for supplementary guidance) and including at least one tactical change (unplanned hold, change of procedure, vectors)* |

# Combined P-RNAV and GPS NPA training
## Training course objectives and structure

- The training for P-RNAV and GPS NPAs may be conducted as an integrated course. Much of the Ground Theory and Pre-flight Briefing content is common to both

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**PART 1: GROUND THEORY**

**Self-study method:**
A pilot may use this manual to self-study the required RNAV theory content in pages with a **P** and/or **A** in the top right corner. 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 prior pages

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

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**PART 2: PRE-FLIGHT BRIEFING:** The pre-flight briefing sessions may require ~2hrs, to include:

**Use of RNAV Equipment:** covering the four avionics topics detailed in Section 5 of this manual

**RNAV Operational procedures:** covering sections 3c and 4c of this manual, and using the actual aircraft or training device checklist/ops manual

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- The simulator or flight training may be combined, although some P-RNAV and GPS NPA tasks need to be conducted independently (ie. not every P-RNAV arrival should be combined with a GPS NPA)

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**PART 3: SIMULATOR OR FLIGHT TRAINING – minimum requirements for an integrated P-RNAV and GPS NPA syllabus; see detailed lesson content for each in prior pages**

1. **Normal operations**
To include at least one manually flown 'normal' P-RNAV SID, P-RNAV STAR and GPS NPA, and one RNAV procedure flown using the autopilot
To include one P-RNAV STAR terminating in an ILS  (and, in a piston aircraft, flown at maximum approach speed)
To include one GPS NPA commencing at the procedure IAF, not from a P-RNAV arrival
To include at least one each of the following tactical changes: an unplanned hold, a change of RNAV procedure, and a direct-to clearance

2. **Contingencies**
To include at least 2 P-RNAV procedures, one with an RNAV failure and one with a non-RNAV failure
To include at least 2 GPS NPA procedures, one with an RNAV failure and one with a non-RNAV failure

# RNAV training: other remarks

### 1. Flight training

Although the syllabus refers to "Simulator or Flight Training", training in an aircraft will often not be possible, because RNAV procedures are not available in the training area

No Instructor should ever create an RNAV procedure manually for training purposes as an alternative to using published and database-coded procedures. GPS procedure operating logic can not be simulated with manual waypoints, and this also sets the student a potentially dangerous example

### 2. Simulator training

Training will usually need to use a synthetic flight training device such as a JAA FNPT2 or an FAA-approved FTD (this manual refers to these as 'simulators', which is not strictly accurate). Many modern simulators incorporate a Garmin GNS430, which is ideal for most students. The Garmin G1000 system uses the same navigation, flight planning and procedure logic as the GNS430/530, so little or no RNAV-specific differences training is needed across these 2 platforms.

Many older simulators include Bendix/King, Trimble, Apollo and other IFR GPS units which are effectively obsolete. These are satisfactory for general IFR training, but not RNAV courses for pilots who will be flying aircraft equipped with a modern GPS

The simulator database should include a geographic coverage which allows a suitable choice of different types of procedure. For P-RNAV, simulator training may need to involve airports like Heathrow and Gatwick, rather than the regional ones more commonly used for instrument training

Paper charts should be available for all these procedures. In Europe, many AIP charts are ICAO-conforming schematics, rather than navigation charts; products from commercial suppliers, designed for in-flight use, are preferable

### 3. Initial Instrument Rating training

There is no reason that P-RNAV and GPS training should not be integrated with a course for an initial Instrument Rating, if the student's budget and aptitude permit

### 4. Course completion certificates

Candidates may need a certificate to document they have successfully completed an RNAV course. For P-RNAV, this should note that the training is in accordance with JAA TGL10 Section 10. For GPS NPA training, a logbook endorsement that theory and practical training has been completed may be used to meet the RNAV approach requirement in some countries

### 5. Recurrent training

Subsequent IFR recurrent training should include, where practical, RNAV procedures and contingencies

# Comments on using this manual for training courses

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- It may be used and printed for training purposes by instructors and flight schools without restriction, but must not be sold or distributed commercially

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- The author may be contacted by PPL/IR Europe members via the website forum (www.pplir.org) with feedback and questions. Any person interested in operating light aircraft under IFR in Europe is welcome to join.

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