Flight crew basic theoretical training for

RNP APCH down to LPV minima

European Satellite Services Provider S.A.S.
Service Provision Unit

Issue 1.3 – April 2019
Introduction

• This training package is focused on covering the theoretical knowledge syllabus for RNP APCH to LPV minima for an Instrument Rated pilot in accordance with:

  Appendix to Annex I to ED Decision 2018/001/R
  ‘Acceptable Means of Compliance (AMCs) and Guidance Material (GM) to Part-FCL Amendment 4’

• To complement it, it also covers the theoretical knowledge syllabus for Global Navigation Satellite Systems

• This training shall be complemented with:
  – Operating Procedures training
  – Specific Aircraft System theoretical training
  – Practical in aircraft or simulator training
Introduction

Some notes:

• All paragraphs intended to cope with Learning Objectives (LOs) sub-references are numbered following the same EASA’s Syllabus Reference i.e. (01), (02), (03), etc.

• Certain contents and/or slides are not part of formal LOs but have been included to provide additional information. This are not marked in any way.

• A significant number of LOs are not applicable to CB-IR(A) and EIR. Only those marked with a [CE] symbol are applicable.

• Text referring to BK LOs has been marked with a [BK] symbol. Explanatory Note to Decision 2018/001/R, which states that:
  “Several LOs have been categorised as comprising ‘Basic Knowledge (BK)’ in a newly added column in the LO tables”
  “These LOs will no longer be the subject of dedicated examination questions”
  “However, student pilots will still be required to assimilate the specific knowledge required by the BK LOs”
Target audience: all IR pilots


- Introducing the necessary changes to Air Crew regulations as to incorporate PBN in the regular training and checking requirements for pilots

- Requesting all ATOs to introduce PBN privileges to their IR courses by 25 August 2020 at the latest, date from which PBN will become mandatory to all IR pilots
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABAS</td>
<td>Airborne Based Augmentation System</td>
</tr>
<tr>
<td>AAIM</td>
<td>Aircraft Autonomous Integrity Monitoring</td>
</tr>
<tr>
<td>AIRAC</td>
<td>Aeronautical Information Regulation And Control</td>
</tr>
<tr>
<td>AMC</td>
<td>Acceptable Means of Compliance</td>
</tr>
<tr>
<td>ANSP</td>
<td>Air Navigation Service Provider</td>
</tr>
<tr>
<td>APV</td>
<td>Approach with Vertical Guidance</td>
</tr>
<tr>
<td>ATS</td>
<td>Air Traffic Services</td>
</tr>
<tr>
<td>CDFA</td>
<td>Continuous Descent Final Approach</td>
</tr>
<tr>
<td>CRC</td>
<td>Cyclic Redundancy Check</td>
</tr>
<tr>
<td>DME</td>
<td>Distance Measuring Equipment</td>
</tr>
<tr>
<td>DOP</td>
<td>Dilution Of Precision</td>
</tr>
<tr>
<td>EGNOS</td>
<td>European Geostationary Navigation Overlay Service</td>
</tr>
<tr>
<td>ESSP</td>
<td>European Satellite Services Provider</td>
</tr>
<tr>
<td>FAF</td>
<td>Final Approach Fix</td>
</tr>
<tr>
<td>FAP</td>
<td>Final Approach Point</td>
</tr>
<tr>
<td>FAS DB</td>
<td>Final Approach Segment Data Block</td>
</tr>
<tr>
<td>FD</td>
<td>Fault Detection</td>
</tr>
<tr>
<td>FDE</td>
<td>Fault Detection and Exclusion</td>
</tr>
<tr>
<td>FTE</td>
<td>Flight Technical Error</td>
</tr>
<tr>
<td>GAGAN</td>
<td>GPS Aided Geo Augmented Navigation</td>
</tr>
<tr>
<td>GBAS</td>
<td>Ground Based Augmentation System</td>
</tr>
<tr>
<td>GCS</td>
<td>Galileo Control Segment</td>
</tr>
<tr>
<td>GLONASS</td>
<td>Global Navigation Satellite System</td>
</tr>
<tr>
<td>GMS</td>
<td>Ground Mission Segment</td>
</tr>
<tr>
<td>GNSS</td>
<td>Global Navigation Satellite System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GSA</td>
<td>European GNSS Agency</td>
</tr>
<tr>
<td>HAL</td>
<td>Horizontal Alert Limit</td>
</tr>
<tr>
<td>ICACO</td>
<td>International Civil Aviation Organisation</td>
</tr>
<tr>
<td>ILS</td>
<td>Instrument Landing System</td>
</tr>
<tr>
<td>IRS</td>
<td>Inertial Reference System</td>
</tr>
<tr>
<td>IRU</td>
<td>Inertial Reference Unit</td>
</tr>
<tr>
<td>LAAS</td>
<td>Local Area Augmentation System</td>
</tr>
<tr>
<td>LNAV</td>
<td>Lateral Navigation</td>
</tr>
<tr>
<td>LO</td>
<td>Learning Objective</td>
</tr>
<tr>
<td>LP</td>
<td>Localiser Performance</td>
</tr>
<tr>
<td>LPV</td>
<td>Localiser Performance with Vercial Guidance</td>
</tr>
<tr>
<td>LTP</td>
<td>Landing Threshold Point</td>
</tr>
<tr>
<td>MEL</td>
<td>Minimum Equipment List</td>
</tr>
<tr>
<td>MED</td>
<td>Medium Earth Orbit</td>
</tr>
<tr>
<td>MSAS</td>
<td>Multi-functional Satellite Augmentation System</td>
</tr>
<tr>
<td>NDB</td>
<td>Non-Directional Beacon</td>
</tr>
<tr>
<td>NM</td>
<td>Nautical Mile</td>
</tr>
<tr>
<td>NSE</td>
<td>Navigation System Error</td>
</tr>
<tr>
<td>OM</td>
<td>Operations Manual</td>
</tr>
<tr>
<td>PBN</td>
<td>Performance Based Navigation</td>
</tr>
<tr>
<td>PDE</td>
<td>Path Definition Error</td>
</tr>
<tr>
<td>PinS</td>
<td>Point in Space</td>
</tr>
<tr>
<td>PL</td>
<td>Protection Level</td>
</tr>
<tr>
<td>PPS</td>
<td>Precise Positioning Service</td>
</tr>
<tr>
<td>PRN</td>
<td>Pseudo-Range Noise</td>
</tr>
<tr>
<td>RAIM</td>
<td>Receiver Autonomous Integrity Monitoring</td>
</tr>
<tr>
<td>RDH</td>
<td>Reference Datum Height</td>
</tr>
<tr>
<td>RNAV</td>
<td>Area Navigation</td>
</tr>
<tr>
<td>RNP</td>
<td>Required Navigation Performance</td>
</tr>
<tr>
<td>SBAS</td>
<td>Satellite Based Augmentation System</td>
</tr>
<tr>
<td>SDCM</td>
<td>System for Differential Corrections and Monitoring</td>
</tr>
<tr>
<td>SNAS</td>
<td>Satellite Navigation Augmentation System</td>
</tr>
<tr>
<td>SPS</td>
<td>Standard Positioning Service</td>
</tr>
<tr>
<td>TAWS</td>
<td>Terrain Awareness Warning System</td>
</tr>
<tr>
<td>TK</td>
<td>Theoretical Knowledge</td>
</tr>
<tr>
<td>TTFF</td>
<td>Time To First Fix</td>
</tr>
<tr>
<td>UHF</td>
<td>Ultra High Frequency</td>
</tr>
<tr>
<td>UTC</td>
<td>Universal Time Coordinated</td>
</tr>
<tr>
<td>VAL</td>
<td>Vertical Alert Limit</td>
</tr>
<tr>
<td>VDB</td>
<td>VHF Data Broadcast</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency</td>
</tr>
<tr>
<td>VOR</td>
<td>VHF Omnidirectional Range</td>
</tr>
<tr>
<td>VPA</td>
<td>Vertical Path Angle</td>
</tr>
<tr>
<td>WAAS</td>
<td>Wide Area Augmentation System</td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>062 06 00 00</td>
<td><strong>GLOBAL NAVIGATION SATELLITE SYSTEMS</strong></td>
</tr>
<tr>
<td>062 06 01 00</td>
<td>Global navigation satellite systems (GNSSs)</td>
</tr>
<tr>
<td>062 06 01 01</td>
<td>General</td>
</tr>
<tr>
<td>062 06 01 02</td>
<td>Operation</td>
</tr>
<tr>
<td>062 06 01 03</td>
<td>Errors and factors affecting accuracy</td>
</tr>
<tr>
<td>062 06 02 00</td>
<td>Ground-, Satellite- and Airborne-based augmentation systems</td>
</tr>
</tbody>
</table>
Course contents: TK /LO’s

<table>
<thead>
<tr>
<th>062 07 00 00</th>
<th>PBN</th>
<th>062 07 00 00</th>
<th>PBN</th>
</tr>
</thead>
<tbody>
<tr>
<td>062 07 01 00</td>
<td>PBN concept</td>
<td>062 07 04 00</td>
<td>PBN operations</td>
</tr>
<tr>
<td>062 07 01 01</td>
<td>PBN principles</td>
<td>062 07 04 01</td>
<td>PBN principles</td>
</tr>
<tr>
<td>062 07 01 02</td>
<td>PBN components</td>
<td>062 07 04 02</td>
<td>On-board performance monitoring and alerting</td>
</tr>
<tr>
<td>062 07 01 03</td>
<td>PBN Scope</td>
<td>062 07 04 03</td>
<td>Abnormal situations</td>
</tr>
<tr>
<td>062 07 02 00</td>
<td>Navigation Specifications</td>
<td>062 07 04 04</td>
<td>Database management</td>
</tr>
<tr>
<td>062 07 02 01</td>
<td>RNAV and RNP</td>
<td>062 07 05 00</td>
<td>Requirements of specific RNAV and RNP specifications</td>
</tr>
<tr>
<td>062 07 02 02</td>
<td>Navigation functional requirements</td>
<td>062 07 05 05</td>
<td>RNP APCH</td>
</tr>
<tr>
<td>062 07 02 03</td>
<td>Designation of RNP and RNAV specifications</td>
<td>062 07 05 09</td>
<td>PBN Point In Space (PinS) Approach</td>
</tr>
<tr>
<td>062 07 03 00</td>
<td>Use of PBN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>062 07 03 03</td>
<td>Specific RNAV and RNP system functions</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
062 06 01 00 – GPS / GLONASS / GALILEO / BeiDou
(01) There are four main Global Navigation Satellite Systems (GNSS)

- USA NAVSTAR GPS (NAVigation System with Timing And Ranging Global Positioning System)
- Russian GLONASS (GLObal Navigation Satellite System)
- European GALILEO (more info [here](#)), to become fully operational in the coming years
- Chinese BEIDOU, to become fully operational in the coming years

(02) All these systems:

- Consist of a constellation of satellites which can be used by suitably equipped receivers to determine position
- Are interoperable

*Unlike GPS and GLONASS, Galileo and BeiDOU are run by civil, not military, authorities*
Modes of operation

1) GNSS can operate in two different modes:
   - SPS (Standard Positioning Service): civilian users
   - PPS (Precise Positioning Service): authorised users

2) SPS is a positioning and timing service originally designed to provide civilian users with a less accurate positioning capability than PPS

3) GNSS are composed of 3 main segments:
   - space segment
   - control segment
   - user segment
062 06 01 02 – Operation

SPACE SEGMENT – example NAVSTAR GPS

(04) Each satellite broadcasts ranging signals on two UHF frequencies
- L1 1575.42 MHz
- L2 1127.60 MHz

GPS can operate in two different modes:
- SPS (Standard Positioning Service): civilian users
- PPS (Precise Positioning Service): authorised users

(05) **SPS is** a positioning and timing service provided on L1 frequency

(06) **PPS uses both** L1 and L2 frequencies. 2 frequencies → higher accuracy
(07) Satellites transmit a coded signal used for ranging, identification (satellite individual PRN code), timing and navigation

(08) The navigation message contains:

- satellite clock correction parameters
- Universal Time Coordinated (UTC) parameters
- an ionospheric model
- satellite health data

(09) Its ionospheric model is used to calculate the time delay of the signal travelling through the ionosphere.

The ionosphere acts as a refractive means (hence a delay is caused) for the GPS signal.
(10) Two codes are transmitted on the L1 frequency: C/A (Coarse Acquisition) and P (Precision)

<table>
<thead>
<tr>
<th>Code</th>
<th>Used by</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/A</td>
<td>SPS (civil)</td>
</tr>
<tr>
<td>P (precision)</td>
<td></td>
</tr>
</tbody>
</table>

(11) Satellites are equipped with atomic clocks, which allow the system to keep very accurate time reference.

Atomic clocks on-board satellites are based on Cesium or Rubidium.

An error of 1 μs (10⁻⁶ sec) in the user clock can produce a positioning error of up to 300m.
(12) The control segment comprises:
- A master control station (may have alternative master control station/s)
- Command and control ground antennas
- Monitoring stations

(13) The control segment provides:
- Monitoring the constellation status
- Correction of orbital parameters
- Navigation data uploading
GNSS supplies three-dimensional position fixes and speed data, plus a precise time reference. A GPS receiver is able to determine the distance to a satellite by determining the difference between the time of transmission by satellite and the time of reception. The initial distance calculated to the satellites is called “pseudo range” as it is biased by the lack of time synchronisation between GPS satellite and receiver clocks. In addition, the “pseudo range” is also biased by other effects such as ionosphere, troposphere and signal-noise.

Pseudo range modelling:

\[ P \lambda = \rho + d\rho + c(dT - dt) + d_{\text{tropo}} + d_{\text{iono}} + M + e \]

- \( \rho \) is the geometric range or geometric distance between the satellite and the receiver
- \( d\rho \) is the orbital error
- \( dt \) is the receiver clock error
- \( dT \) is the satellite clock error
- \( d_{\text{ion}} \) is the iono delay
- \( d_{\text{trop}} \) is the tropo delay
- \( M \) multipath
- \( e \) noise
(17) Each range defines a sphere with its centre at the satellite.

(18) To resolve 4 unknown parameters (X, Y, Z, ΔT) and calculate the position, we require the measurement of ranges to four different satellites. Rationale ΔT (receiver clock offset): the 3 spheres do not intersect in a single point. Hence ΔT constitutes a new variable to be determined.

(19) The GPS receiver synchronises to the correct time base when receiving four satellites.

(20) The receiver is able to calculate aircraft groundspeed using the SV Doppler frequency shift and/or the change in receiver position over time.
NAVIGATION System with Timing And Ranging Global Positioning System (NAVSTAR GPS) Integrity

RAIM (Receiver Autonomous Integrity Monitoring) provides integrity over GPS-only navigation

(21) RAIM is a technique that ensures the integrity of the provided data by redundant measurements

(22) RAIM is achieved by consistency check among range measurements → when a sufficient number of satellites is tracked by the receiver, individual faulty pseudo ranges can be isolated

(23) Basic RAIM requires 5 satellites. A 6th satellite is required for isolating a faulty satellite from the navigation solution

When the GPS receiver is fed with barometric altitude, the number of satellites needed for the receiver to perform RAIM function may be reduced by one
NAVIGATION System with Timing And Ranging Global Positioning System (NAVSTAR GPS) Integrity

(24) Agreements have been concluded between the appropriate agencies for the compatibility and interoperability by any approved user of NAVSTAR and GLONASS systems.

(25) Even if...different GNSSs may use different data with respect to reference systems, orbital data, and navigation services.

Animation available in
https://upload.wikimedia.org/wikipedia/commons/b/b4/Comparison_satellite_navigation_orbits.svg
(01) The most significant factors affecting accuracy of GNSS positioning are:

<table>
<thead>
<tr>
<th>Factor</th>
<th>GPS</th>
<th>GPS + SBAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionospheric propagation delay (IPD)</td>
<td>2 m</td>
<td>0,3 m</td>
</tr>
<tr>
<td>Dilution of position (horizontal)</td>
<td>1,1 m</td>
<td>1,1 m</td>
</tr>
<tr>
<td>Satellite clock errors</td>
<td>1 m</td>
<td>0,5 m</td>
</tr>
<tr>
<td>Satellite orbital variations</td>
<td>0,2 m</td>
<td>0,2 m</td>
</tr>
<tr>
<td>Multipath</td>
<td>0,25 m</td>
<td>0,25 m</td>
</tr>
<tr>
<td>Tropospheric propagation delay</td>
<td>0,5 m</td>
<td>0,5 m</td>
</tr>
<tr>
<td>Receiver noise</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(02) A user equivalent range error (UERE) can be computed from all these factors
(03) (04) Ionospheric propagation delay (IPD)

- The IPD constitutes the most significant error, it can achieve several tens of meters

- It can be almost eliminated if using two frequencies → this is the main reason why GPS PPS is today more precise than SPS

- The IPD can be reduced by modelling, using a model of the ionosphere

In GPS SPS receivers, IPD is currently corrected by using a ionospheric model contained in the navigation message. However the error is only reduced by 50%
**Errors and Factors affecting accuracy**

- **Dilution of Precision**

  (05) Arises from the geometry and number of satellites in view. It is called the **Geometric Dilution of Precision (GDOP)**

  (06) The UERE, in combination with the geometric dilution of precision (GDOP), allows for an estimation of position accuracy.

**DOP is an indicator of the geometrical distribution of the satellites used to compute the navigation solution**

A bad geometry (high DOP) contributes to a bigger error in the estimated position.

In A the measurement has some error bounds, and the true location will lie anywhere in the black area. In B the measurement error is the same, but the error on the position has grown considerably due to the arrangement of the satellites.

Source: adaptation from Wikipedia and Academic
The errors in the satellite orbits are due to:

- Solar winds
- Gravitation effects of the sun and the moon (and planets)
062 06 02 00 – Ground, Satellite and Airborne based augmentation systems

GBAS
Source: Honeywell

SBAS
Source: SES

ABAS
Source: Cirrus
GROUND BASED AUGMENTATION SYSTEMS

(01) Its main principle is to measure on ground the signal errors transmitted by GNSS satellites and relay the measured errors to the user for correction.

(02) The ICAO GBAS standard is based on this technique through the use of a data link in the VHF band of ILS-VOR systems (108-118 MHz).

(05) One ground station can support all the aircraft subsystems within its coverage providing the aircraft with approach data, corrections and integrity information for GNSS satellites in view via a VHF data broadcast (VDB).

(03) The coverage of the GBAS station is of about 20 NM / 30 km.
(04) GBAS provides (1) information for guidance in the terminal area, and (2) for three-dimensional guidance in the final approach segment (FAS) by transmitting the FAS data block.

(06) The minimum software designed coverage area is (aka GBAS Service Volume) is 10° on either side of the final approach path to a distance between 15 and 20 NM, and 35° on either side of the final approach path up to a distance of 15 NM.

(07) Outside this area, FAS data (2) is not used.

(08) GBAS based on GPS is sometimes called Local Area Augmentation System (LAAS).
062 06 02 01 – Ground-based augmentation systems

GROUND BASED AUGMENTATION SYSTEMS

(09) A GBAS-based approach is called GLS approach (GLS-GNSS landing system)
062 06 02 02 – Satellite-based augmentation systems

SBAS BASED AUGMENTATION SYSTEMS

(01) Its main principle is to measure on the ground the signal errors transmitted by GNSS satellites and transmit differential corrections and integrity messages through geostationary satellites.

(02) The frequency band of the data link is identical to that of the GPS signals.

(03) The use of geostationary satellites enables messages to be broadcast over very wide areas.

(04) The pseudo-range measurements to these geostationary satellites can also be made, as if they were GPS satellites.

Note the difference in the below image between the GEOs coverage area (footprints) and the Service Area.
(05) SBAS consists of 2 elements:
- The ground infrastructure (network of monitoring and processing stations)
- The SBAS satellites
(06) SBAS allows the implementation of three dimensional Type A and Type B approaches

- 3D Type A: \( DH \geq 250\text{ft} \)
- 3D Type B: \( DH \geq 200\text{ft} \)

(07) SBAS examples:

- European Geostationary Navigation Overlay Service (EGNOS) in western Europe and the Mediterranean
- Wide Area Augmentation System (WAAS) in the USA
- Multi-functional Transport Satellite (MTSAT)-based augmentation system (MSAS) in Japan
- GPS and geostationary earth orbit augmented navigation (GAGAN) in India

(Others under development: SDCM in Russia, SNAS is China)
SBAS BASED AUGMENTATION SYSTEMS

(08) SBAS is designed to significantly improve accuracy and integrity

(09) The integrity and safety are improved by alerting SBAS users within the following Time To Alert (TTA) if a GPS malfunction occurs:

- 3D Type A: 10 seconds (in Europe, EGNOS reduces this figure to 6 seconds)
- 3D Type B: 6 seconds
EGNOS

- The European Geostationary Navigation Overlay Service

- EGNOS uses 3 geostationary satellites and a network of ground stations to receive, analyse and augment, and then re-transmit GPS and eventually Galileo signals

- The system is designed to improve accuracy to 1-2 m horizontally and 3-5 m vertically

- Integrity and safety are improved by alerting users within 6 seconds if a GPS malfunction occurs (up to 3 hrs GPS alone)

You can find more information about the status of the EGNOS Space Segment in http://www.essp-sas.eu/download/service_notices/essp_com_11851_01_00_service_notice_11_prn124_decommisioning.pdf
EGNOS - benefits

• More landings under severe atmospheric conditions

• More landings at less well-equipped airports

• Increased capacity, benefiting both airport and airline operators

• Curved approaches and more efficient routes → fuel and noise savings

• Possibility to phase-out some expensive ground based navaids infrastructure and to free valuable radio spectrum that can be exploited for new/other services
AIRBORNE BASED AUGMENTATION SYSTEMS

(01) Its main principle is to use redundant elements within the GPS constellation (e.g. multiplicity of distance measurements to various satellites) or the combination of GNSS measurements with those of other navigation sensors (such as inertial systems), to develop integrity control.

Unlike GBAS and SBAS, ABAS does not provide corrections to improve positioning accuracy.
(02) The type of ABAS using only GNSS information is RAIM (Receiver Autonomous Integrity Monitoring)

(03) The type of ABAS using addition information from on-board sensors is named AAIM (Aircraft Autonomous Integrity Monitoring)

(04) Typical sensors used in AAIM are barometric altimeter, clock and inertial navigation system (IRS)
   - Barometric altimetry sources are used sometimes to improve the TTFF (Time to First Fix), which refers to the time required to acquire satellite signals and navigation data and calculate a position solution
(05) The Receiver Autonomous Integrity Monitoring (RAIM) is a technique that ensures the integrity of the provided data by redundant measurements

- The GPS ground stations monitor GPS satellites and detect faults

- It can take too much time to detect a fault and update the navigation messages sent to the users to declare a particular satellite SIS erroneous

(06) To solve this, GPS receivers have an autonomous way of assuring the integrity of GPS pseudo-ranges: the RAIM algorithm, which is achieved by consistency checks among range measurements

- GPS receivers require a minimum set of 4 satellites to compute a 3D position

(07) With additional satellites, the “RAIM algorithm” comes into play

- A 5th satellite provides Fault Detection (FD) capability: the receiver recognises a faulty satellite, but is not able to identify which one in particular (aka basic RAIM)

- A 6th satellite provides Fault Detection and Exclusion (FDE) capability: the receiver is able to isolate the faulty satellite
062 07 00 00

PERFORMANCE-BASED NAVIGATION
Performance-based navigation: area navigation (RNAV) based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.
Conventional navigation

- Aircrafts navigate based on direct signals from ground-based radio NAVAIDs
- Navigation relies on aircraft crossing radio beacons and tracking to and from them directly
- Routes are dependent on the location of the navigation beacons, resulting in longer routes

Area Navigation

- Within the coverage of the available nav aids → AREA
- Aircrafts compute their latitude-longitude position
- Navigation relies on aircraft crossing fixes defined by name, latitude and longitude
- Routes are no or less dependent on the location of NAVAIDs, resulting in much more flexible route designs

*Images from ICAO*
The PBN concept specifies that aircraft RNAV and RNP system performance requirements be defined in terms of:

- Accuracy
- Integrity
- Availability
- Continuity

Performance requirements are identified in navigation specifications, which also identify the choice of navigation sensors and equipment that may be used to meet the performance requirements.

Difference between RNAV and RNP is explained later.
(02) RNAV and RNP systems are necessary to optimise the utilisation of airspace, which is a limited resource.

(03) Both the flight crew and air traffic controllers need to be aware of the on-board RNAV or RNP system capabilities in order to determine whether the performance of the RNAV or RNP system is appropriate for the specific airspace requirements.

   – Information for ATC is contained in the flight plan.
ACCURACY

(04) Definition “conformance of the true position and the required position”

Example of GPS static measurements
062 07 01 01 – PBN principles

AVAILABILITY

(09) Definition “percentage of time (annually) that the services of the system are usable by the navigator”

• (Alt: proportion of time during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft)

CONTINUITY

(05) Definition “capability of the system to perform its function without unscheduled interruptions during the intended operation”

• (Alt from ICAO SARPS: It relates to the capability of the navigation system to provide a navigation output with the specified accuracy and integrity during the approach, assuming that it was available at the start of the operation)

The availability of a system (or service) establishes the percentage of time during when the operation (for example a final approach) can be started.

The continuity of the system guarantees that once an operation (for example a final approach) is initiated, it will not be interrupted.
INTEGRITY

(06) Definition “a measure of the trust that can be placed in the correctness of the information supplied”

• The system must have the ability to provide timely and valid alerts to the user

Loss of integrity Alert for a Garmin G1000 (source: Garmin)
INTEGRITY (extra info not included in official LOs)

• The parameters defining the integrity are:
  
  – **Alert Limit (AL):** the error tolerance not to be exceeded without issuing an alert
    
    - Means the region (horizontal and vertical) which is required to contain the indicated position with the required probability for a particular navigation mode
    
    - Required ALs depend on the type of operation
  
  – **Time to Alert:** the maximum allowable time elapsed from the onset of the navigation system being out of tolerance until the equipment enunciates the alert
  
  – **Integrity Risk:** probability that, at any moment, the position error exceeds the Alert Limit
  
  – **Protection Level:** statistical bound error computed so as to guarantee that the probability of the absolute position error exceeding said number is smaller than or equal to the target integrity risk
    
    - Means the region (horizontal and vertical) assured to contain the indicated position. It defines the region where the missed alert requirement can be met
    
    - PLs are computed by the on board receiver
INTEGRITY cont. (extra info not included in official LOs)

if during an operation the PLs exceed the required ALs, the operation cannot continue
- VPL only used for operations with vertical guidance (e.g. LPV)

\[ xAL \]: fixed value during operation

\[ xPL \]: value calculated by on-board receiver
(varies depending on aircraft and satellite geometry and SBAS corrections)

The integrity of the system (or service) establishes to which degree the navigation source can be trusted during the flight.
Unlike conventional navigation, PBN is not sensor-specific.

- The **PBN concept** represents a shift from sensor-based to PBN.

**Advantages of PBN over sensor-specific methods of developing airspace:**
- reduces the need to maintain sensor-specific routes and procedures, and their associated costs;
- avoids the need for developing sensor-specific operations with each new evolution of navigation systems, which would be cost-prohibitive;
- allows for more efficient use of airspace (route placement, fuel efficiency and noise abatement);
- clarifies how RNAV and RNP systems are used; and
- facilitates the operational approval process for operators by providing a limited set of navigation specifications intended for global use.

**Performance requirements (PR)**

**Navigation sensors meeting them**

*A certain set of PRs may be met by more than one sensor.*
062 07 01 01 – PBN principles

CE (08) Computed vs raw data

Conventional navigation

- The navigation performance data used to determine the separation minima or route spacing depend on the accuracy of the raw data from specific NAVAIDs such as VOR, DME or NDB

PBN

- Requires an RNAV or RNP system that integrates raw navigation data to provide a positioning and navigation solution. In determining separation minima and route spacing in a PBN context, this integrated navigation performance “output” (computed data) is used

- Area navigation system will confirm the validity of the individual sensor data and, in most systems, will also confirm the consistency of the computed data before they are used.
062 07 01 02 – PBN components

(01) PBN is composed of 3 constituents

- **Navigation Specification**: set of aircraft and aircrew requirements needed to support a navigation application within a defined airspace concept

- **Navigation Infrastructure**: ground based NAVAIDS or space based NAVAIDS

- **Navigation Application**: application of a navigation specification and the supporting NAVAID infrastructure, to routes, procedures, and/or defined airspace volume, in accordance with the intended airspace concept

Adapted from Eurocontrol
EXAMPLE – RNAV 1

- RNAV 1 refers to an RNAV **navigation specification** which includes a requirement for 1 NM navigation accuracy (among other requirements)

- In terms of **navigation infrastructure**, the following systems enable RNAV 1: GNSS, DME/DME and DME/DME/IRU

- RNAV 1 can support en-route and terminal **navigation applications**, like SIDs or STARs

*State A’s AIP could stipulate GNSS as a requirement for its RNAV 1 specification because State A only has GNSS available in its NAVAID infrastructure. State B’s AIP could require DME/DME/IRU for its RNAV 1 specification (policy decision not to allow GNSS).*
(01) For Oceanic/remote, en-route and terminal operations, PBN is limited to operations with linear lateral performance requirements and time constraints

(02) For Approach operations, PBN accommodates both linear and angular laterally guided operations

Image from ICAO
062 07 02 00 – Navigation specifications

Navigation specifications

RNP specifications
(Includes a requirement for on-board performance monitoring and alerting)

- Designation
  - RNP 4
  - RNP 2
  - Oceanic and remote navigation applications

- Designation
  - RNP 2
  - RNP 1
  - A-RNP
  - RNP APCH
  - RNP AR APCH
  - RNP 0.3
  - En-route and terminal navigation applications

RNAV specifications
(No requirement for on-board performance monitoring and alerting)

- Designation
  - RNAV 10
  - Oceanic and remote navigation applications

- Designation
  - RNAV 5
  - RNAV 2
  - RNAV 1
  - En-route and terminal navigation applications
RNAV and RNP systems are fundamentally similar. The key difference between them is the requirement for on-board performance monitoring and alerting.

A navigation specification that includes a requirement for on-board navigation performance monitoring and alerting is referred to as an RNP specification.
RNAV and RNP specifications include requirements for certain navigation functionalities. At the basic level, these functional requirements may include:

a) continuous indication of **aircraft position relative to track** to be displayed to the pilot flying on a navigation display situated in his primary field of view;

b) display of **distance and bearing to the active (To) waypoint**;

c) display of **ground speed or time to the active (To) waypoint**;

d) navigation **data storage function**; and

e) appropriate **failure indication** of the RNAV or RNP system, including the sensors.
The expression “X” means a lateral navigation (LNAV) accuracy* in Nautical Miles (NM), expected to be achieved 95% of the flight time by the population of aircraft operating within the airspace, route or procedure.

- Navigation systems are specified in terms of NSE, and therefore hypotheses on the FTE and PDE contributions to the TSE are made to qualify a system for a given navigation specification.

* Lateral navigation accuracy referring in this context to Total System Error (TSE)
(02) Because specific performance requirements are defined for each navigation specification, an aircraft approved for a particular navigation specification is not automatically approved for any other navigation specification, even if the later has a less stringent accuracy requirement.

- In other words: an aircraft approved for an RNP or RNAV specification having stringent accuracy requirements (e.g. RNP 0.3 specification) is not automatically approved for a navigation specification having a less stringent accuracy requirement (e.g. RNP 4).

<table>
<thead>
<tr>
<th>RNAV Specifications</th>
<th>RNP* Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceanic/Remote</td>
<td>RNP 4</td>
</tr>
<tr>
<td>En-route/ Terminal/Approach</td>
<td>Oceanic/Remote</td>
</tr>
<tr>
<td></td>
<td>RNP 4</td>
</tr>
<tr>
<td></td>
<td>En-route/ Terminal/Approach</td>
</tr>
<tr>
<td></td>
<td>Basic RNP 1, RNP APCH, RNP (AR) APCH</td>
</tr>
</tbody>
</table>

* Includes on-board navigation performance monitoring and alerting
### 062 07 02 03 – Designation of RNP and RNAV specifications

#### RNAV 10

(03) Oceanic / remote phases of flight

- Without on-board performance monitoring and alerting function, even when operationally approved as “RNP 10”
- Lateral TSE must be within ±10 NM for at least 95 per cent of the total flight time
- 50NM lateral and 50NM longitudinal separation
- Based on INS, IRS FMS or GNSS

#### RNP 4

(03) Oceanic / remote phases of flight

- With on-board performance monitoring and alerting function (usually RAIM)
- Lateral TSE must be within ±4 NM for at least 95 per cent of the total flight time
- 30 NM lateral and 30 NM longitudinal separation
- Primarily based on GNSS
RNAV 5*

(04) En-route and arrival** phases of flight

- Without on-board performance monitoring and alerting function
- Lateral TSE must be within ±5 NM for at least 95 per cent of the total flight time
- Route spacing may vary among regional implementations
- Based on VOR/DME, DME/DME, INR, IRS or GNSS

* Almost equivalent to Basic RNAV (B-RNAV) within ECAC
**may be used for the initial part of a STAR outside 30 NM and above MSA.
062 07 02 03 – Designation of RNP and RNAV specifications

(05) RNAV 2 and RNP 2 also used as navigation specifications

**RNAV 2**

(07) **En-route continental, arrival and departure phases of flight**

- Without on-board performance monitoring and alerting function

- Lateral TSE must be within ±2 NM for at least 95 per cent of the total flight time

- Based on DME/DME, DME/DME/IRU and GNSS

**RNP 2**

(06) **En-route and oceanic/remote phases of flight**

- With on-board performance monitoring and alerting function (usually RAIM)

- Lateral TSE must be within ±4 NM for at least 95 per cent of the total flight time

- Based on GNSS
**Designation of RNP and RNAV specifications**

<table>
<thead>
<tr>
<th><strong>RNAV 1</strong>*</th>
<th><strong>RNP 1</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>(08) Arrival and departure phases of flight</td>
<td>(08) Arrival and departure phases of flight</td>
</tr>
<tr>
<td>• Without on-board performance monitoring and alerting function</td>
<td>• With on-board performance monitoring and alerting function (usually RAIM)</td>
</tr>
<tr>
<td>• Lateral TSE must be within ±1 NM for at least 95 per cent of the total flight time</td>
<td>• Lateral TSE must be within ±1 NM for at least 95 per cent of the total flight time</td>
</tr>
<tr>
<td>• Based on DME/DME, DME/DME/IRU and GNSS</td>
<td>• For terminal airspace with no or limited ATS surveillance, with low to medium density traffic</td>
</tr>
<tr>
<td></td>
<td>• Based on GNSS</td>
</tr>
</tbody>
</table>

*Almost equivalent to Precision RNAV (P-RNAV) within ECAC*
062 07 02 03 – Designation of RNP and RNAV specifications

**RNP APCH**

(09) Approach phase of flight

- With on-board performance monitoring and alerting function (usually RAIM or SBAS)
- Lateral TSE varies with minima and approach segment (initial, intermediate, final missed)
- Based on:
  - GNSS for LNAV minimum
  - GNSS + barometric VNAV for LNAV/VNAV minimum*
  - GNSS augmented by SBAS for LP and LPV minima

---

**RNP AR**

(10) Approach phase of flight

- With on-board performance monitoring and alerting function (usually RAIM)
- Cross-track error must be lower than the lateral applicable accuracy value for 95 per cent of flight time
- For terminal airspace with no or limited ATS surveillance, with low to medium density traffic
- Based on GNSS + (usually) barometric-based VNAV

---

*GNSS-based vertical guidance may be used*
062 07 02 03 – Designation of RNP and RNAV specifications

**RNP 0.3**

(11) All phases of flight except oceanic/remote and final approach

- With on-board performance monitoring and alerting function (usually RAIM or SBAS)
- Lateral TSE must be within ±0.3 NM for at least 95 percent of the total flight time
- Primarily for helicopters
- Based GNSS

**Helicopter Operations**

(12) RNAV 1, RNP 1 and RNP 0.3 may also be used in en-route phases of low-level instrument flight rule (IFR) helicopter flights.
062 07 03 00 – Use of PBN

• Generic navigation requirements are defined based on operational needs

• Operators then evaluate options in respect of available technology and navigation services

• PBN brings the opportunity to select cost-effective options
(05) The standard that fixes database formats and contents is the ARINC 424 ‘Navigation System Data Base Standard’

Allows coding the SIDs, STARs and instrument approach procedures (IAPs) from the official published government source documentation into the ARINC navigation database format.

(04) Waypoints coordinates are loaded in the on-board aircraft’s database. Types:

- **Fly-by**: the navigation system anticipates the turn onto the next leg
- **Fly-over**: the aircraft overflies the waypoint before starting the turn onto the next route leg

*Note that the depiction of fly-by and fly-over waypoints is different*
(06) **ARINC 424** also defines the **Path Terminator**: define a specific type of termination of the previous flight path.

- The Path Terminator is a two-letter code, which defines a specific type of flight path along a segment of a procedure and a specific type of termination of that flight path.

- Path terminators are assigned to all RNAV SID, STAR and approach procedure segments in an airborne navigation database.

- This allows translating into computer language (FMS) the procedures designed for clock & compass manual flight.

- Charted procedures are translated into a sequence of ARINC 424 legs in the database.

- There are 23 different path terminators defined in ARINC 424. Those which can be expected in RNAV or RNP charts are depicted in next slide.
062 07 03 03 – Specific RNAV and RNP system functions

**Initial Fix (IF)**
- It defines a point in space
- The coding of RNAV procedures starts at an IF

![IF Diagram](image)

**Track to a fix (TF)**
- Preferred type for straight legs
- Geodesic path between two waypoints

![TF Diagram](image)

**Course to an altitude (CA)**
- Course that terminates at an altitude with an unspecified position
- For departures or Missed App

![CA Diagram](image)

**Direct to a fix (DF)**
- Segment from an unspecified position to a known waypoint

![DF Diagram](image)

**Course to a Fix (CF)**
- Course that terminates at a waypoint
- CF legs are subject to magnetic variation issues

![CF Diagram](image)

**Course from a fix to an altitude (FA)**
- Begins at a fix and terminates when aircraft altitude is at, or above, a specified altitude

![FA Diagram](image)
There are two types of **FIXED RADIUS PATHS**

1. **Radius to Fix (RF)**
   - Is also a type of Path Terminator
   - Specific curved path radius in a terminal or approach procedure
   - Is defined by radius, arc length, and fix

2. **Fixed radius transition (FRT)**
   - To be used* with en-route procedures
   - It falls upon the RNP system to create it between two route segments
   - These turns have two possible radii, 22.5 NM for high altitude routes (above FL 195) and 15 NM for low altitude routes. Using such path elements in an RNAV ATS route enables improvement in airspace usage through closely spaced parallel routes

* The “Concept of Use” of FRT is currently being evaluated by ICAO, who is carefully addressing promulgation, airspace design and avionics capabilities aspects, among others. No State has published yet any ATS Routes that require the FRT function.
(07) Many aircraft have the capability to fly a path parallel to, but offset left or right from, the original active route → **offset flight path**

- **The purpose of this function is to enable offsets for tactical operations authorized by ATC**

- **Capability for the flight crew to specify a lateral offset from a defined route (generally in increments of 1NM to 20 NM)**

*Source: Garmin*
Many aircraft have the capability to execute a **holding pattern** manoeuvre using their RNAV system, which can provide flexibility to ATC in designing RNAV operations.

- The RNAV system facilitates the holding pattern specification by allowing the definition of the inbound course to the holding waypoint, turn direction and leg time or distance on the straight segments, as well as the ability to plan the exit from the hold.
What pilots need to know about PBN operations is whether the aircraft and flight crew are qualified to operate in the airspace, on a procedure or along an ATS route.

The flight operations element considers:

1. The operator’s infrastructure for conducting PBN operations and flight crew operating procedures, training and competency demonstrations
2. The operator’s MEL, OMs, checklists, navigation database validation procedures, etc
There are 3 main independent lateral errors in the context of on-board performance monitoring and alerting. Together they account for the **Total System Error (TSE)**, which forms the basis for performance estimation and monitoring.

1. **Path Definition Error (PDE)**: occurs when the path defined in the RNAV system (database) does not correspond to the desired path, i.e. the path expected to be flown over the ground.

2. **Flight Technical Error (FTE)**: relates to the air crew or autopilot’s ability to follow the prescribed path or track, including any display error (e.g. CDI centering error). Sometimes, if adding display error, referred as PSE (Path Steering Error).

3. **Navigation System Error (NSE)**: refers to the difference between the aircraft’s estimated position and actual position. The accuracy of a navigation system may be referred to as NSE. Sometimes referred as **EPE (Estimated Position Error)**.

**Total System Error (TSE)**: Root Sum of PDE, FTE and NSE.

**With SBAS, expect: NSE << FTE**
062 07 04 02– On-board performance monitoring and alerting

- This function allows the air crew to detect whether or not the RNP system satisfies the navigation performance required (requirements based on TSE) in the navigation specification
  - **On-board** means that the performance monitoring and alerting is effected on board the aircraft and not elsewhere
  - **Monitoring** refers to the monitoring of the aircraft’s performance as regards its ability to determine positioning error and/or to follow the desired path
  - **Alerting** relates to monitoring: if the aircraft’s navigation system does not perform well enough, this will be alerted to the air crew

- **Path Definition Error (PDE):** cannot be monitored or controlled but generally is sufficiently small that it can be ignored.
- **Flight Technical Error (FTE):** FTE can be controlled by the flight crew and should be minimized.
- **Navigation System Error (NSE):** cannot be controlled by the flight crew but should be monitored to ensure that it remains within acceptable limits. That is why it is characterized by the ANP (Actual Navigation Performance)
### On-board performance monitoring and alerting

**REMINDER!**
RNAV specifications do not require monitoring and alerting functions!

<table>
<thead>
<tr>
<th>NSE (monitoring and alerting)</th>
<th>Requires no alerting on position error or pilot cross-check of NSE.</th>
<th>Alerting on position accuracy and integrity.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTE (monitoring)</td>
<td>Managed by on-board system or crew procedure.</td>
<td>Managed by on-board system or crew procedure. More specific display scaling.</td>
</tr>
<tr>
<td>PDE (monitoring)</td>
<td>Assumed to be zero; the desired path is not defined on turns.</td>
<td>Assumed to be zero; path defined on RF and FRT.</td>
</tr>
<tr>
<td>NET EFFECT ON TSE</td>
<td>TSE distribution not bounded. In addition, the wide variation in turn performance results in need for extra protection on turns.</td>
<td>TSE distribution bounded, but extra protection needed on turns; TSE distribution bounded; no extra protection needed if turns defined by RF or FRT.</td>
</tr>
</tbody>
</table>

**Example:** RAIM or FDE algorithm + CDI crew monitoring

---

**CE**
(01) On board performance monitoring and alerting of FTE is managed by on board systems or crew procedures

**CE**
(02) On board performance monitoring and alerting of NSE is a requirement of on-board equipment for RNP

**CE**
(06) On board performance monitoring and alerting of PDE are managed by gross reasonableness of navigation data
On-board performance monitoring shall not be regarded as error monitoring

Alerts are issued when the system cannot guarantee with sufficient integrity that the position meets the accuracy requirement

When an alert is issued, the probable reason is the loss of capability to validate the position data (insufficient satellites being a potential reason in the case of GNSS)

In other words, even if the position was able to meet the accuracy requirement, since the system is unable to prove it, an alert would be issued.
062 07 04 02– On-board performance monitoring and alerting

(04) **Navigation System Error (NSE)** *(also known as Estimated Position Error - EPE)*

- **More common terms**, as displayed in the cockpit, are ‘**ANP**’ (Actual Navigation Performance), ‘**EPU**’ (Estimated Position Uncertainty) or ‘**ACTUAL**’

- **EPE/ANP** is defined as an statistical bound on the NSE and not TSE

- Multiple sources of navigation data may be integrated to determine the ANP. Inertial systems initially are very accurate but may tend to drift if not updated accurately throughout the flight. GNSS units generally provide exceptionally accurate data but must be monitored for undetected failures, etc.

- These sources of data are analyzed continuously to calculate the best estimate of current a/c position and ANP/EPU. If any source is deleted, the confidence in the navigation position will decrease. Thus, the ANP value will increase.

(03) **Depending on the navigation sensor, ANP is compared with the RNP:**

![Image of cockpit display showing ANP and RNP values]
Considerations:

• Management of FTE is usually a pilot procedure

• On-board performance monitoring requirement is unique to RNP specifications

• PDE vanishes as the airborne system uses the same coordinate system and computations as the designer to define the path, so monitoring requirement is reduced to FTE and NSE

\[
TSE^2 = PDE^2 + FTE^2 + NSE^2
\]
Performance assessment

- The:
  - aircraft navigation system; or the
  - aircraft navigation system and pilot in combination
- Must monitor the TSE and provide alerts if:
  1. **Accuracy requirement** (i.e. TSE remains equal to or less than 1xRNP for 95 per cent of the flight time) is not met; or
  2. **Integrity requirement** (probability that the lateral TSE is below x2 the accuracy value is higher than 1 x 10^-5) is not met. In other words, the lateral TSE should be below 2xRNP for 99.999 percent of the time.
     - Probability calculations (10^-5 at 2xRNP) based on complex algorithms certified as part of airborne systems
     - The objective of this requirement is to limit the exposure of the aircraft to conditions where the containment limit is exceeded without annunciation

- Various manufacturers of flight management computers (FMC) use different mathematical equations, or algorithms, to calculate actual navigation performance (ANP), depending also on the navigation sensor

**RNP NavSpecs**

- PDE assumed to be zero
- NSE requires **monitoring and alerting**
- FTE requires **monitoring**

\[ TSE^2 = PDE^2 + FTE^2 + NSE^2 \]
(05) Example of how the loss of the ability to operate in RNP airspace may be indicated by the navigation system.

**BOEING**
When ANP exceeds RNP, an UNABLE RNP message is displayed to the flight crew. This indicates that the FMS position does not meet the required accuracy, so the procedure (such as an approach) must be aborted.
EXAMPLE 1: how is this achieved with RNP 1?

The RNP 1 accuracy requirement is (extracted from the ICAO PBN Manual):

“During operations in airspace or on routes designated as RNP 1, the lateral TSE must be within ±1 NM for at least 95 percent of the total flight time. The along-track error must also be within ±1 NM for at least 95 percent of the total flight time. To satisfy the accuracy requirement, the 95 percent FTE should not exceed 0.5 NM”

Check of the Accuracy requirement TSE < ± 1NM

- Aircraft navigation system
  “the use of an autopilot or flight director has been found to be an acceptable means of compliance (roll stabilization systems do not qualify)”

- Aircraft navigation system and pilot in combination:
  “the use of a deviation indicator [CDI] with 1 NM full-scale deflection [FSD] has been found to be an acceptable means of compliance”

  The CDI displays the FTE:

  FSD = 2 dots = 1 NM  →  1 dot= 0.5 NM i.e. pilot must fly below 1 dot.

  If flying at 1 dot, pilot must monitor that ANP < 0.5NM

Check of the integrity requirement TSE < 2NM for 99.999 % of the time

For systems operating in a GNSS mode, some derivative of the GNSS performance could be used: Horizontal Dilution of Precision (HDOP), the Horizontal Protection Level (HPL), etc.
EXAMPLE 2: how is this achieved with RNP APCH down to LPV?

The ICAO PBN Manual states that:
“NSE requirements are fulfilled (…) if the equipment computes (…) solution in accordance with RTCA DO 229C (or subsequent version) Appendix J”
“FTE performance is considered acceptable if the lateral and vertical display full-scale deflection is compliant with (…) requirements of RTCA DO 229 C (or subsequent version) and if the crew maintains the aircraft within one-third the full scale deflection for the lateral deviation and within one-half the full scale deflection for the vertical deviation”

Check of the Accuracy requirement
- NSE monitoring and alerting
  Equipment compliant with DO-229[x]
- FTE monitoring
  approach guidance must be displayed on a lateral and vertical deviation display (HSI, EHSI, CDI/VDI) including a failure indicator for crew monitoring

Check of the integrity requirement

With probability of $1-2\times10^{-7}$, DO-229[x] equipment checks at all times that:
- Horizontal Protection Level (HPL) < Horizontal Alert Limit (HAL)
- Vertical Protection Level (VPL) < Vertical Alert Limit (VAL)
- and provide alerts within 10 seconds before FAP, and 6 seconds after FAP
(01) Abnormal and contingency procedures are to be used in case of the loss of PBN capability

• **Abnormal procedures** should be available to address cautions and warnings resulting from the following conditions:
  
  - *Failure of the navigation system components including those affecting flight technical error (e.g. failures of the flight director or auto pilot)*;
  
  - *RAIM alert or loss of integrity function*;
  
  - *Warning flag or equivalent indicator on the lateral and/or vertical navigation display*;
  
  - *Degradation of the GNSS approach mode during a LPV approach procedure (e.g. downgrade from LPV to LNAV)*;
  
  - *Low altitude alert (if applicable)*
• LPV to LNAV reversion (adapted from French DGAC/DSAC)

  - For LPV approaches, some systems allow LPV to LNAV reversion if the vertical signal is lost or degraded
  - If LPV to LNAV reversion takes place before the FAF/FAP, the crew can envisage continuing with the approach to the LNAV minima
  - If reversion occurs after the FAF/FAP, go-around is required, unless the pilot has in sight the visual references required to continue the approach
• In case of a complete RNAV guidance loss during the approach, the crew must follow the **operator defined contingency procedure/s**

• In the event of communications failure:
  
  ▪ *Flight crew should continue with the 2D/3D RNAV(GNSS) procedure in accordance with published lost communication procedures; or*

  ▪ *Follow procedures stated in the chart;*

• The flight crew should react to TAWS warnings in accordance with approved procedures

• The flight crew should notify ATC of any problem with the navigation system that results in the loss of the approach capability
062 07 04 04– Database management

• The navigation database must contain all the necessary data/information to fly the published approach procedure

(01) Therefore, the on-board navigation data must be valid for the current AIRAC cycle and must include the appropriate flight procedures, unless otherwise specified in the operations documentation or AMC

• The operator should implement procedures that ensure timely distribution and insertion of current and unaltered electronic navigation data to all aircraft that require it
062 07 05 00– Requirements for specific RNAV and RNP specifications

- **RNP APCH**
  - **WITHOUT VERTICAL GUIDANCE**
    - LNAV
      - GPS NPA
      - Expected to be flown with CDFA
    - LP
      - NPA SBAS supported
      - Localiser Performance
  - **WITH VERTICAL GUIDANCE**
    - LNAV/VNAV
      - APV Baro
      - (can also be supported by SBAS)
    - LPV
      - APV SBAS supported
      - Localiser Performance with Vertical Guidance
(01) An RNP APCH shall not be flown unless it is retrievable by procedure name from the onboard navigation database and conforms to the charted procedure.
062 07 05 05– RNP APCH

- Retrieving a procedure from the database:
  - By name: usually IAF
  - If LPV is available, also by SBAS Channel Number, which is a unique worldwide identifier composed of 5 numeric characters, in the range of 40000 to 99999

- Example GRAZ RNAV (GNSS) RWY 35
  - 3 IAFs: WG832, WG834 and WG833
  - 1 Channel Number: 48472
  - Pilot can select one of the 4 previous options. Selecting the channel number will load an ‘extended’ Final Approach Segment, as an ILS. In this later case, pilot is expected to intercept the extended FAS following ATC Vectors To Final
  - ‘Direct to’ waypoints following ATC clearances are allowed except for FAP
062 07 05 05 – RNP APCH

RNP APCH

WITHOUT VERTICAL GUIDANCE

LNAV

GPS NPA
Expected to be flown with CDFA

LP

NPA SBAS supported Localiser Performance

WITH VERTICAL GUIDANCE

LNAV/VNAV

APV Baro (can also be supported by SBAS)

LPV

APV SBAS supported Localiser Performance with Vertical Guidance

2D approach operations

3D approach operations
In terms of **phraseology**, no distinction is made between the different types of RNAV (GNSS) approaches (no distinction according to LPV, LNAV/VNAV and LNAV minima).

- The minima to which the procedure is flown is unknown to Air Traffic Controllers

*(adapted from French DGAC/DSAC)*
(02) **LNAV minima**
- Non Precision Approach
- 2D operation
- Linear lateral guidance based on GNSS
- Expected to be flown using CDFA technique
- Integrity provided by RAIM, unless SBAS is available

**LP minima**
- Non Precision Approach
- 2D operation
- SBAS required:
  - angular lateral guidance based on GNSS augmented by SBAS
  - Integrity provided by SBAS
- Expected to be flown using CDFA technique
- LP Final Approach Segment specially coded into a Data Block inside the on-board navigation database.
- Not published at runways with LPV minima

*If SBAS-certified equipment is available on-board, SBAS can provide integrity during LNAV operations.*
• (03) **LNAV/VNAV minima**
  - Approach with Vertical guidance (APV)
  
  (07) **3D operation**
  
  - Linear lateral guidance based on GNSS

(04) **Vertical guidance based on Baro-VNAV or SBAS. In any case, the used angular vertical guidance must be certified for the purpose**

- Integrity provided by RAIM, unless SBAS is available

---

If SBAS-certified equipment is available on-board, SBAS can provide integrity during LNAV/VNAV operations.
062 07 05 05– RNP APCH

CE (06) LNAV/VNAV minima

Considerations about the use of the Barometric sensor

- Affected by temperature variation → LNAV/VNAV based on Baro-VNAV can only be flown when aerodrome temperature is within a promulgated range, unless a/c has an approved temperature compensation system

- Altimeter setting is critical → to safe conduct LNAV/VNAV based on Baro-VNAV, remote altimeter setting is prohibited

Barometer is affected by temperature. The effect of the -statistically- coldest day is therefore studied.

Procedure not flyable if “Temp” < “Min Promulgated Temp”

Cold temperatures reduce the VPA
• LPV minima

   Precision Approach CAT-I or APproach with Vertical guidance (APV)

(08) 3D operation

(10) SBAS required:

   • angular lateral and vertical guidance based on GNSS augmented by SBAS
   • Integrity provided by SBAS

(09) LPV Final Approach Segment is specially coded into a Data Block inside the on-board navigation database. It is known as the FAS DB
(11) FAS DB

- "The set of parameters to identify a single precision approach or APV and define its associated approach path" (ICAO)"

- Is part of the data package of an SBAS approach procedure:
  - The FAS-DB contain the parameters that define the Final Approach Segment geometry
  - The integrity of the data is ensured by the generation of a CRC algorithm (Cyclic redundancy check)

- References:
  - ICAO Doc 8168: procedure design criteria
  - ICAO Annex 10: Aeronautical Telecommunications
  - RTCA Do-229: Approval of GPS/SBAS Rx equipment
FAS DB: why?

- To ensure the integrity of databases

- In ILS/MLS approaches, integrity is ensured by:
  - Proper alignment of transmitting antennas
  - Flight checks
  - Integrity monitors on the transmitted signal

LPV approaches:

- A kind of approach based on on-board data
- Integrity rests on the data describing the approach path
- Hence the importance of having a CRC wrapping the FAS DB
• Most RNAV (GNSS) final approach procedures leading to LNAV, LNAV/VNAV or LPV minima, may be preceded by either an initial and intermediate T-bar or Y-bar approach. In this case all segments are published on the same chart.

• A T- or Y-bar arrangement permits direct entry to the procedure from any direction, provided entry is made from within the capture region associated with an IAF.

• Where one or both offset IAFs are not provided, a direct entry will not be available from all directions. In such cases a holding pattern may be provided at the IAF to enable entry to the procedure via a procedure turn.
062 07 05 05– RNP APCH

90 degree turn

70 degree turn

T-bar arrangement

Y-bar arrangement

IAF, IF, FAF Fly-by MAPt Fly-over

All segments: 5NM optimum length

(source: ICAO)
(01) The Point-in-Space approach is based on GNSS or SBAS and is an approach procedure designed for helicopters only that includes both a visual and an instrument segment. Therefore, it can be published with LNAV and/or LPV minima

- Obstacle clearance is provided for all IFR segments of the procedure including the missed approach segment

- During an approach to land, the instrument segment ends at the PinS (MAPt). From there, flight continues with a visual segment

- In an approach procedure, the visual segment (VS) is the segment of a helicopter PinS approach between a point (MAPt) and the heliport or the landing location

*The flexibility that offers the free positioning of the PinS is the main asset of this concept.*
**Visual Segment (VS)**

(02) The PinS approach procedure includes either a “proceed visually” instruction or a “proceed VFR” instruction from the MAPt to the heliport or landing location.

(03) **Proceed VFR**: developed for heliport or landing locations that do not meet the standards for a heliport. The PinS instrument approach delivers the helicopter to a MAPt. Prior to or at the MAPt, the pilot shall decide to proceed VFR or to execute a missed approach, based on visibility.

- Pilot determines whether visibility is met based on the published minimum visibility or the visibility required by State regulations (whichever is higher).
- There is no protection after the MAPt if MA is not initiated. The pilot is responsible to see and avoid obstacles.

**Proceed visually**: developed for a heliport or a landing location. The PinS instrument approach segment delivers the helicopter to a MAPt. Prior to or at the MAPt, the pilot shall decide to proceed visually to the heliport or landing location or to execute a missed approach.

- A Direct VS or a Manoeuvring VS connects the MAPt to the heliport or landing location.
- The minimum visibility is based on the distance from the MAPt to the heliport or landing location.
- IFR obstacle clearance areas are not applied to the visual segment. However, the visual segment is protected, by operational limitations in the case of “manoeuvring” VS.
062 07 05 09 – PBN Point in Space (PinS) Approach

COPTER RNAV (GNSS) 079
INTERLAKEN HOSPITAL
LSIK
Interlaken Switzerland

MISSED APPROACH:
Climbing left turn direct to ECEKU. Maintain VMC.

NA
Use Meiringen Ctr QNH or
REGA base Altimeter Setting.

Restricted to REGA
Flight Trials Only
under VMC

WAYPOINTS FOR FLIGHT:
AKUVE: 46-40.4452 / 06
BURBE: 46-39.3138 / 06
CABGI: 46-41.3167 / 06
DACAG: 46-43.0356 / 06
HP: 46-40.8828 / 06
ECEKU: 46-43.9008 / 06
Bibliography

- EASA NPA 2013-25
- ICAO State Letter SP 65/4-13/24, 14 June 2013
- RTCA DO-229D, RTCA DO-236C
- Technical Guidelines 01 – PBN, Guidelines for RNP APCH operations also known as RNAV (GNSS), Ed 2, DGAC/DSAC
- Official U.S. Government information about the Global Positioning System (GPS) and related topics (gps.gov)
- Aeronautical Information Publication Austria
- digital — Terminal Procedures Publication (d-TPP)/Airport Diagrams, FAA
- www.boeing.com
DISCLAIMER

This document and its contents (hereinafter the “Data”) have been prepared by European Satellite Services Provider S.A.S. (ESSP) under its EGNOS Service Provision contract with the European Global Navigation Satellite Systems Agency (GSA).

The Data are provided for free and for the sole purpose of training on EGNOS-based operations, in the framework of EGNOS Service Provision, to airspace users. The Data are not public and may be protected by property rights. Therefore, any other use shall require the prior written authorization of ESSP SAS, which can be contacted via the EGNOS Helpdesk (egnos-helpdesk@essp-sas.eu). Total or partial reproduction of the Data is authorised for the abovementioned purpose provided there is no modification to any part and the source is acknowledged.

The European Union, as owner of EGNOS, including the GSA, and ESSP SAS, as EGNOS services provider, disclaim all warranties of any kind (whether express or implied) to any party and/or for any use of the Data including, but not limited to, their accuracy, integrity, reliability and fitness for a particular purpose or user requirements. By using the Data, the user agrees that the European Union, including the GSA, and ESSP SAS shall not be held liable for any direct or indirect or consequential loss or damage (such as loss of profits, business, contracts, anticipated savings, goodwill or revenue) resulting from the use, misuse or inability to use the Data.