Flight crew basic theoretical training for

RNP APCH down to LPV minima

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

Issue 1.2 – October 2017
Introduction

• This training package is focussed in covering the **theoretical knowledge syllabus** for RNP APCH to LPV minima for an Instrument Rated pilot in accordance with **EASA NPA 2013-25 “Revision of operational approval criteria for performance-based navigation”**

• To complement it, it also covers the **theoretical knowledge syllabus** for Global Navigation Satellite Systems
  – Several slides have been marked with a red stripe to ease the identification of those covering the theoretical knowledge syllabus related to GNSS, defined in “**Commission Regulation (EU) No 245/2014 of 13 March 2014, amending Commission Regulation (EU) No 1178/2011 of 3 November 2011 laying down technical requirements and administrative procedures related to civil aviation aircrew**”

• This training shall be complemented with:
  – Operating Procedures training
  – Specific Aircraft System theoretical training
  – Practical in aircraft or simulator training
Commercial operators must have a training programme addressing the operational practices, procedures and training items related to RNP APCH.

- Operators need not establish a separate training programme if they already integrate RNAV training as an element of their training programme. However, the operator should be able to identify the aspects of RNP APCH operations to LNAV, LNAV/VNAV, LP and/or LPV minima covered within their training programme.

Private operators must be familiar with the practices and procedures identified in Section A/B, 5.3.5 “Pilot knowledge and training” (of the ICAO PBN Manual).
<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>AIRC</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>Dillution Of Precision</td>
</tr>
<tr>
<td>EGNOS</td>
<td>European Geostationary Navigation Overlay Service Provider</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>ICAO</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 Vertical 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>MEO</td>
<td>Medium Earth Orbit</td>
</tr>
<tr>
<td>MLS</td>
<td>Microwave Landing System</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 System</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>
</tbody>
</table>
Course contents: TK /LO’s

062 06 00 00  GLOBAL NAVIGATION SATELLITE SYSTEMS
062 06 01 00  GPS/GLONASS/GALILEO
062 06 01 01  Principles
062 06 01 02  Operation
062 06 01 03  Errors and factors affecting accuracy
062 06 02 00  Ground, Satellite and Airborne based augmentation systems
# 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 06</td>
<td>RNP AR APCH</td>
</tr>
<tr>
<td>062 07 03 00</td>
<td>Use of PBN</td>
<td>062 07 05 09</td>
<td>PBN Point In Space (PinS) Approach</td>
</tr>
<tr>
<td>062 07 03 01</td>
<td>Airspace Planning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>062 07 03 02</td>
<td>Approval</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>
<tr>
<td>062 07 03 04</td>
<td>Data processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GLOBAL NAVIGATION SATELLITE SYSTEMS

062 06 00 00
062 06 01 00 – GPS / GLONASS / GALILEO
062 06 01 01 – Principles

• There are two main Global Navigation Satellite Systems (GNSS) currently in existence by the end of 2014
  - USA NAVSTAR GPS (NAVigation System with Timing And Ranging Global Positioning System)
  - Russian GLONASS (GLObal Navigation Satellite System)

• Two more will become fully operational in the coming years:
  - European GALILEO (more info [here](#))
  - Chinese BEIDOU

• 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 is run by civil, not military, authorities*
The GPS system is composed of 3 segments:

- **Space segment**: consists of a constellation of satellites transmitting radio signals to users

- **Control segment**: consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation

- **User segment**: consists on L-band radio receiver/processors and antennas which receive GPS signals, determine pseudoranges (and other observables), and solve the navigation equations in order to obtain their coordinates and provide a very accurate time
SPACE SEGMENT - constellation

- Nominal constellation of 24 operational satellites
  - 7 additional satellites are currently orbiting to guarantee the coverage whenever the baseline satellites are serviced or decommissioned

- Orbit characteristics:
  - Inclination of 55° to the plane of the equator
  - Medium Earth Orbits (MEO) at an altitude of approximately 20200 km (10900 NM)
  - 6 orbital planes with at least 4 baseline satellites in each
  - Satellites complete one orbit each 12 hours → Each satellite circles the Earth twice a day
SPACE SEGMENT - signals and services

- 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

- **SPS is** a positioning and timing service **provided on L1** frequency

- **PPS uses both** L1 and L2 frequencies

- SPS was originally designed to provide civil users with a less accurate positioning capability than PPS
SPACE SEGMENT - signals and services

• GPS ranging signal contains a Coarse Acquisition (C/A) code and a navigational data message

• The navigation message contains the following information...
  - Almanac data
  - Ephemeris
  - Satellite clock correction parameters
  - UTC parameters
  - Ionospheric model
  - Satellite health data

• ...and it takes 12.5 minutes for a GPS receiver to receive all data frames in the navigation message
SPACE SEGMENT - signals and services

- **Almanac**
  - Contains the orbital data about all the satellites in the GPS constellation

- **Ephemeris**
  - Contains health and location data of the satellites, plus data used to correct the orbital data of the satellites due to small disturbances

- **Satellite clock correction parameters**
  - Contains data for the correction of the satellite time

- **UTC parameters**
  - Are factors determining the difference between GPS time and UTC

- **Ionospheric model**
  - Is currently used to calculate the time delay of the signal travelling through the ionosphere

- **Satellite health data**
  - Is used to exclude unhealthy satellites from the position solution. Satellite health is determined by the validity of the navigation data
SPACE SEGMENT - signals and services

- Two codes are transmitted on the L1 frequency

<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>PPS</td>
</tr>
</tbody>
</table>

- The C/A code is a pseudo random noise (PRN) code sequence
  - Repeats every millisecond
  - Is unique and therefore provides the mechanism to identify each satellite (PRN 01, PRN 02, PRN 03...)

Whenever a GPS satellite is retired, its PRN code is assigned to future replacements
SPACE SEGMENT - signals and services

• Satellites broadcast the PRN codes with reference to the satellite vehicle time which are subsequently changed by the receiver to UTC

• 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
SPACE SEGMENT - modernisation

- In 2005, the first replacement satellite was launched with a new military M code on the L1 frequency and a second signal for civilian use L2C on the L2 frequency.

- In 2009, the Air Force successfully broadcast an experimental L5 signal on the GPS IIR-20(M) satellite. The first GPS IIF satellite with a full L5 transmitter launched in May 2010.

- GPS modernization program:

  ![Diagram of GPS modernization program]

  *Source: United States Government*
CONTROL SEGMENT

• The control segment comprises:
  - A master control station (plus an alternative master control station)
  - 12 command and control ground antennas
  - 16 monitoring stations

• The master control station is responsible for all aspects of the constellation command and control

• The main tasks of the control segment are:
  - Managing SPS performance
  - Navigation data upload
  - Monitoring satellites

Source: United States Government
USER SEGMENT

• GPS supplies three-dimensional position fixes and speed data, plus a precise time reference

• The GPS receiver used in aviation is a multi-channel type: each channel is assigned to track individual satellites

• 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
USER SEGMENT

• Each range defines a sphere with its centre at the satellite

• Three spheres (hence three satellites) are needed to determine a two-dimensional position

• Four spheres (hence four satellites) are needed to determine a three-dimensional position

• The GPS receiver synchronises to the correct time base when receiving four satellites

• The receiver is able to calculate aircraft groundspeed using the SV Doppler frequency shift and/or the change in receiver position over time
NAVSTAR GPS Integrity

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

- RAIM is a technique whereby a receiver processor determines the integrity of the navigation signals

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

- Basic RAIM requires 5 satellites

- A 6\(^{th}\) 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
SPACE SEGMENT - constellation

• Nominal constellation of 24 operational satellites
  - 4 additional satellites are currently orbiting as spares, testing or flight check

• Orbit characteristics:
  - Inclination of 64.8º to the plane of the equator
  - Medium Earth Orbits (MEO) at an altitude of approximately 19,100 km
  - 3 orbital planes with at least 8 baseline satellites in each,
  - Satellites complete one orbit every 11 hours 15 minutes

The GLONASS-K satellite (Source: Roscosmos and Information Satellite Systems Reshetnev Company)

GLONASS Constellation
(Source: http://www.spacecorp.ru/en/directions/glonass/orbital/)
The GLONASS system has 3 components:

- **Space segment**, which contains the constellation of satellites
- **Control segment**, which contains the ground based facilities
- **User segment**, which contains the user equipment
062 06 01 02 – Operation

SPACE SEGMENT - constellation

• Each satellite transmits navigation signals on two frequencies of L-band
  
  - L1 1602 MHz
  - L2 1246 MHz

• GLONASS is designed for two types of users:
  
  - Civilian world-wide users: using L1 frequency achieving standard accuracy
  - Authorised users: using L1 and L2 frequencies achieving high accuracy

• The time reference of the system is UTC

• Correction to GLONASS time relative to UTC must remain within 1 microsecond
062 06 01 02 – Operation

SPACE SEGMENT - signals and services

• The navigation message has a duration of 2 seconds and contains “immediate data” which relates to the actual satellite transmitting the given navigation signal and “non-immediate data” which relates to all other satellites within the constellation

• Immediate data consists of:
  - Enumeration of the satellite time marks
  - Difference between on board time scale of the satellite and GLONASS time
  - Relative differences between carrier frequency of the satellite and its nominal value
  - Ephemeris parameters

• Non-immediate data consists of:
  - Data on the status of all satellites within the space segment
  - Coarse corrections to on board time scales of each satellite relative to GLONASS time
  - Orbital parameters of all satellites within the space segment
CONTROL SEGMENT

• The control segment comprises:
  - SCC – System Control Centre
  - TT&C – Telemetry, Tracking, Commanding station
  - ULS – UpLink Station
  - MS – Monitoring Station
  - CC – Central Clock
  - SLR – Laser Tracking Station

• The control segment provides:
  - Monitoring of the constellation status
  - Correction of orbital parameters
  - Navigation data upload

Source: Federal Space Agency
USER SEGMENT

- Consists of receivers and processors for the navigation signals for the calculation of the coordinates, velocity and time

- The control segment provides:
  - Monitoring of the constellation status
  - Correction of orbital parameters
  - Navigation data upload
GLONASS Integrity Monitoring

- It is implemented in 2 ways:
  
  - **Continuous automatic operability monitoring of principal systems in each satellite.** If a malfunction occurs an “unhealthy” flag appears within the “immediate data” of the navigation message.
  
  - **Special tracking stations within the ground-based control segment** are used to monitor the space segment performance. If a malfunction occurs an “unhealthy” flag appears within the “immediate data” of the navigation message.
INTEROPERABILITY

• Finally, it is worth mentioning the important agreements made between the appropriate agencies for the interoperability by any one approved user of GPS and GLONASS systems.

In 2011, the Russian Ministry of Transport published a mandate for installation of GLONASS-capable receivers in Russian registered aircraft. It has a six-year implementation horizon.
• The Galileo system is divided into three major segments

  - **Space segment**: is main functions are to generate and transmit code and carrier phase signals and to store and retransmit the navigation message sent by the Control Segment

  - **Ground segment**: constitutes the major system element controlling the entire constellation, the navigation system facilities and the dissemination services

  - **User segment**: is composed of Galileo receivers
SPACE SEGMENT - constellation

- Core constellation of 30 operational satellites
  - Plus 3 spare satellites, 1 in each of the three orbital planes

- Orbit characteristics:
  - Inclination of 56º to the plane of the equator
  - Medium Earth Orbits (MEO) at an altitude of approximately 23222 km
  - 3 orbital planes, 9+1 satellites in each
  - Satellites complete one orbit each 14 hours
SPACE SEGMENT - signals

- Each satellite broadcasts signals in three frequency bands
  - E5a/E5b 1164-1215 MHz
  - E6 1260-1300 MHz
  - E1 1559-1591 MHz this band shared with GPS on a non-interference basis

- Summary of frequencies allocation:

  ![Frequency Allocation Diagram](image)

  GPS, GLONASS and Galileo navigational frequency bands (source: Navipedia)
SPACE SEGMENT - signals

• Each satellite has three sections
  - Timing
  - Signal generation
  - Transmit

• In the Timing section, two clocks have been developed
  - Rubidium Frequency Standard clock
  - Passive Hydrogen Maser clock (more precise)

• The Signal generation contains the navigation signals

• Navigation signals consist of a ranging code identifier and the navigation message
SPACE SEGMENT - navigation message

- The navigation message contains information concerning the satellite orbit (ephemeris) and clock references

- Is “up-converted” on four navigation signal carriers and the outputs are combined in a multiplexer before transmission in the Transmit section

- The navigation antenna has been designed to minimise interference between satellites by having equal power level propagation paths independent of elevation angle
GROUND SEGMENT - navigation message

- The core of the GALILEO ground segment are two control centres (GCC)

- Each control centre manages control functions supported by a dedicated Galileo Control Segment (GCS) and mission functions, supported by a dedicated Galileo Mission Segment (GMS)

- The GCS handles spacecraft housekeeping and constellation maintenance while the GMS handles navigation system control

- The system is monitored in a similar way to both GPS and GLONASS but also by a new method based on spread-spectrum signals

- The tracking, telemetry and command operations are controlled by sophisticated data encryption and authentication procedures
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></td>
<td></td>
</tr>
<tr>
<td>Multipath</td>
<td>0,2 m</td>
<td>0,2 m</td>
</tr>
<tr>
<td>Tropospheric propagation delay</td>
<td>0,25 m</td>
<td>0,25 m</td>
</tr>
<tr>
<td>Receiver noise</td>
<td>0,5 m</td>
<td>0,5 m</td>
</tr>
</tbody>
</table>
• 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
  
  - 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%
062 06 01 03 – Errors and Factors affecting accuracy

• Dilution of Precision

- Arises from the geometry and number of satellites in view

- It is called the Position Dilution of Precision (PDOP)

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 and receiver clocks and orbits are due to:

- Clocks are affected by noise and drifts
- Satellites are mainly drifted out of their orbits due to solar winds, radiation pressure and gravitation effects of the sun, moon and planets
• Multipath

- When the signal arrives at the receiver via more than one path
- The signal is reflected from surfaces near the receiver

Source: Navipedia
062 06 02 00 – Ground, Satellite and Airborne based augmentation systems

GBAS
Source: Honeywell

SBAS
Source: SES

ABAS
Source: Cirrus
GROUND BASED AUGMENTATION SYSTEMS

- 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.

- 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).

- 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).

*The coverage of the GBAS station is of about 30 km*
GROUND BASED AUGMENTATION SYSTEMS

• The GBAS ground subsystems provide two services:
  - The precision approach service: provides deviation guidance for Final Approach Segments
  - The GBAS positioning service: provides horizontal position information to support RNAV operations in terminal areas
GROUND BASED AUGMENTATION SYSTEMS

• The minimum GBAS Service Volume is 15NM from the Landing Threshold Point (LTP), within 35° apart the final approach path and 10° apart between 15 and 20 NM
062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

GROUND BASED AUGMENTATION SYSTEMS

• GBAS based on GPS is sometimes called LAAS: Local Area Augmentation System

• In GBAS/LAAS:
  - Differential corrections are applied to satellite pseudo-ranges by a ground-reference station
  - GBAS systems are operated by local/regional ANSPs: therefore they are responsible for the computation of the integrity of the satellite signals over their region
  - Extra accuracy for extended coverage around airports may be improved as required
SBAS BASED AUGMENTATION SYSTEMS

• 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.

• The frequency band of the date link is identical to that of the GPS signals.

• The use of geostationary satellites enables messages to be broadcast over very wide areas.

• The pseudo-range measurements of these geostationary satellites can also be used by users as if they were GPS satellites.
SBAS BASED AUGMENTATION SYSTEMS

• SBAS systems regionally augment GPS and GLONASS by making them suitable for safety critical applications

• SBAS can provide:
  - Approach and landing operations with Vertical guidance (APV)
  - Precision approach service

• SBAS include:
  - EGNOS in Europe
  - WAAS in USA
  - MSAS in Japan
  - GAGAN in India
  - SDCM in Russia
  - SNAS in China
SBAS BASED AUGMENTATION SYSTEMS - Elements

- SBAS consists of 3 elements:
  - The ground infrastructure (network of monitoring and processing stations)
  - The SBAS satellites
  - The SBAS airborne receivers
SBAS BASED AUGMENTATION SYSTEMS

• The SBAS station network measures pseudo-range between the ranging source and an SBAS receiver at the known locations and provides separate corrections for ranging source:
  - Ephemeris errors
  - Clock errors
  - Ionospheric errors

• The user applies the previous jointly with tropospheric corrections obtained from a model for the tropospheric delay
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, GLONASS 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

• 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
AIRBORNE BASED AUGMENTATION SYSTEMS

• There are various types of ABAS:

  - The type of ABAS using only GNSS information is RAIM (Receiver Autonomous Integrity Monitoring)

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

    ▪ Typical sensors used are barometric altimeter, clock and inertial navigation system
    ▪ 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

More info in these slides
062 07 00 00
PERFORMANCE-BASED NAVIGATION
062 07 01 00 – PBN concept

- **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.

- **RNP concept** («ICAO RNP manual»)

- **PBN concept**

- **Shift from sensor-based to performance-based navigation**

ICAO Doc 9613
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

- 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.
Integrity: a measure of the trust that can be placed in the correctness of the information supplied. The parameters defining the integrity are specific to navigation specifications:

- **Alert Limit**: 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)
  
  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)

\[x_{\text{AL}}: \text{fixed value during operation}\]

\[x_{\text{PL}}: \text{value calculated by on-board receiver} \]

(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.*
062 07 01 01 – PBN principles

- **Availability**: percentage of time 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)

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

- **Continuity**: the 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 continuity of the system guarantees that once an operation (for example a final approach) is initiated, it will not be interrupted.
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.
Compared to conventional navigation, PBN (Performance-Based Navigation) relies on integrated navigation systems that use a combination of multiple sensors to determine an accurate position and provide a navigation solution. Here’s how it works:

### 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.
- 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.

### 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.
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
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 to not allow GNSS).*
For Oceanic/remote, en-route and terminal operations, PBN is limited to operations with linear lateral performance requirements and time constraints.

For Approach operations, PBN accommodates both linear and angular laterally guided operations.

a) Linear lateral performance requirements using an RNP system, e.g. RNP and RNAV specs

b) Angular lateral performance requirements using an RNP system, e.g. RNP APCH to LPV minima
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

Designation
RNP with additional requirements to be determined (e.g. 3D, 4D)

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
062 07 02 01 – RNAV and RNP

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 the aircraft can follow a pre-defined track (lateral navigation) with X Nautical Miles (NM) accuracy 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.
062 07 02 03 – Designation of RNP and RNAV specifications

• 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.

• Similarly, 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/</td>
<td>Basic RNP 1, RNP</td>
</tr>
<tr>
<td>Terminal/Approach</td>
<td>APCH, RNP (AR)</td>
</tr>
<tr>
<td></td>
<td>APCH</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th><strong>RNAV 10</strong></th>
<th><strong>RNP 4</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Oceanic / remote phases of flight</td>
<td>• Oceanic / remote phases of flight</td>
</tr>
<tr>
<td>• Without on-board performance monitoring and alerting function, even when operationally approved as “RNP 10”</td>
<td>• With on-board performance monitoring and alerting function (usually RAIM)</td>
</tr>
<tr>
<td>• Lateral TSE must be within ±10 NM for at least 95 per cent of the total flight time</td>
<td>• Lateral TSE must be within ±4 NM for at least 95 per cent of the total flight time</td>
</tr>
<tr>
<td>• 50NM lateral and 50NM longitudinal separation</td>
<td>• 30 NM lateral and 30 NM longitudinal separation</td>
</tr>
<tr>
<td>• Based on INS, IRS FMS or GNSS</td>
<td>• Primarily based on GNSS</td>
</tr>
</tbody>
</table>
RNAV 5*

- 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

#### RNAV 2

- 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

- Oceanic, continental, en-route and airspaces considered to be remote
- 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
062 07 02 03 – 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>• Arrival and departure phases of flight</td>
<td>• 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**

- 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**

- 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

- 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 per cent of the total flight time

- Primarily for helicopters

- Based GNSS
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.
• PBN is one of several enablers of an **airspace concept**

• Communications, ATS surveillance and Air Traffic Management are also essential elements of an airspace concept
• The determination of separation minima and route spacing* for use by aircraft is a major element of airspace planning

  ▪ Manual on Airspace Planning Methodology for the Determination of separation Minima (Doc 9689)
  ▪ Manual on the Use of Performance-Based Navigation (PBN) in Airspace Design (Doc 9992)

• Separation minima and route spacing can generally be described as being a function of three factors:

  Navigation performance  
  Aircraft’s exposure to risk
  Mitigation measures which are available to reduce risk

The complexity of determining route spacing and separation minima is affected by the availability of a radar surveillance service and the type of communications used.

If an ATS surveillance service is available, this means that the risk can be mitigated by including requirements for ATC intervention.

* aircraft-to-aircraft separation and ATS route spacing are not the same
062 07 03 02 – Approval

- The **airworthiness approval** process assures that each item of the area navigation equipment installed is of a type and design appropriate to its intended function and that the installation functions properly under foreseeable operating conditions.

- Accuracy, integrity, continuity, functional requirements, on-board performance monitoring and alerting, navigation database, path terminators...

- It also details:
  - Limitations
  - Other relevant information

*Any information relevant to the approval of the RNAV and RNP system installations are documented in the AFM, or AFM Supplement, as applicable.*
Some PBN specifications require (and will require) operational approval, including:


- **RNP AR APCH**, as detailed in AMC 20-26

- **Advanced RNP**: to be developed

The RNAV system shall enable the crew to navigate in accordance with operational criteria as defined in the Navigation Specification.

- **The State of the Operator is the authority responsible** for approving flight operations
062 07 03 03 – Specific RNAV and RNP system functions

• The standard that fixes database formats and contents is the ARINC 424 ‘Navigation System Data Base Standard’

• Area Navigation (RNAV) involves flying between waypoints not coinciding with ground fixes

• Waypoints coordinates are hence 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*
ARINC 424 also defines the Path Terminator: permits defining how to navigate to, from and between waypoints.

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

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

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

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

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

## Course from a fix to an altitude (FA)
- Begins at a fix and terminates when aircraft altitude is at, or above, a specified altitude
There are two types of **FIXED RADIUS PATHS**

- **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*

- **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*
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)*
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.
• All RNAV and RNP applications use aeronautical data to define, inter alia, ground-based NAVAIDs, runways, gates, waypoints and the route/procedure to be flown

• The safety of the application is contingent upon the accuracy, resolution and integrity of the data

• Therefore:
  
  ▪ The *accuracy of the data depends upon the processes applied during the data origination*
  
  ▪ The *integrity of the data depends upon the entire aeronautical data chain from the point of origin to the point of use*

The European Commission adopted on 26 January 2010 the Regulation 73/2010 laying down requirements on the quality of aeronautical data and aeronautical information for the single European sky.

More information available at [https://www.eurocontrol.int/adq](https://www.eurocontrol.int/adq)
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:

- *The operator’s infrastructure for conducting PBN operations and flight crew operating procedures, training and competency demonstrations*

- *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)**.

- **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.

- **Flight Technical Error (FTE)**: relates to the air crew or autopilot’s ability to follow the defined path or track.

- **Navigation System Error (NSE)**: refers to the difference between the aircraft’s estimated position and actual position.

**With GPS/SBAS, you can expect:** $\text{NSE} \ll \text{FTE}$
• This function allows the air crew to detect whether or not the RNP system satisfies the navigation performance required in the navigation specification

  - Relates to both lateral and longitudinal navigation performance

• 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
• RAIM (Receiver Autonomous Integrity Monitoring) - a form of ABAS
  
  ▪ 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
  
  ▪ To solve this, GPS receivers have an autonomous way of assuring the integrity of GPS pseudo-ranges: the RAIM algorithm
  
  ▪ GPS receivers require a minimum set of 4 satellites to compute a 3D position
  
  ▪ With additional satellites, the “RAIM algorithm” comes into play
    
    o A 5th satellite provides **Fault Detection (FD)** capability: the receiver recognises a faulty satellite, but is not able to identify which one in particular
    
    o A 6th satellite provides **Fault Detection and Exclusion (FDE)** capability: the receiver is able to isolate the faulty satellite
• RAIM (Receiver Autonomous Integrity Monitoring) - a form of ABAS
  - *RAIM prediction is required before conducting a flight which will use a GPS approach*
    - This prediction can be used using the GPS receiver or with an internet-based RAIM prediction tool
  - *During flight, the receiver’s RAIM (FD or FDE) algorithm monitors the position*
    - Approach will be discontinued if fault detection detects a position failure when integrity is provided by FDE
  - *LPV is based on SBAS integrity; if RAIM is unavailable the approach can be performed anyway*
### On-board performance monitoring and alerting

<table>
<thead>
<tr>
<th>Feature</th>
<th>RNAV specification</th>
<th>RNP specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RNP X specification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>not requiring RF or FRT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RNP X specification</td>
</tr>
<tr>
<td></td>
<td></td>
<td>requiring RF or FRT</td>
</tr>
<tr>
<td>NSE (monitoring and alerting)</td>
<td>Requires no alerting on position error or pilot cross-check of NSE.</td>
<td>Alerting on position accuracy and integrity.</td>
</tr>
<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;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TSE distribution bounded; no extra protection needed if turns defined by RF or FRT.</td>
</tr>
</tbody>
</table>

**Example:** RAIM or FDE algorithm

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

**On board performance monitoring and alerting of FTE is managed by on-board systems or crew procedures**

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

**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 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.
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.

- Therefore, the on-board navigation data must be valid for the current AIRAC cycle and must include the appropriate flight procedures.

- 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
**RNP APCH**

**WITHOUT VERTICAL GUIDANCE**
- LNAV
- LP

**GPS NPA**
- Expected to be flown with CDFA

**NPA SBAS supported**
- Localiser Performance

**WITH VERTICAL GUIDANCE**
- LNAV/VNAV
- LPV

**APV Baro**
- (can also be supported by SBAS)

**APV SBAS supported**
- Localiser Performance with Vertical Guidance

**2D approach operations**

**3D approach operations**
062 07 05 05 – RNP APCH

• 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
  ▪ Angular lateral guidance based on GNSS augmented by SBAS
  ▪ Expected to be flown using CDFA technique
  ▪ Integrity provided by SBAS
  ▪ Not published at runways with LPV minima

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

- LNAV/VNAV minima
  - Approach with Vertical guidance (APV)
  - 3D operation
  - Linear lateral guidance based on GNSS
  - Linear vertical guidance based on BaroVNAV (can also be supported by SBAS and, 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.
• **LNAV/VNAV minima**

Considerations about the use of the **Barometric sensor**

- **Affected by temperature variation** → LNAV/VNAV based on BaroVNAV 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 safely conduct LNAV/VNAV based on BaroVNAV, remote altimeter setting is prohibited.

Cold temperatures reduce the VPA.

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

Procedure not flyable if “Temp” < “Min Promulgated Temp”
• LPV minima
  - Approach with Vertical guidance (APV)
  - 3D operation
  - Angular lateral and vertical guidance based on GNSS augmented by SBAS
  - Integrity provided by SBAS
  - **LPV Final Approach Segment is specially coded into a Data Block** inside the on-board navigation database. It is known as the FAS DB
• **LPV minima 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 APV SBAS procedure:**
    o The FAS-DB contain the parameters that define the Final Approach Segment **geometry**
    o The integrity of the data in ensured by the generation of a **CRC algorithm** (Cyclic redundancy check)

  ▪ **References:**
    o ICAO Doc 8168: procedure design criteria
    o ICAO Annex 10: Aeronautical Telecommunications
    o RTCA Do-229: Approval of GPS/SBAS Rx equipment

---

**SBAS FAS Data Block Coding Table**

<table>
<thead>
<tr>
<th>Graz RNAV (GPS) RWY 35</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Input Data Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Type</td>
<td>0</td>
</tr>
<tr>
<td>SBAS Provider</td>
<td>1</td>
</tr>
<tr>
<td>Airport Identifier</td>
<td>LOWG</td>
</tr>
<tr>
<td>Runway</td>
<td>35</td>
</tr>
<tr>
<td>Runway Direction</td>
<td>2</td>
</tr>
<tr>
<td>Approach Performance Designator</td>
<td>0</td>
</tr>
<tr>
<td>Route Indicator</td>
<td>0</td>
</tr>
<tr>
<td>Reference Path Data Selector</td>
<td>0</td>
</tr>
<tr>
<td>Reference Path Identifier</td>
<td>E35A</td>
</tr>
<tr>
<td>LTP/FTP Latitude</td>
<td>465840,0300N</td>
</tr>
<tr>
<td>LTP/FTP Longitude</td>
<td>0152635,8100E</td>
</tr>
<tr>
<td>LTP/FTP Ellipsoidal Height (metres)</td>
<td>378,5</td>
</tr>
<tr>
<td>FPA Latitude</td>
<td>470604,1468N</td>
</tr>
<tr>
<td>Delta FPA Latitude (seconds)</td>
<td>94,1160</td>
</tr>
<tr>
<td>FPA Longitude</td>
<td>0132609,9025E</td>
</tr>
<tr>
<td>Delta FPA Longitude (seconds)</td>
<td>-25,8075</td>
</tr>
<tr>
<td>Threshold Crossing Height</td>
<td>53.0</td>
</tr>
<tr>
<td>TCM Units Selector</td>
<td>0</td>
</tr>
<tr>
<td>Glidepath Angle (degrees)</td>
<td>3.10</td>
</tr>
<tr>
<td>Course Width (metres)</td>
<td>107.00</td>
</tr>
<tr>
<td>Length Offset (metres)</td>
<td>224</td>
</tr>
<tr>
<td>HAL (metres)</td>
<td>40.0</td>
</tr>
<tr>
<td>VAL (metres)</td>
<td>50.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output Data Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Block</td>
<td>10 07 17 0F 0C A3 00 00 01 35 55 05 3C 22 29 14 44 A6 A0 06 C9 22 48 br 02 95 35 ff 12 02 36 01 6C 1C C8 FA A9 39 5C AF</td>
</tr>
<tr>
<td>Calculated CRC Value</td>
<td>AE3B5C5F</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICAO Code</td>
<td>LO</td>
</tr>
<tr>
<td>LTP/FTP Orthometric Height (metres)</td>
<td>331.5</td>
</tr>
<tr>
<td>FPA Orthometric Height (metres)</td>
<td>331.5</td>
</tr>
</tbody>
</table>

Source: Austrocontrol
• LPV minima FAS DB: why?
  
  ▪ To ensure the *integrity of databases*
  
  ▪ In ILS/MLS approaches, integrity is ensured by:
    
    o Proper alignment of transmitting antennas
    o Flight checks
    o Integrity monitors on the transmitted signal
  
  ▪ LPV approaches:
    
    o A kind of approach based on on-board data
    o Integrity rests on the data describing the approach path
    o Hence the importance of having a *CRC wrapping the FAS DB*
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)
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.

Sometimes may be preceded by an initial and intermediate RNAV 1 approach (generally preceded by a RNAV 1 STAR) or by radar guidance.
90 degree turn

70 degree turn

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

All segments: 5NM optimum length

(source: ICAO)
An RNP APCH shall not be flown unless it is retrievable by procedure name from the on-board navigation database and conforms to the charted procedure.
• 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

Source: Austrocontrol
062 07 05 05– PBN Point in Space (PinS) Approach

• 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)

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

• **Proceed 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 05– PBN Point in Space (PinS) Approach

COPTER RNAV (GNSS) 079
INTERLAKEN HOSPITAL
L5IK
Interlaken Switzerland

Missed Approach:
Climbing left turn direct to ECEKU. Maintain VMC.

Restricted to REGA Flight Trials Only under VMC

WAYPOINTS FOR FLIGHT:
AKUVE: 46-40.4452 / 06
BURBE: 46-39.8183 / 06
CABGI: 46-41.3167 / 06
DACAG: 46-43.0356 / 06
HPP: 46-40.8828 / 06
ECEKU: 46-43.9008 / 06

EGNOS
EGNOS, it's there. Use it.
Bibliography

- EASA NPA 2013-25
- ICAO State Letter SP 65/4-13/24, 14 June 2013
- 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
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.