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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

European Global Navigation Satellite Systems Agency

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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

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Target audience

Text extracted and adapted from ICAO PBN Manual (Doc 9613)

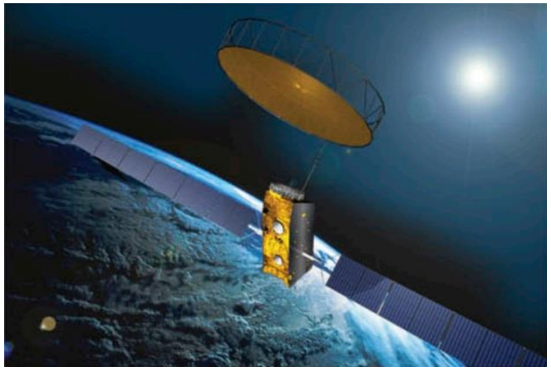
- **Commercial operators** must have a training programme addressing the operational practices, procedures and training items related to RNP APCH
  - *Operators need not establish a separate training programme if they already integrate RNAV training as an element of their training programme. However, 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)

List of acronyms

ABAS	Airborne Based Augmentation System	FTE	Flight Technical Error	LP	Localiser Performance	RDH	Reference Datum Height
AAIM	Aircraft Autonomous Integrity Monitoring	GAGAN	GPS Aided Geo Augmented Navigation	LPV	Localiser Performance with Vercial Guidance	RNAV	Area Navigation
AIRAC	Aeronautical Information Regulation And Control	GBAS	Ground Based Augmentation System	LTP	Landing Threshold Point	RNP	Required Navigation Performance
AMC	Acceptable Means of Compliance	GCS	Galileo Control Segment	MEL	Minimum Equipment List	SBAS	Satellite Based Augmentation System
ANSP	Air Navigation Service Provider	GLONASS	Global Navigation Satellite System	MEO	Medium Earth Orbit	SDCM	System for Differential Corrections and Monitoring
APV	Approach with Vertical Guidance	GMS	Ground Mission Segment	MLS	Microwave Landing System	SNAS	Satellite Navigation Augmentation System
ATS	Air Traffic Services	GNSS	Global Navigation Satellite System	MSAS	Multi-functional Satellite Augmentation System	SPS	Standard Positioning Service
CDFA	Continuous Descent Final Approach	GPS	Global Positioning System	NDB	Non-Directional Beacon	TAWS	Terrain Awareness Warning System
CRC	Cyclic Redundancy Check	GSA	European GNSS Agency	NM	Nautical Mile	TK	Theoretical Knowledge
DME	Distance Measuring Equipment	HAL	Horizontal Alert Limit	NSE	Navigation System Error	TTFF	Time To First Fix
DOP	Dillution Of Precision	ICAO	International Civil Aviation Organisation	OM	Operations Manual	UHF	Ultra High Frequency
EGNOS	European Geostationary Navigation Overlay Service	ILS	Instrument Landing System	PBN	Performance Based Navigation	UTC	Universal Time Coordinated
ESSP	European Satellite Services Provider	IRS	Inertial Reference System	PDE	Path Definition Error	VAL	Vertical Alert Limit
FAF	Final Approach Fix	IRU	Inertial Reference Unit	PinS	Point in Space	VDB	VHF Data Broadcast
FAP	Final Approach Point	LAAS	Local Area Augmentation System	PL	Protection Level	VHF	Very High Frequency
FAS DB	Final Approach Segment Data Block	LNAV	Lateral Navigation	PPS	Precise Positioning Service	VOR	VHF Omnidirectional Range
FD	Fault Detection	LNAV/VNAV	Lateral Navigation / Vertical Navigation	PRN	Pseudo-Range Noise	VPA	Vertical Path Angle
FDE	Fault Detection and Exclusion	LO	Learning Objective	RAIM	Receiver Autonomous Integrity Monitoring	WAAS	Wide Area Augmentation System

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

062 07 00 00	PBN
062 07 01 00	PBN concept
062 07 01 01	PBN principles
062 07 01 02	PBN components
062 07 01 03	PBN Scope
062 07 02 00	Navigation Specifications
062 07 02 01	RNAV and RNP
062 07 02 02	Navigation functional requirements
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062 07 03 00	Use of PBN
062 07 03 01	Airspace Planning
062 07 03 02	Approval
062 07 03 03	Specific RNAV and RNP system functions
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062 07 00 00	PBN
062 07 04 00	PBN operations
062 07 04 01	PBN principles
062 07 04 02	On-board performance monitoring and alerting
062 07 04 03	Abnormal situations
062 07 04 04	Database management
062 07 05 00	Requirements of specific RNAV and RNP specifications
062 07 05 05	RNP APCH
062 07 05 06	RNP AR APCH
062 07 05 09	PBN Point In Space (PinS) Approach

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062 06 00 00
GLOBAL NAVIGATION SATELLITE SYSTEMS

062 06 01 00 – GPS / GLONASS /GALILEO

CB-IR(A), EIR

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

062 06 01 02 – Operation

NAVSTAR GPS | GLONASS | GALILEO

CB-IR(A), EIR

- 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

062 06 01 02 – Operation

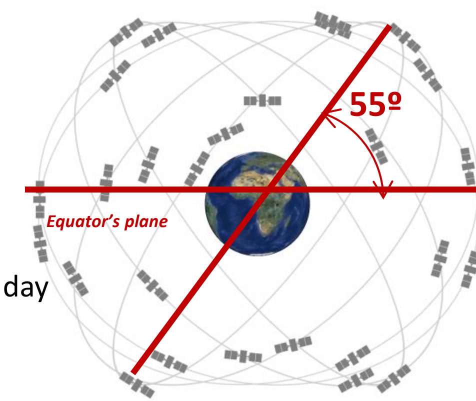
NAVSTAR GPS | GLONASS | GALILEO

SPACE SEGMENT - constellation

GPS-III-A satellite (source: United States Government)

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

- Orbit characteristics:
  - Inclination of 55º 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



GPS constellation (source: adapted rom United States Government)

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NAVSTAR GPS | GLONASS | GALILEO

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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

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NAVSTAR GPS | GLONASS | GALILEO

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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

062 06 01 02 – Operation

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

062 06 01 02 – Operation

NAVSTAR GPS | GLONASS | GALILEO

SPACE SEGMENT - signals and services

- Two codes are transmitted on the L1 frequency

Code	Used by	
C/A	SPS (civil)	PPS
P (precision)		PPS

- The C/A code is a pseudo random noise (PRN) code sequence

GPS status page showing PRN-identified satellites
(source: http://theflyingengineer.com/)

  - 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

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NAVSTAR GPS GLONASS GALILEO

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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

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NAVSTAR GPS | GLONASS | GALILEO

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:

Source: United States Government

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NAVSTAR GPS | GLONASS | GALILEO

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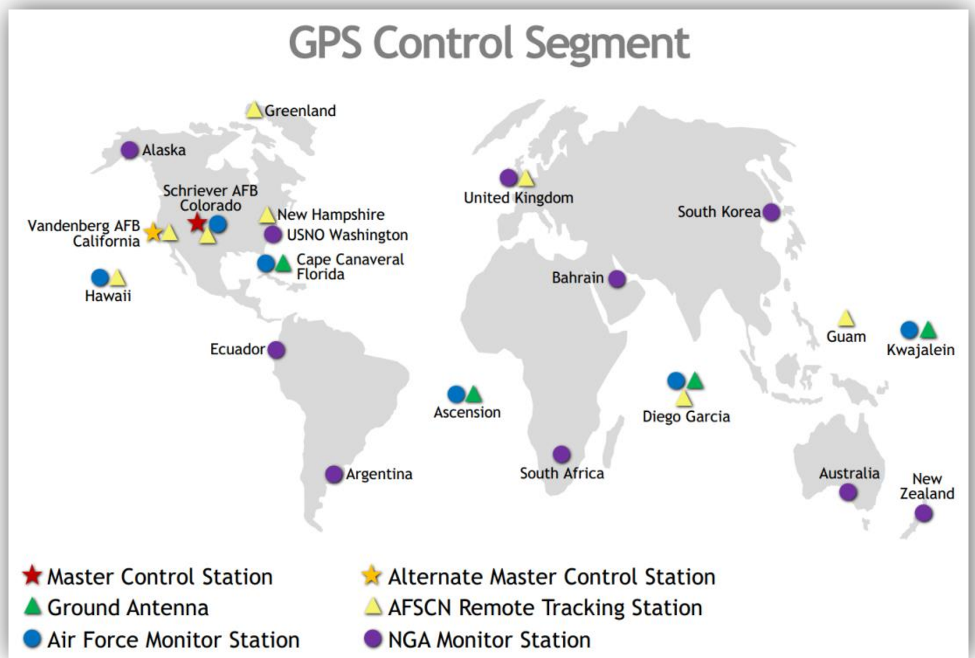
CONTROL SEGMENT

- 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

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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

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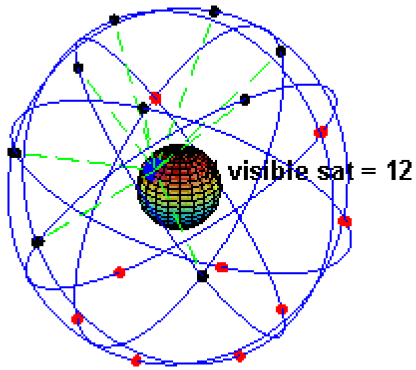
USER SEGMENT

- 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

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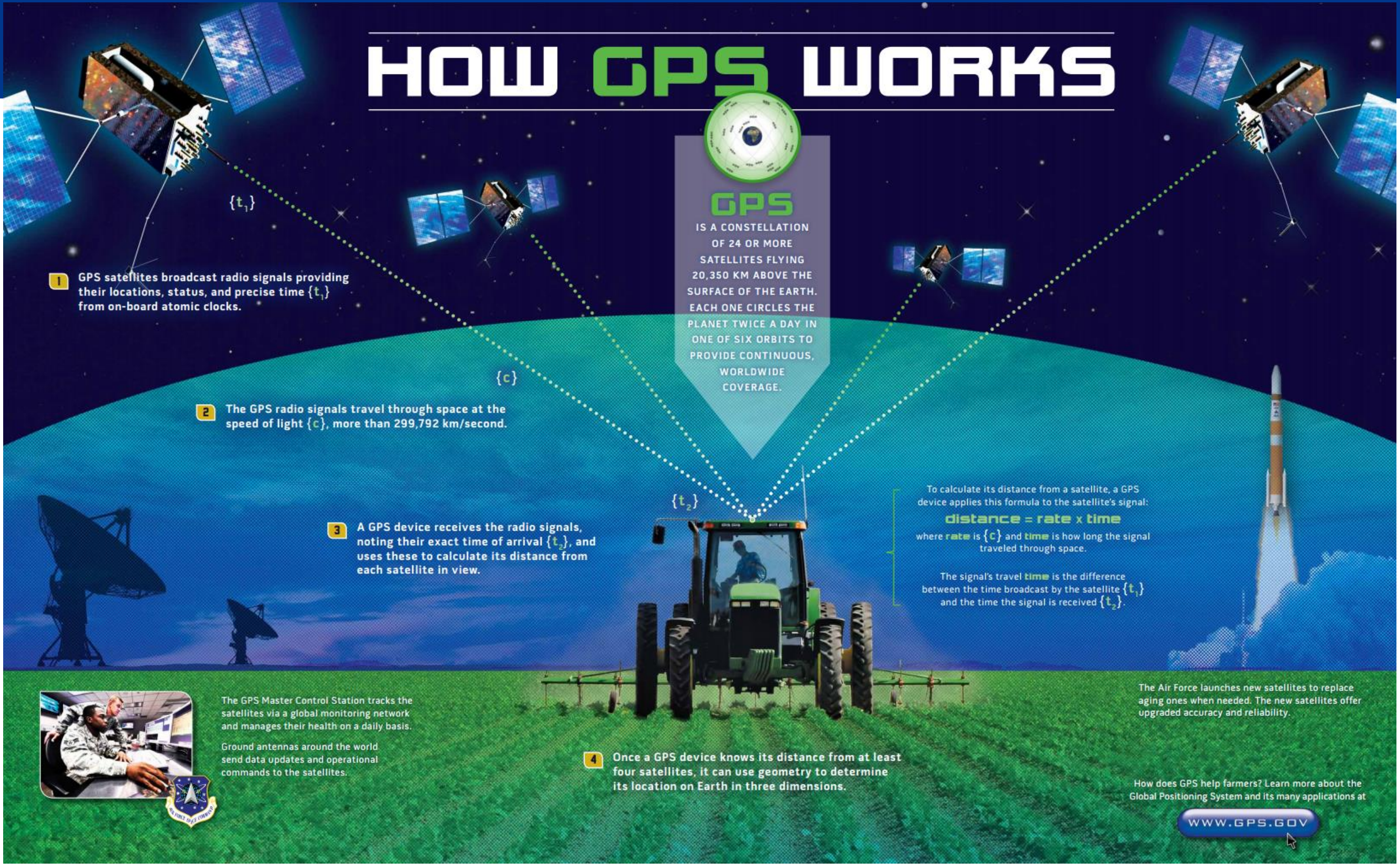
NAVSTAR GPS Integrity

More info in these slides

- **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 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

SUMMARY



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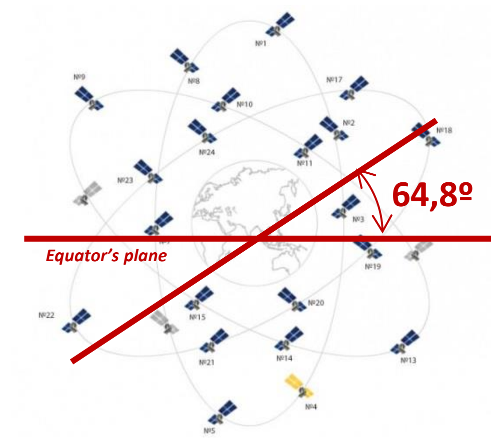
SPACE SEGMENT - constellation

- 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 19100 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/)

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NAVSTAR GPS | GLONASS | GALILEO

- 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

NAVSTAR GPS | GLONASS | GALILEO

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

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NAVSTAR GPS | **GLONASS** | GALILEO

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

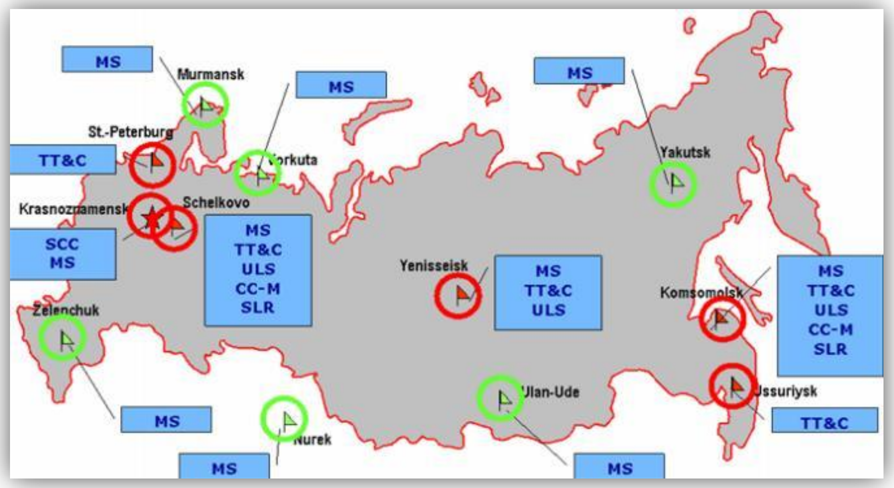
062 06 01 02 – Operation

NAVSTAR GPS | GLONASS | GALILEO

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

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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

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NAVSTAR GPS | GLONASS | GALILEO

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

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NAVSTAR GPS | GLONASS | GALILEO

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.

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NAVSTAR GPS | GLONASS | GALILEO

- 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

Source: ESA

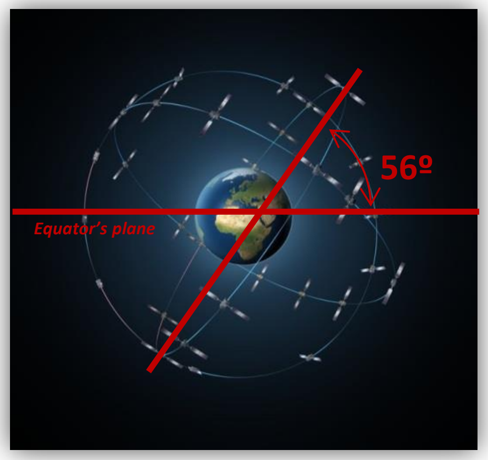
062 06 01 02 – Operation

NAVSTAR GPS
GLONASS
GALILEO

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

Galileo Full Operational Capability (FOC) satellite (source: ESA)



30-satellite Galileo constellation (source: ESA)

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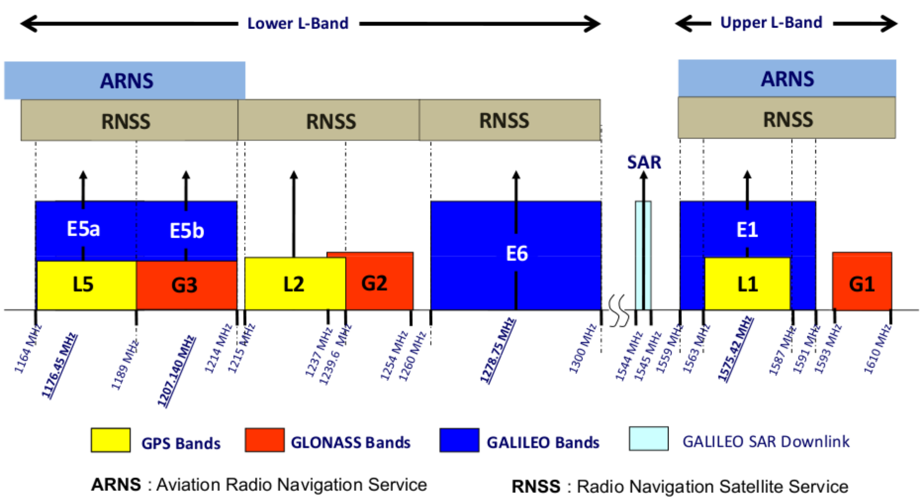
GALILEO

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:



GPS, GLONASS and Galileo navigational frequency bands (source: Navipedia)

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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**

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GALILEO

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

062 06 01 02 – Operation

NAVSTAR GPS | GLONASS | GALILEO

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

062 06 01 03 – Errors and Factors affecting accuracy

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- The most significant factors affecting accuracy of GNSS positioning are:

	GPS	GPS + SBAS
- Ionospheric propagation delay (IPD)	2 m	0,3 m
- Dilution of position (horizontal)	1,1 m	1,1 m
- Satellite clock errors - Satellite orbital variations	1 m	0,5 m
- Multipath	0,2 m	0,2 m
- Tropospheric propagation delay	0,25 m	0,25 m
- Receiver noise	0,5 m	0,5 m

062 06 01 03 – Errors and Factors affecting accuracy

- Ionospheric propagation delay (IPD)

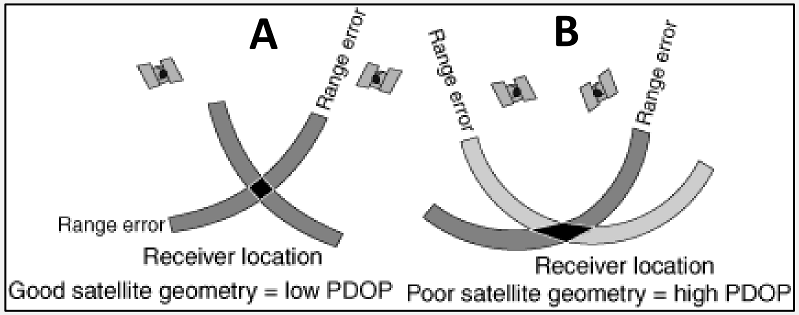
  - The IPD constitutes the most significant error, it can achieve several tens of meters

  - 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

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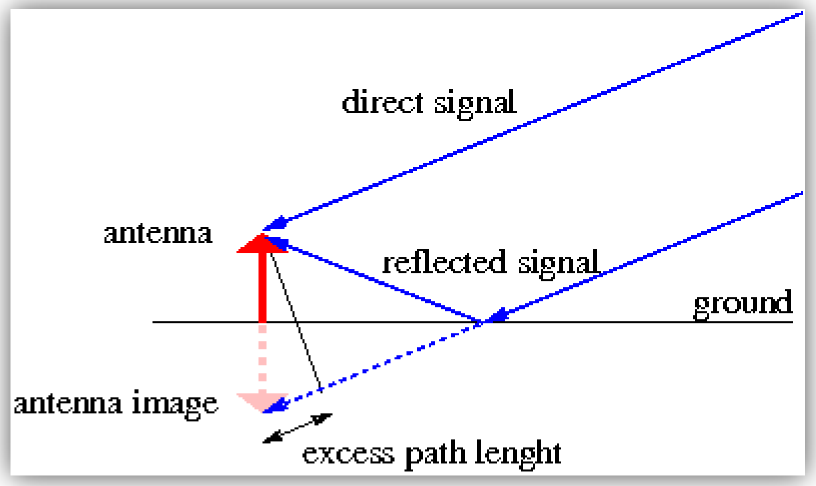
062 06 01 03 – Errors and Factors affecting accuracy

- 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

062 06 01 03 – Errors and Factors affecting accuracy

- 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

CB-IR(A), EIR

GBAS

SBAS

ABAS

Source: Honeywell

Source: SES

Source: Cirrus

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062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

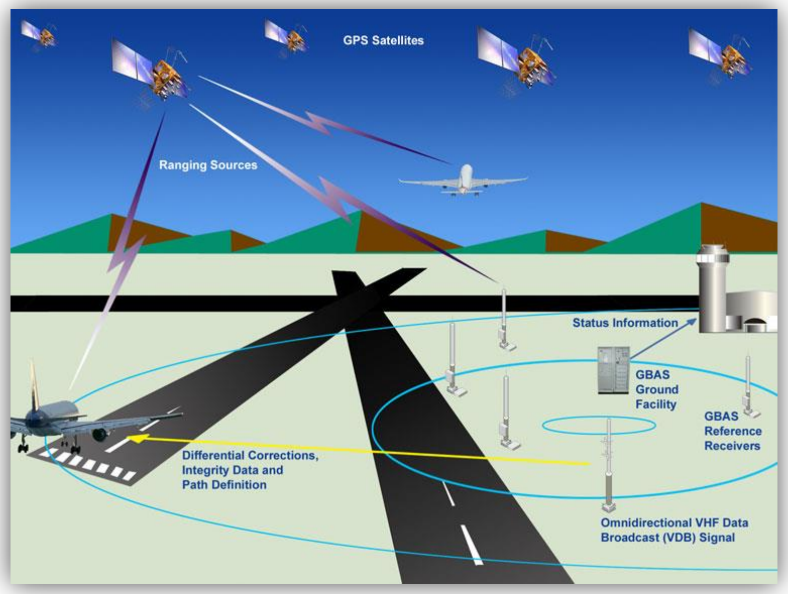
GBAS SBAS ABAS

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)



Source: FAA

The coverage of the GBAS station is of about 30 km

062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

GBAS | SBAS | ABAS

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

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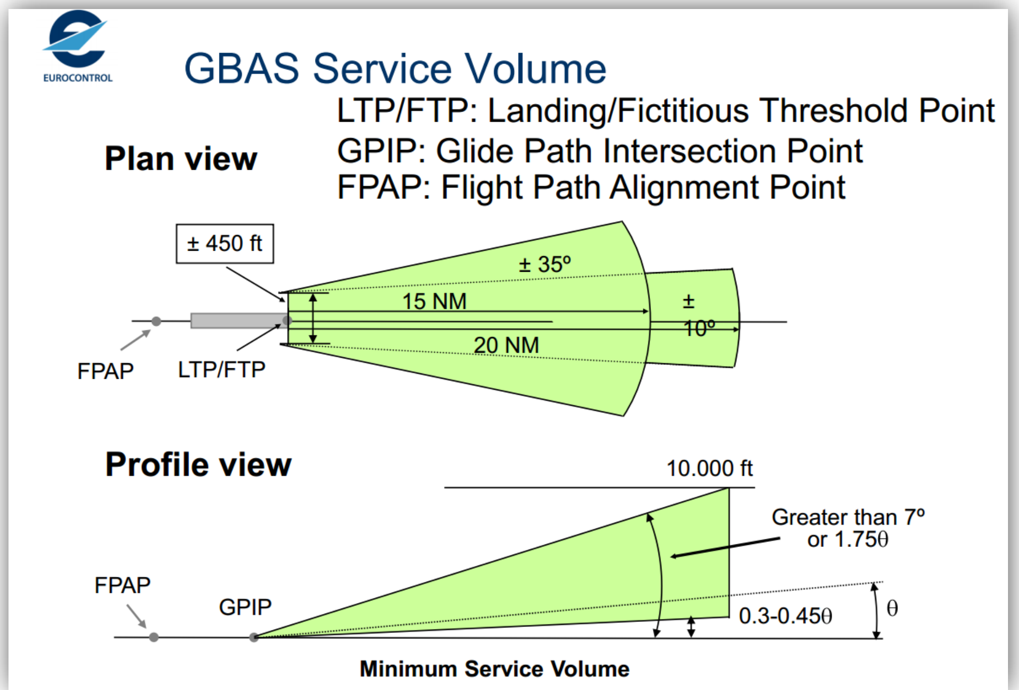
062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

GBAS SBAS ABAS

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



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062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

GBAS SBAS ABAS

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

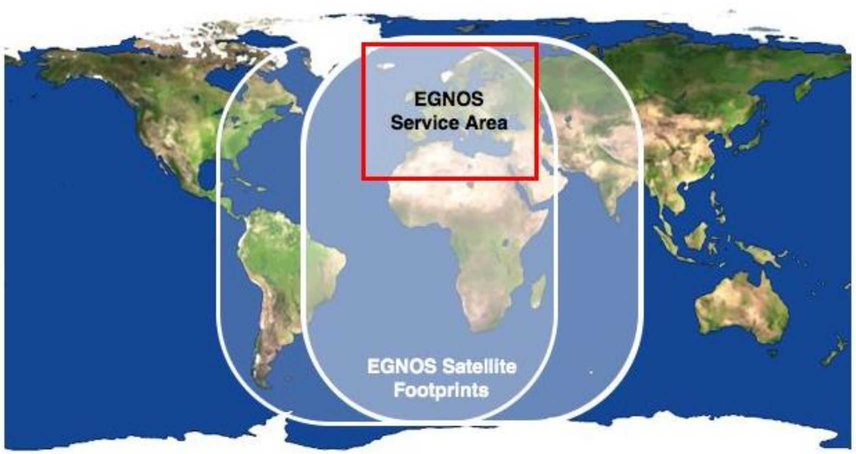
062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

GBAS | SBAS | ABAS

CB-IR(A), EIR

SBAS BASED AUGMENTATION SYSTEMS

Note the difference in the below image between the GEOs coverage area (footprints) and the Service Area



EGNOS GEO footprints

- 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

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062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

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 is China

062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

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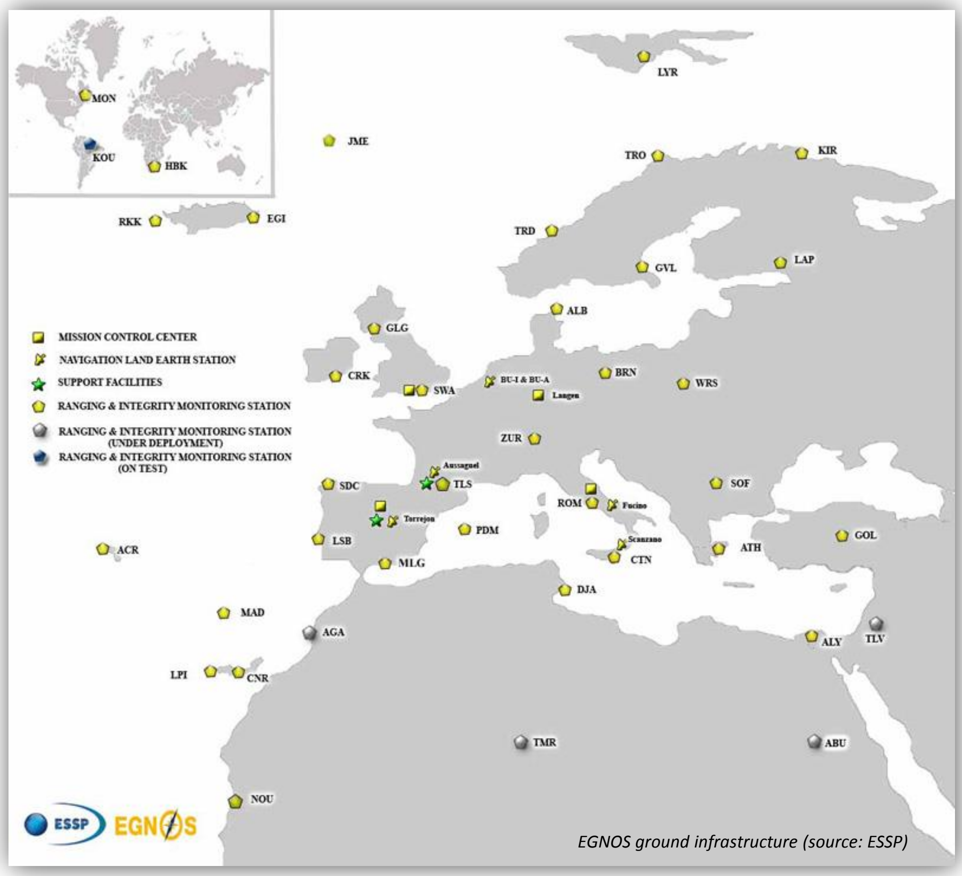
GBAS | SBAS | ABAS

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



EGNOS ground infrastructure (source: ESSP)

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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

062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

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GBAS | SBAS | ABAS

EGNOS

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- 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

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GBAS | SBAS | ABAS

EGNOS - benefits

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- 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

062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

GBAS SBAS ABAS

CB-IR(A), EIR

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

062 06 02 02 – Ground, Satellite and Airborne based augmentation systems

AIRBORNE BASED AUGMENTATION SYSTEMS

- There are various types of ABAS:
  - The type of ABAS using only GNSS information is RAIM (Receiver Autonomous Integrity Monitoring)

More info in these slides

  - The type of ABAS using addition 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

CB-IR(A), EIR

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

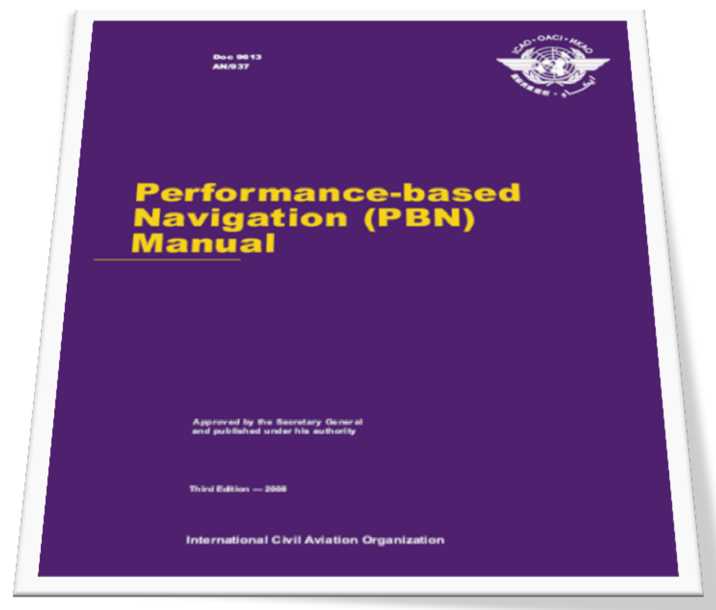
~~RNP concept (« ICAO RNP manual)~~

↓

PBN concept →

↓

Shift from sensor-based to performance-based navigation



ICAO Doc 9613

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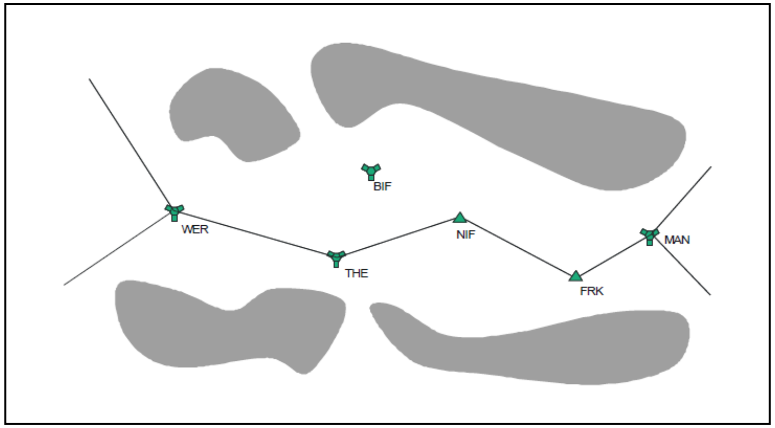
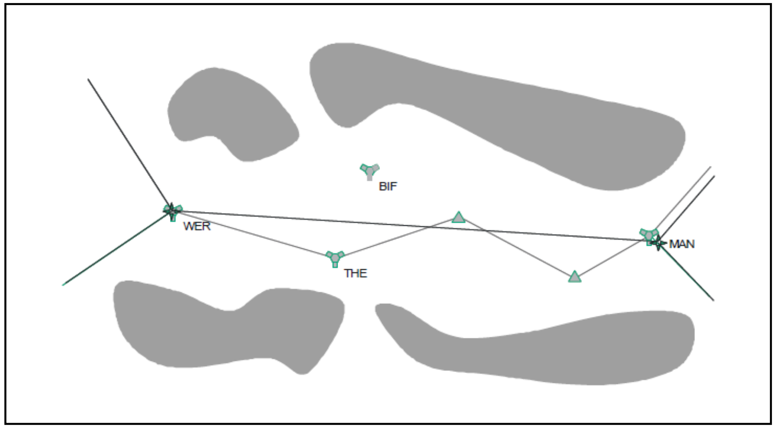
062 07 01 00 – PBN concept

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

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062 07 01 01 – PBN principles

- 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

062 07 01 01 – PBN principles

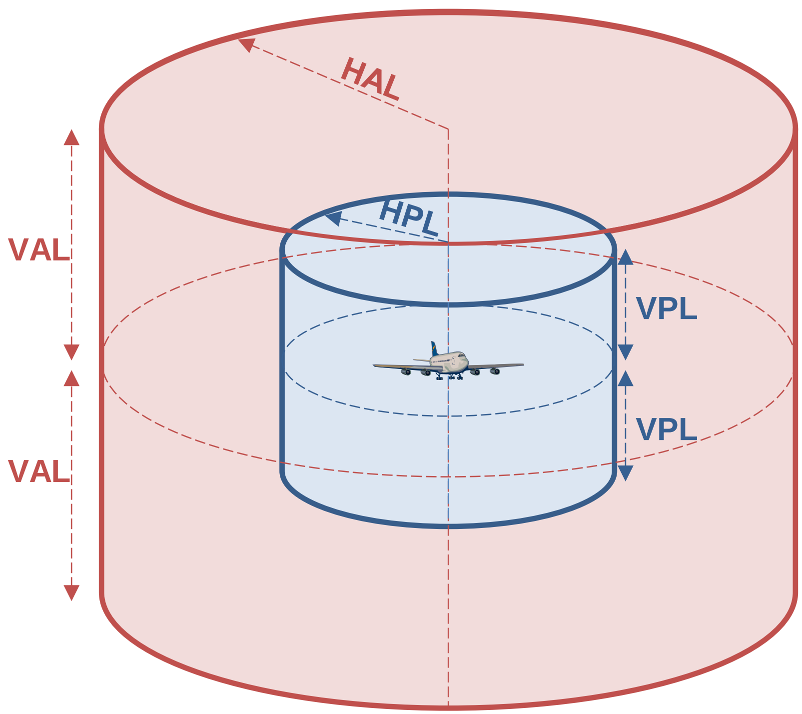
- **Integrity**: a measure of the trust that can be placed in the correctness of the information supplied. The parameters defining the integrity are specific to navigation specifications:
  - **Alert Limit:** the error tolerance not to be exceeded without issuing an alert
    - Means the region (horizontal 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

062 07 01 01 – PBN principles

- **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)



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.

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.

062 07 01 01 – PBN principles

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

Navigation specifications Specify →

- **Performance requirements (PR)**
- **Navigation sensors meeting them**

A certain set of PRs may be met by more than one sensor.

- 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.

062 07 01 01 – PBN principles

Computed vs raw data

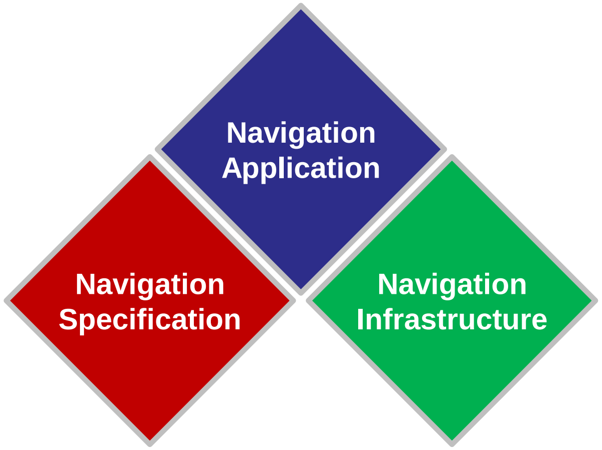
Conventional navigation

- 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



Adapted from Eurocontrol

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

062 07 01 02 – PBN components

EXAMPLE – RNAV 1

Navigation Specification

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

Navigation Infrastructure

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

Navigation Application

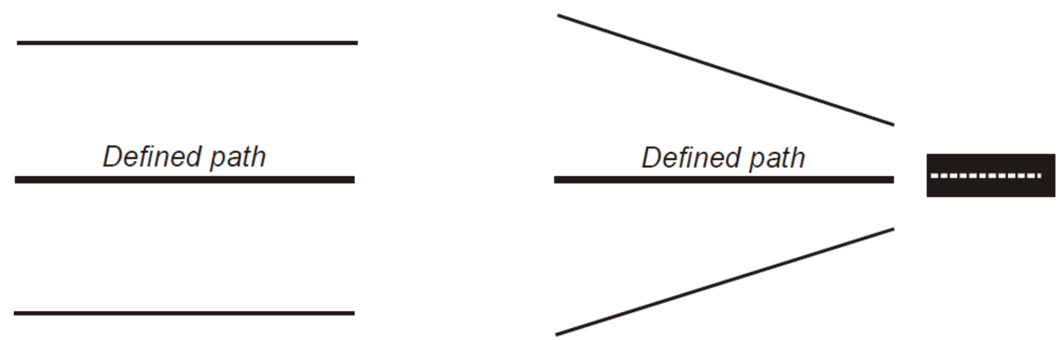
- RNAV 1 can support en-route and terminal **navigation applications**, like SIDs or STARs

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).

062 07 01 03 – PBN scope

- 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

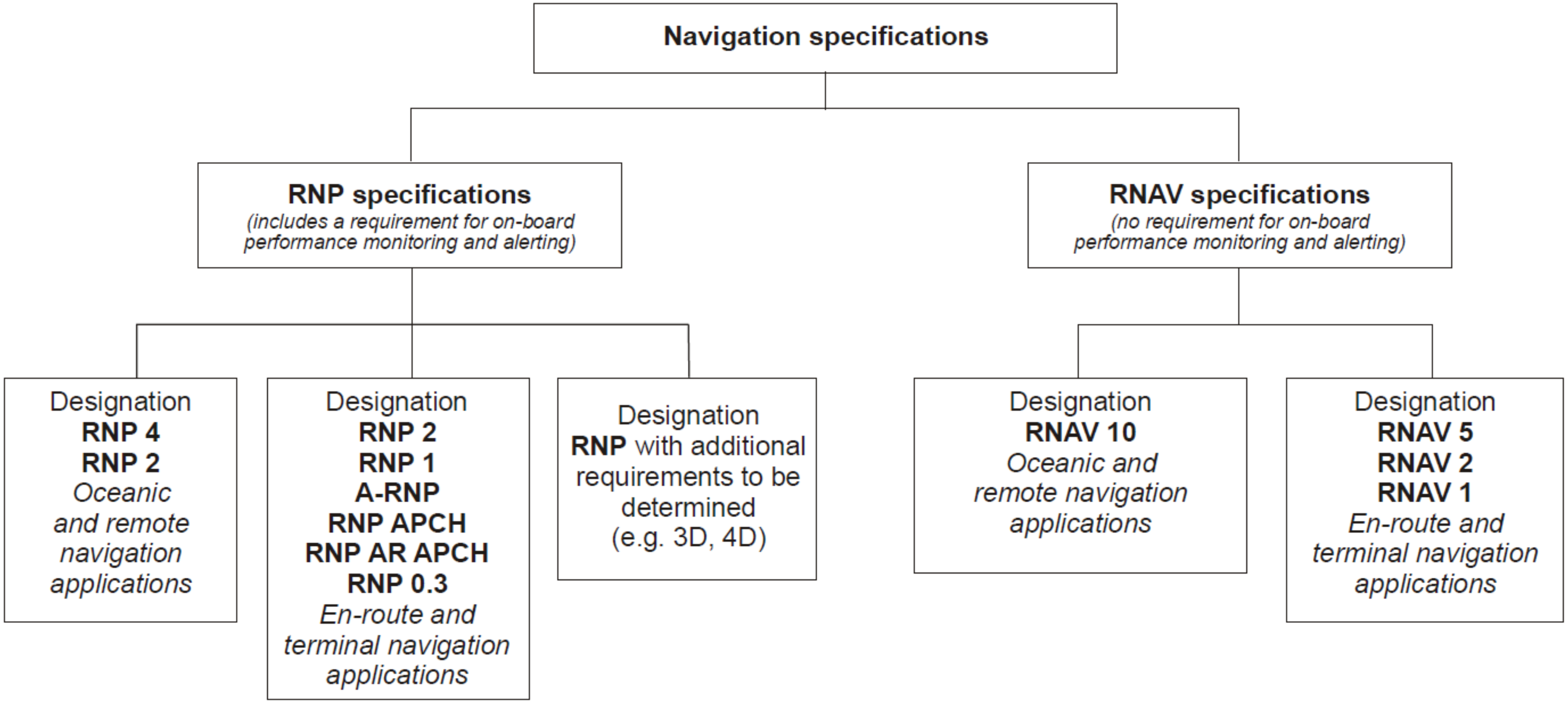


a) Linear lateral performance requirements using an RNP system, e.g. RNP and RNAV specs

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

Image from ICAO

062 07 02 00 – Navigation specifications



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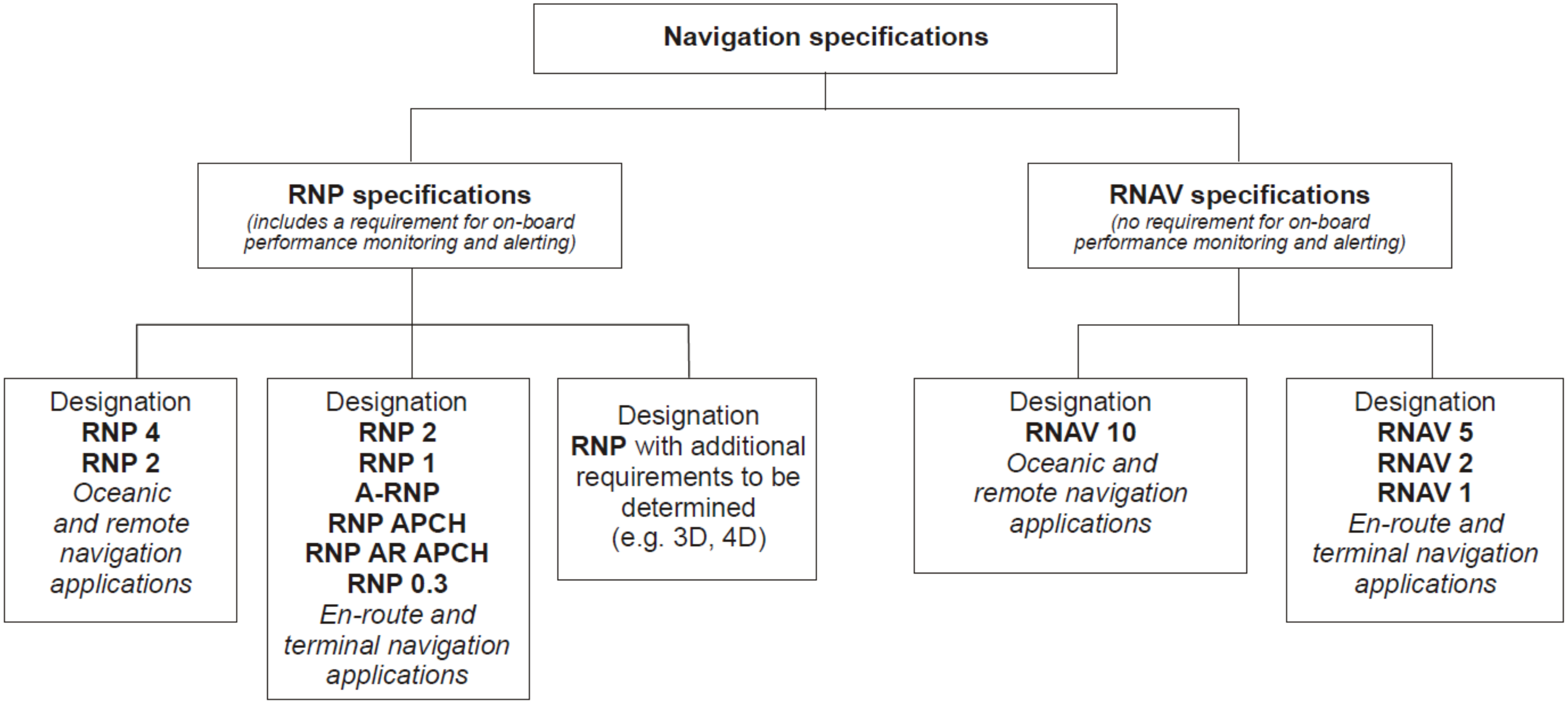
062 07 02 01 – RNAV and RNP



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.

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062 07 02 02 – Navigation functional requirements

- 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;

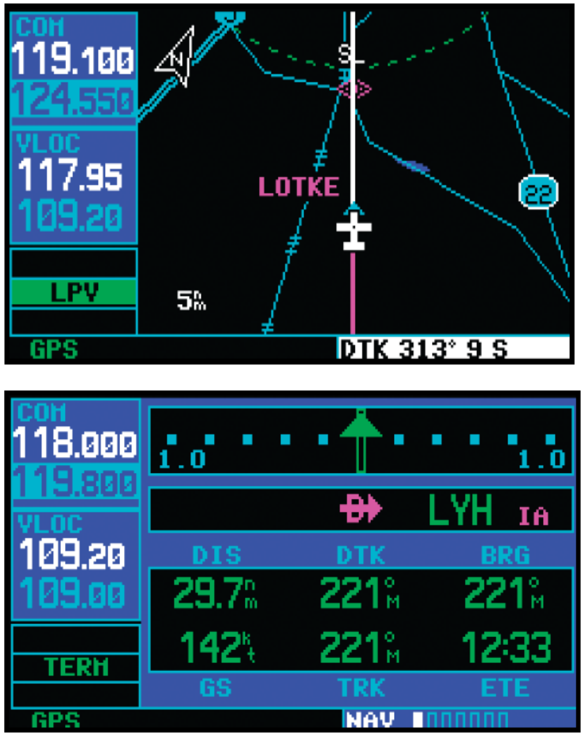
  b) display of **distance and bearing to the active** (To) waypoint;

  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.

Example: Garmin GNS 430W



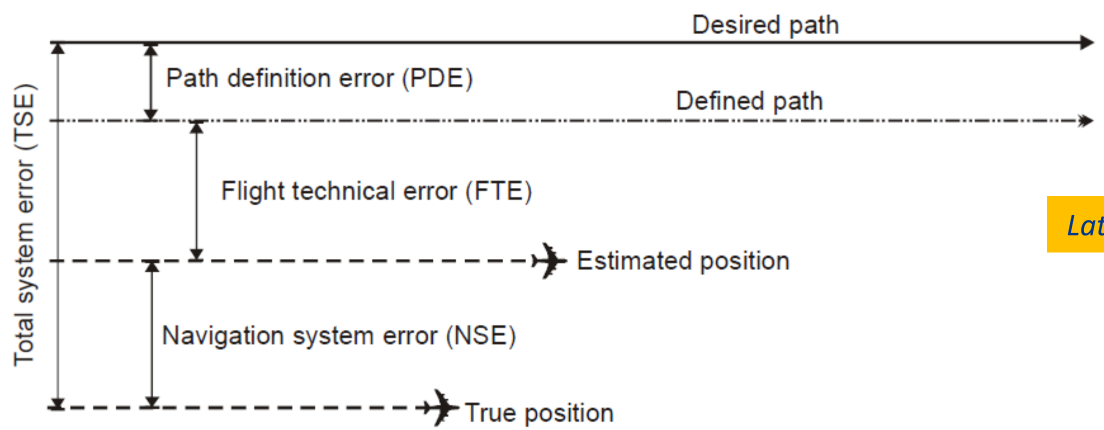
Source: Garmin

062 07 02 03 – Designation of RNP and RNAV specifications

RNAV **X**
RNP **X**

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



Lateral navigation accuracy = TSE

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).

RNAV Specifications	
Oceanic/Remote	RNAV 10
En-route/ Terminal/Approach	RNAV 5, RNAV 2, RNAV 1

RNP* Specifications	
Oceanic/Remote	RNP 4
En-route/ Terminal/Approach	Basic RNP 1, RNP APCH, RNP (AR) APCH

** Includes on-board navigation performance monitoring and alerting*

062 07 02 03 – Designation of RNP and RNAV specifications

RNAV 10

- 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

- 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

062 07 02 03 – Designation of RNP and RNAV specifications

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

RNAV 1*

- Arrival and departure phases of flight
- Without on-board performance monitoring and alerting function
- Lateral TSE must be within ±1 NM for at least 95 per cent of the total flight time
- Based on DME/DME, DME/DME/IRU and GNSS

RNP 1

- Arrival and departure phases of flight
- With on-board performance monitoring and alerting function (usually RAIM)
- Lateral TSE must be within ±1 NM for at least 95 per cent of the total flight time
- For terminal airspace with no or limited ATS surveillance, with low to medium density traffic
- Based on GNSS

**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, finall, 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

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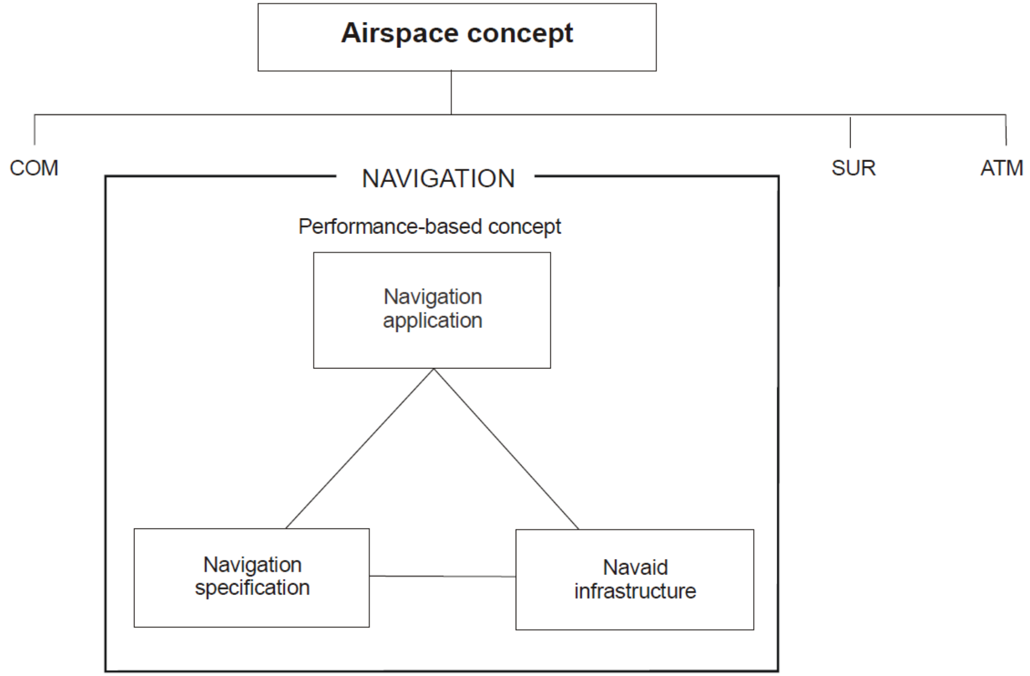
062 07 03 00 – Use of PBN

- 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**

062 07 03 01 – Airspace Planning

- 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



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062 07 03 01 – Airspace Planning

- 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 PBN

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.

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062 07 03 02 – Approval

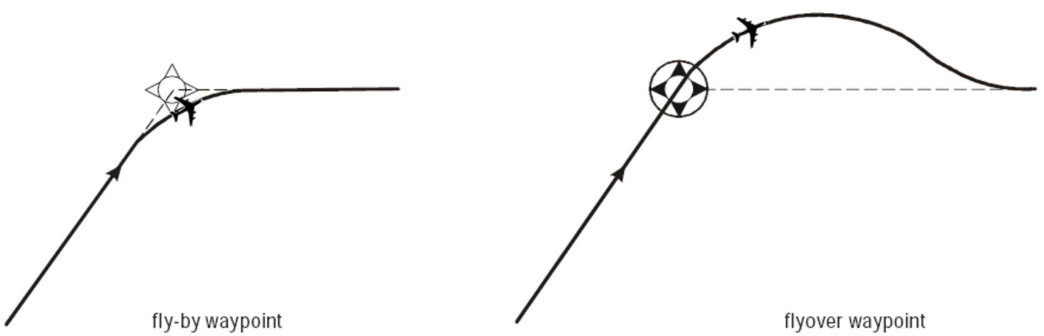
- Some PBN specifications require (and will require) operational approval, including:
  - **RNP APCH**, as detailed in AMC 20-27 and AMC 20-28. Requirement for operational approval will be removed once NPA 2013-25 is adopted
  - **RNP AR APCH**, as detailed in AMC 20-26
  - **Advanced RNP**: to be developed
- 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

FB/FO | Path Terminators | Fixed radius paths | Off/Hold

- 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



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062 07 03 03 – Specific RNAV and RNP system functions

FB/FO | **Path Terminators** | Fixed radius paths | Off/Hold

- **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

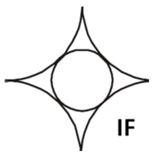
- This allows translating into computer language (FMS) the procedures designed for clock & compass manual flight

- 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

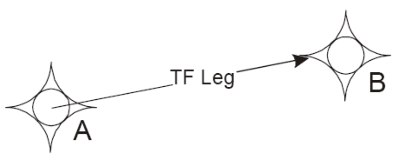
Initial Fix (IF)

- It defines a point in space
- The coding of RNAV procedures starts at an IF



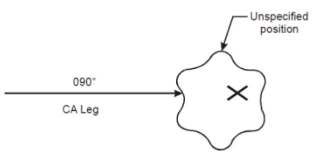
Track to a fix (TF)

- Preferred type for straight legs
- Geodesic path between two waypoints



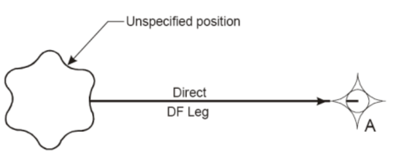
Course to an altitude (CA)

- Course that terminates at an altitude with an unspecified position
- For departures or Missed App



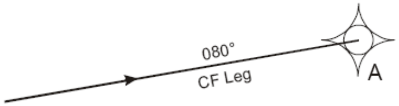
Direct to a fix (DF)

- Segment from an unspecified position to a known waypoint



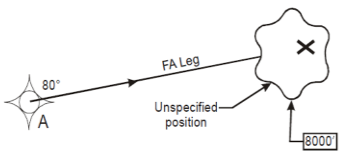
Course to a Fix (CF)

- Course that terminates at a waypoint
- CF legs are subject to magnetic variation issues



Course from a fix to an altitude (FA)

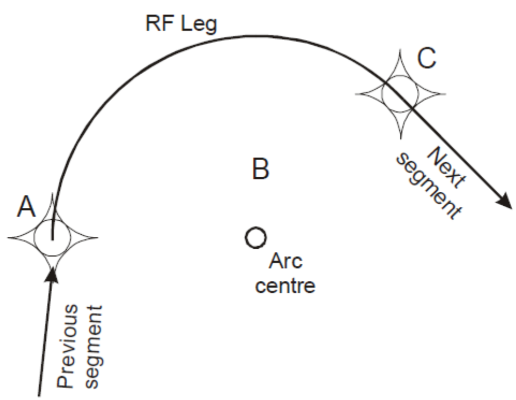
- Begins at a fix and terminates when aircraft altitude is at, or above, a specified altitude



062 07 03 03 – Specific RNAV and RNP system functions

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*

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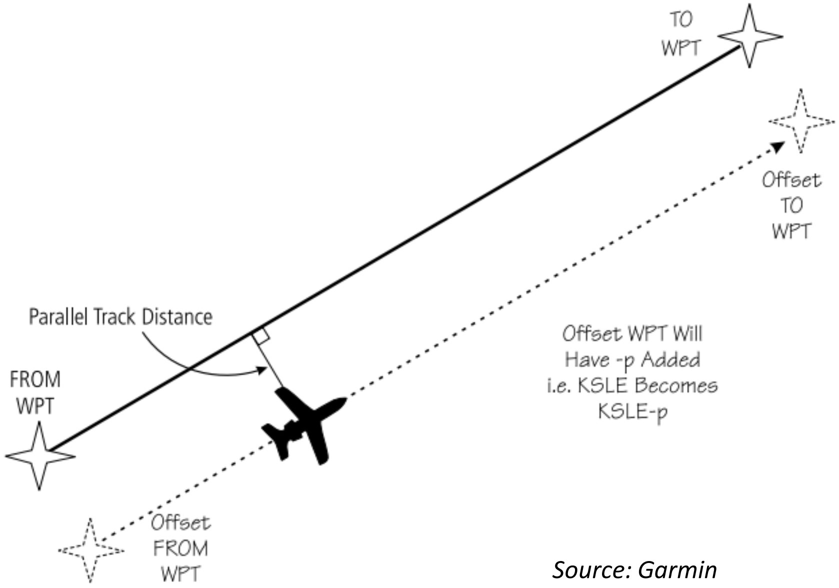
062 07 03 03 – Specific RNAV and RNP system functions

FB/FO | Path Terminators | Fixed radius paths | Off/Hold

- Many aircraft have the capability to fly a path parallel to, but offset left or right from, the original active rout → **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

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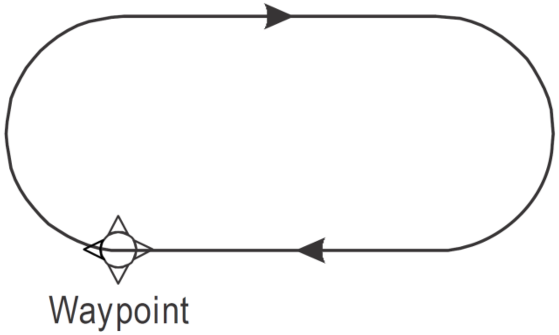
062 07 03 03 – Specific RNAV and RNP system functions

FB/FO | Path Terminators | Fixed radius paths | Off/Hold

- 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*



062 07 03 04 – Data processes

- 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

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062 07 04 00 – PBN operations

- 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

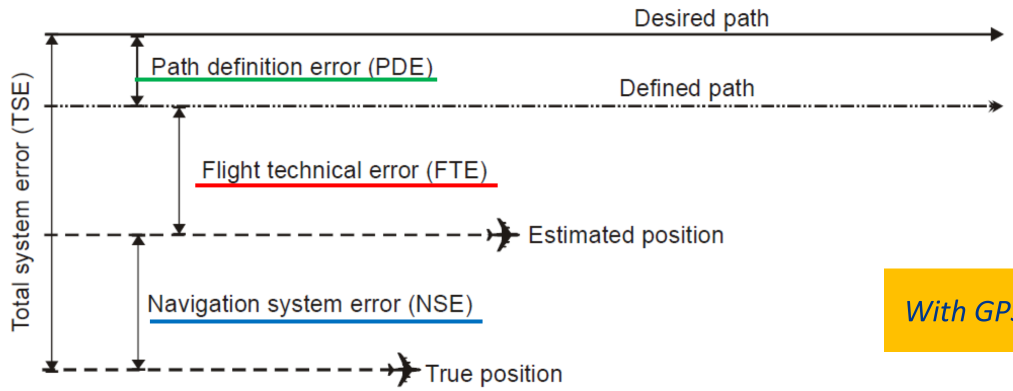
- The flight operations element considers:

  - *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*

062 07 04 01 – PBN operations

- 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: NSE << FTE

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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 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

062 07 04 02– On-board performance monitoring and alerting

- **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*
    - *A 5th satellite provides **Fault Detection (FD)** capability: the receiver recognises a faulty satellite, but is not able to identify which one in particular*
    - *A 6th satellite provides **Fault Detection and Exclusion (FDE)** capability: the receiver is able to isolate the faulty satellite*

062 07 04 02– On-board performance monitoring and alerting

- **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***

062 07 04 02– On-board performance monitoring and alerting

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

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

Example: RAIM or FDE algorithm

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

062 07 04 02– On-board performance monitoring and alerting

- 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.

Click here to return to GPS intro slides

062 07 04 03– Abnormal situations

Abnormal procedures | Contingency procedures

- 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)*

062 07 04 03– Abnormal situations

Abnormal procedures | Contingency procedures

- 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*

062 07 04 03– Abnormal situations

Abnormal procedures | **Contingency procedures**

- 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

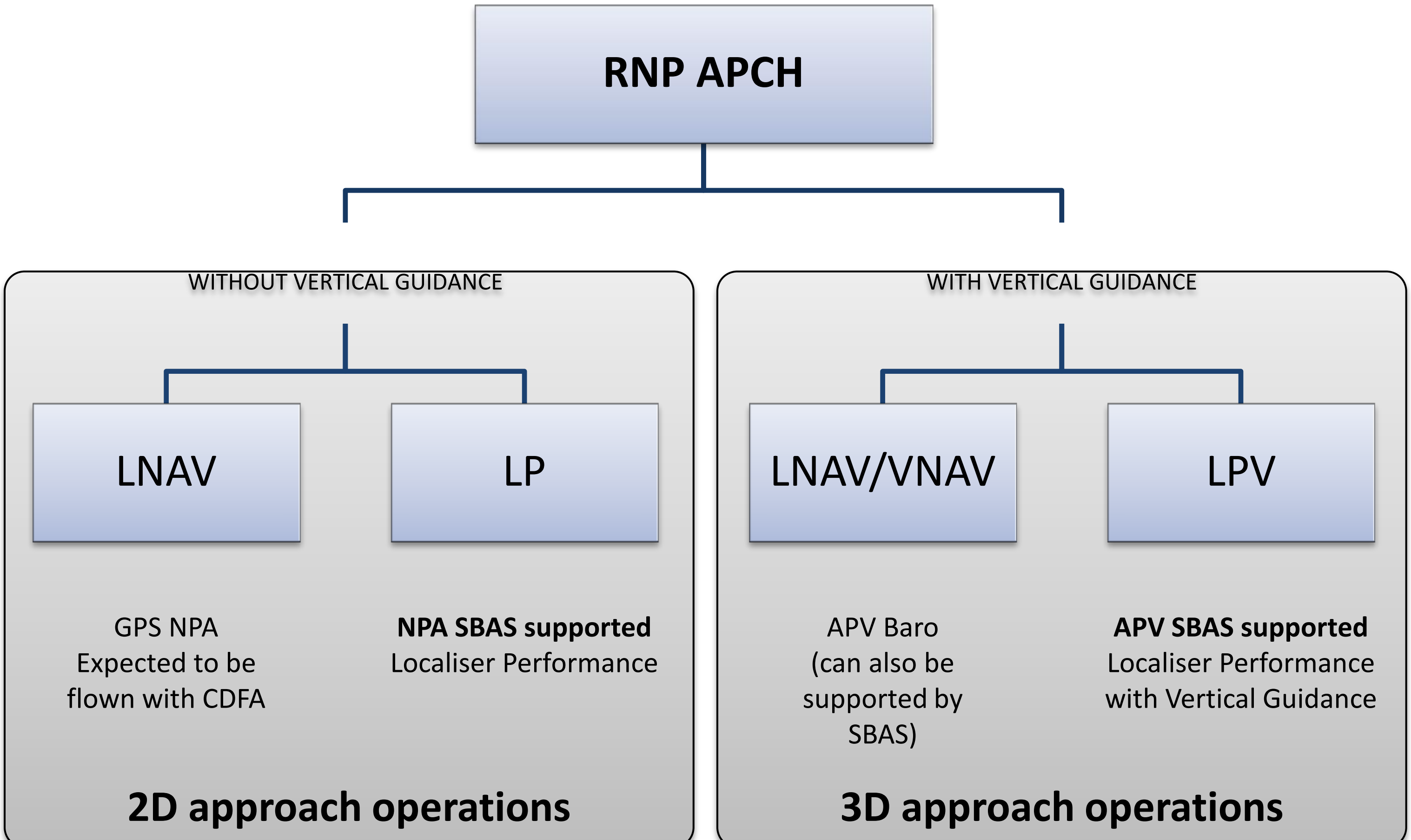
WITHOUT VERTICAL GUIDANCE

- **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

062 07 05 05– RNP APCH



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062 07 05 05– RNP APCH

LNAV | LP | LNAV/VNAV | LPV

- **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 | LP | LNAV/VNAV | LPV

- **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.

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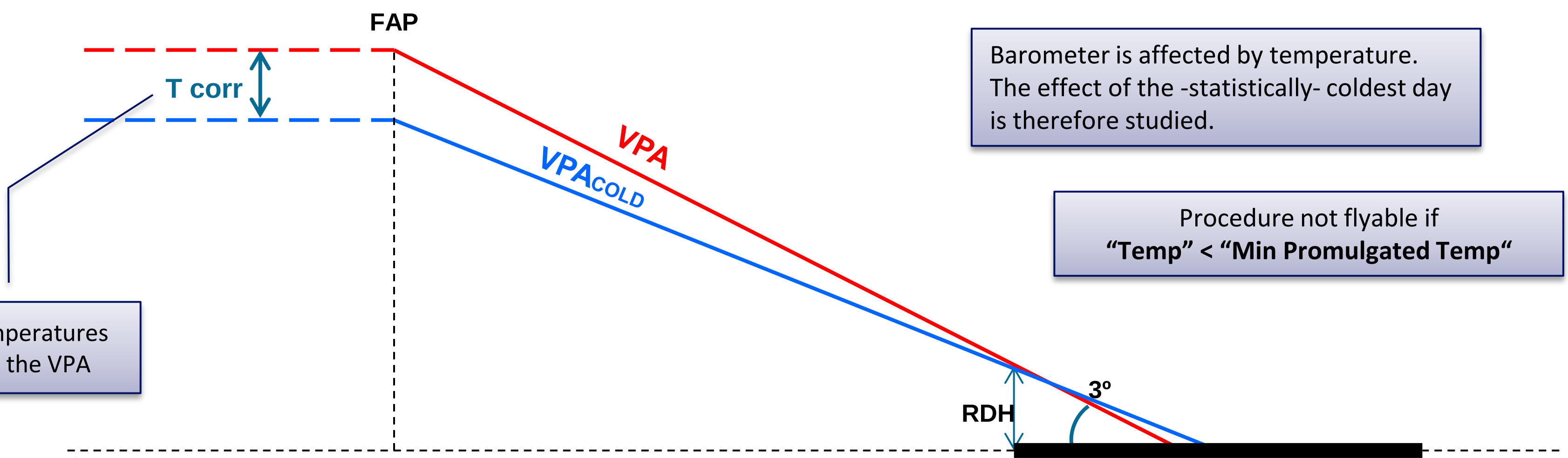
- **LNAV/VNAV minima**

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 safe conduct LNAV/VNAV based on BaroVNAV, 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

062 07 05 05– RNP APCH

LNAV | LP | LNAV/VNAV | LPV

- **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*

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062 07 05 05– RNP APCH

LNAV | LP | LNAV/VNAV | **LPV**

- **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:*
    - *The FAS-DB contain the parameters that define the Final Approach Segment **geometry***
    - *The integrity of the data in 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*

SBAS FAS Data Block Coding Table
Graz RNAV (GNSS) RWY 35

Input Data

Parameters	Values
Operation Type	0
SBAS Provider	1
Airport Identifier	LOWG
Runway	35
Runway Direction	2
Approach Performance Designator	0
Route Indicator	
Reference Path Data Selector	0
Reference Path Identifier	E35A
LTP/FTP Latitude	465840.0300N
LTP/FTP Longitude	0152635.8100E
LTP/FTP Ellipsoidal Height (metres)	378.5
FPAP Latitude	470014.1460N
Delta FPAP Latitude (seconds)	94.1160
FPAP Longitude	0152609.9025E
Delta FPAP Longitude (seconds)	-25.9075
Threshold Crossing Height	53.0
TCH Units Selector	0
Glidepath Angle (degrees)	3.10
Course Width (metres)	107.00
Length Offset (metres)	224
HAL (metres)	40.0
VAL (metres)	50.0

Output Data

Data Block	10 07 17 0F 0C A3 00 00 01 35 33 05 3C 22 29 14 44 A6 A0 06 C9 22 48 DF 02 99 35 FF 12 02 36 01 6C 1C C8 FA AE 38 5C AF
Calculated CRC Value	AE385CAF

Parameters	Values
ICAO Code	LO
LTP/FTP Orthometric Height (metres)	331.5
FPAP Orthometric Height (metres)	331.5

Source: Austrocontrol

062 07 05 05– RNP APCH

LNAV | LP | LNAV/VNAV | **LPV**

- **LPV minima 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***

062 07 05 05– RNP APCH

- 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)

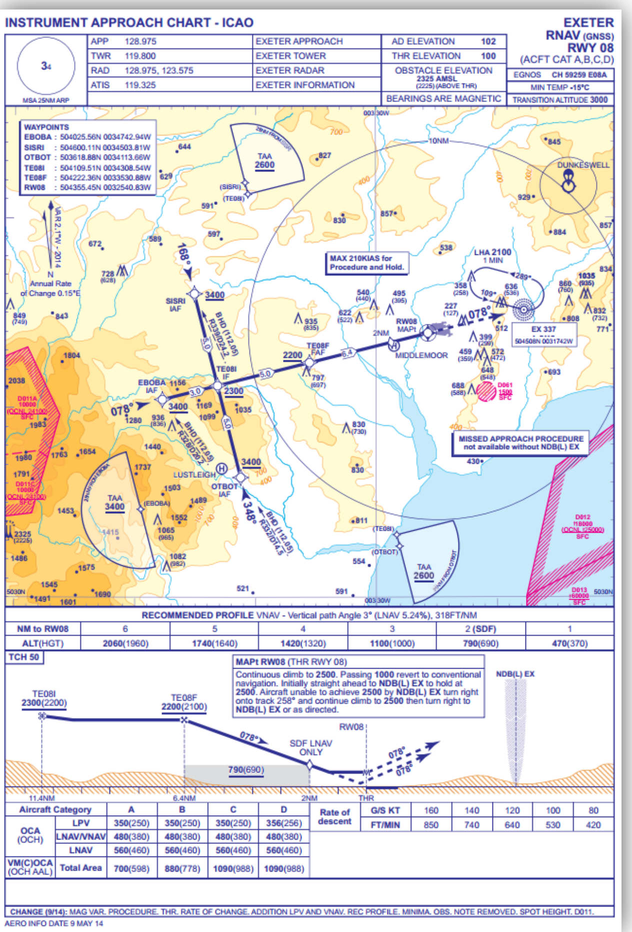
062 07 05 05– RNP APCH

- 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



(source: UK CAA)

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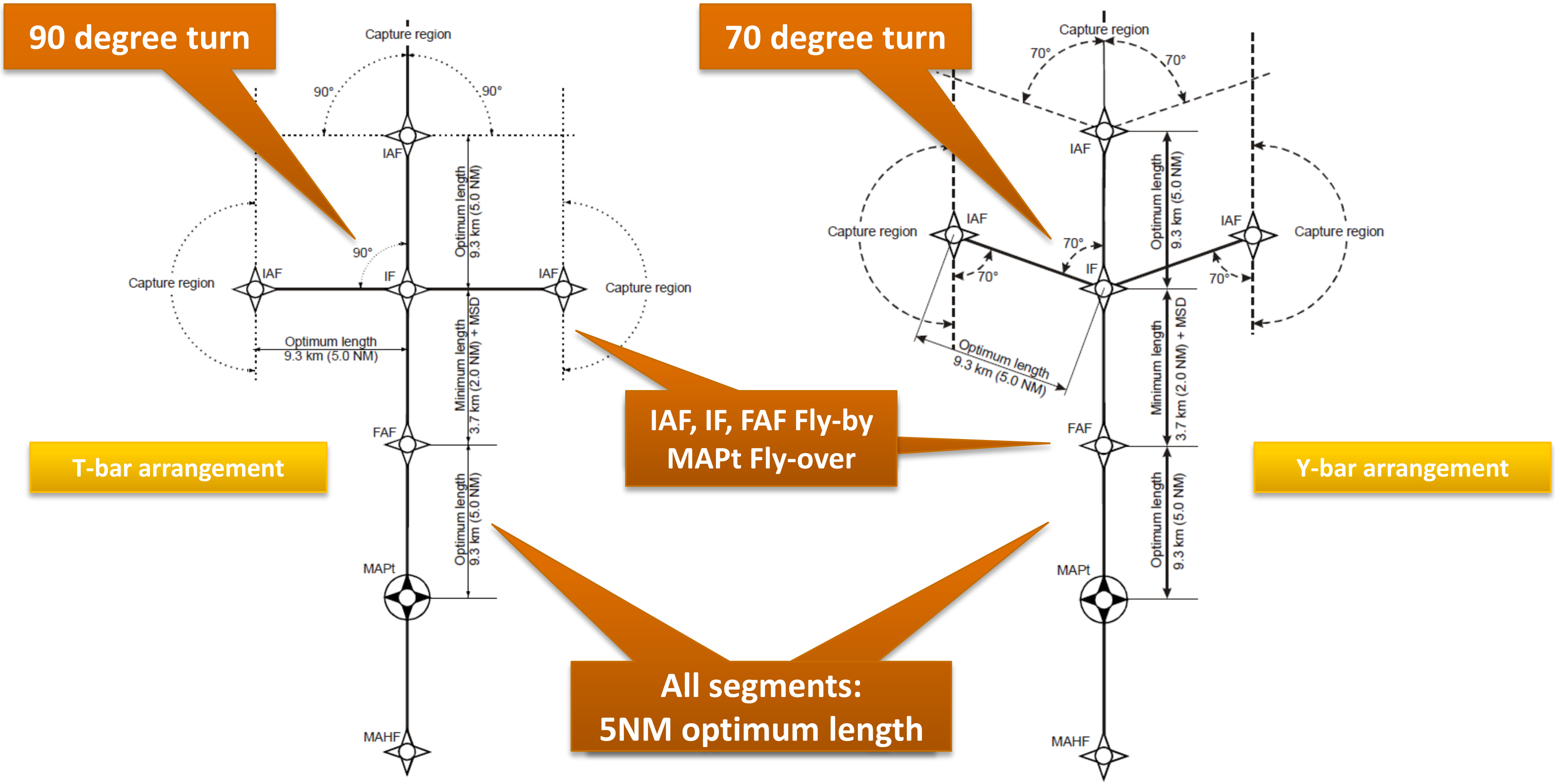
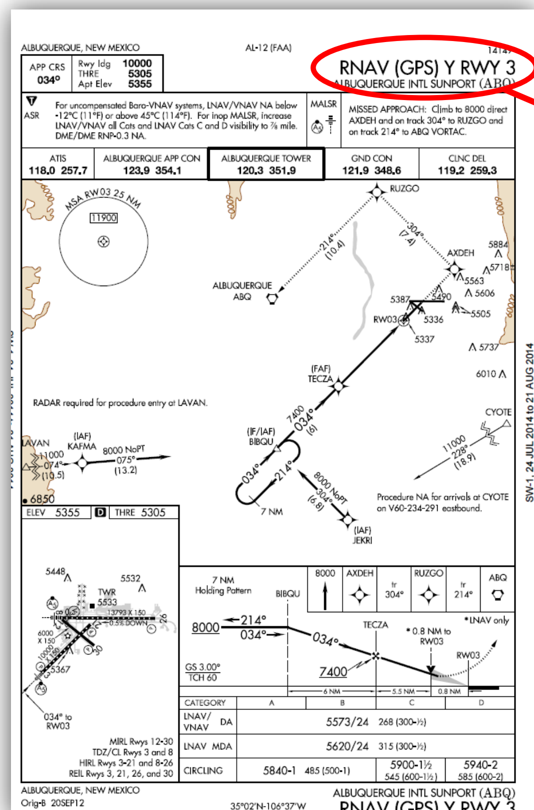
062 07 05 05– RNP APCH



(source: ICAO)

062 07 05 05– RNP APCH

- 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



Source: Bendix King by Honeywell

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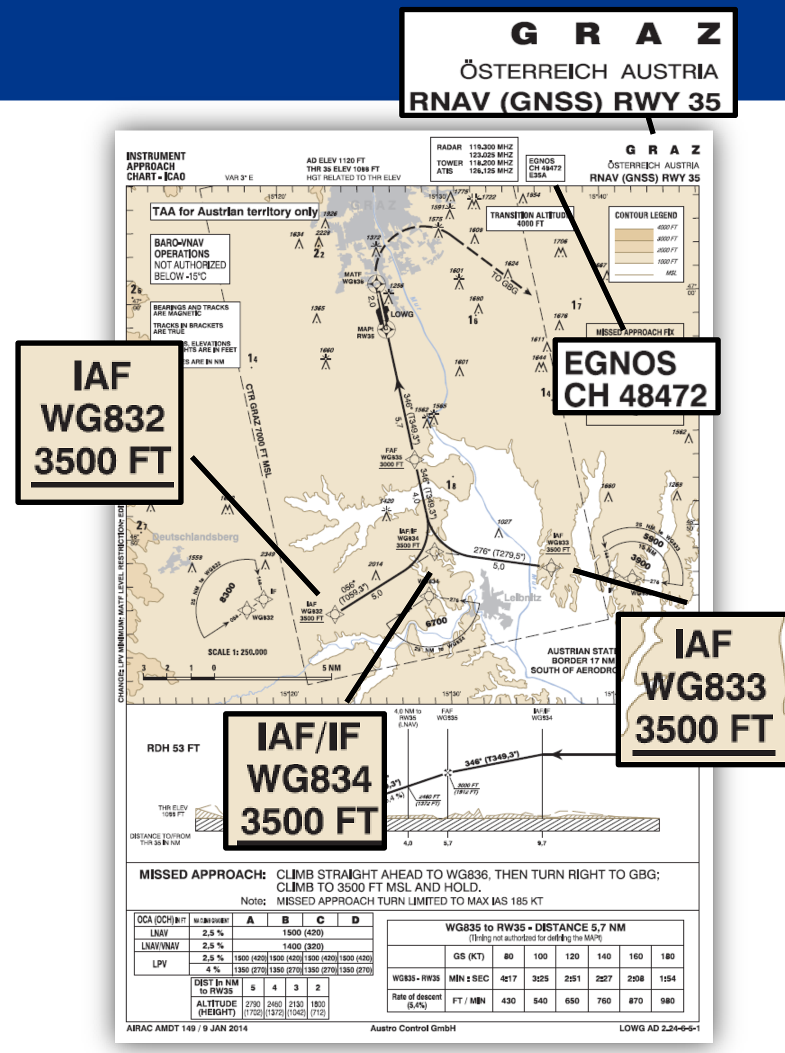
062 07 05 05– RNP APCH

- 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



Source: Austrocontrol

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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.

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

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

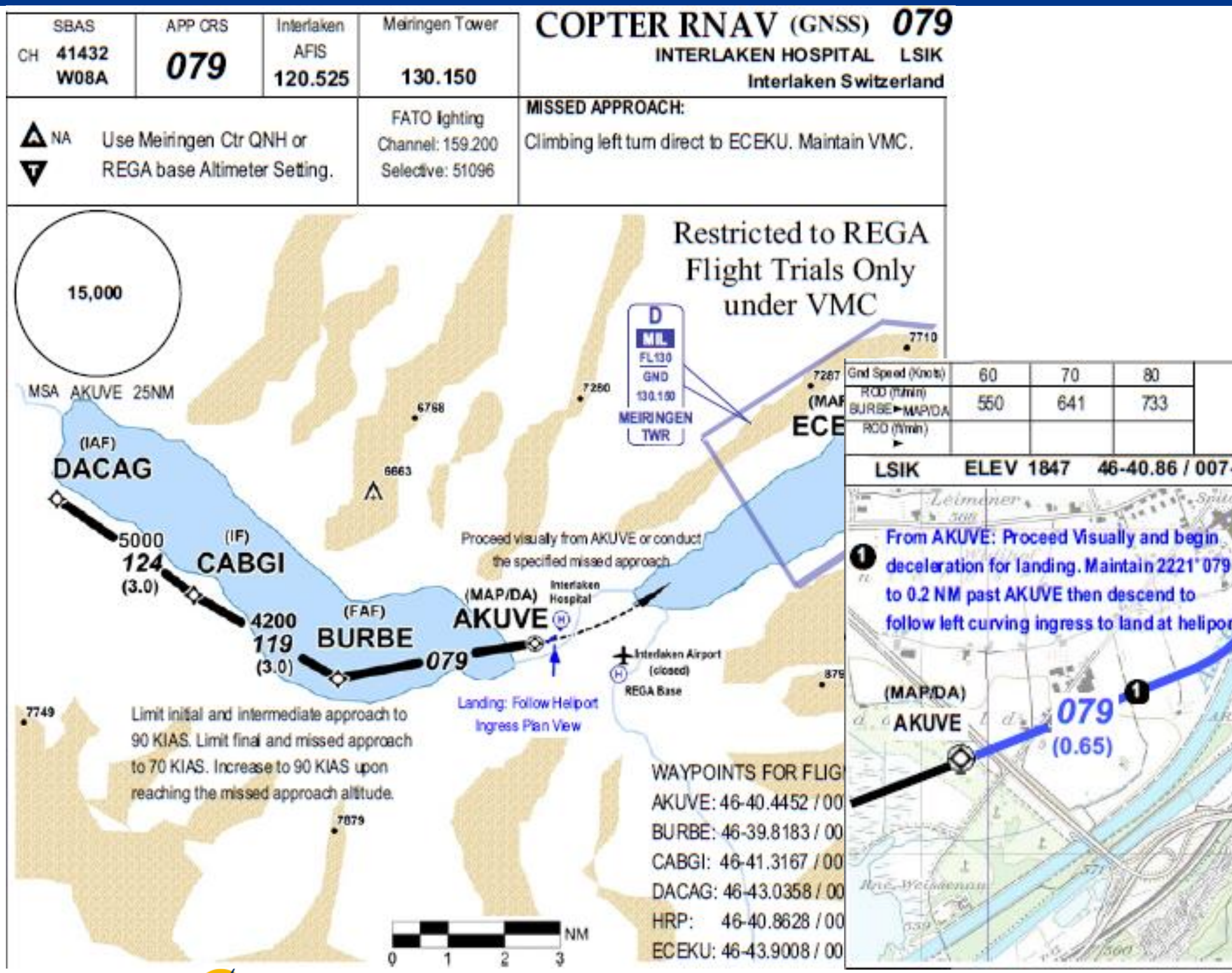
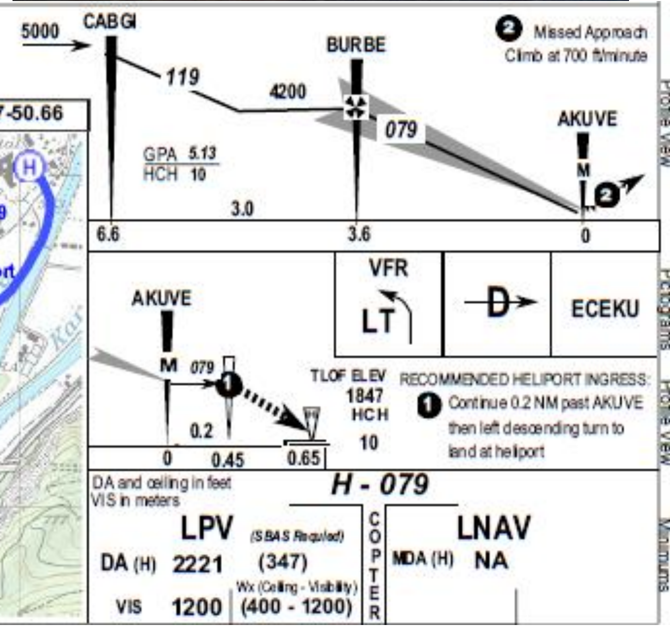
- **Proceed VFR**: developed for heliport or landing locations that do not meet the standards for a heliport. The PinS instrument approach delivers the helicopter to a MAPt. Prior to or at the MAPt, the pilot shall decide to proceed VFR or to execute a missed approach, based on visibility

  - 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

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