ICAO WACAF Workshop

1st – 4th September 2015

GNSS and PBN Generalities

AIRBUS

GNSS and PBN Generalities

Why GNSS

GNSS History and Concept

Some history

Visual References (Stars…)

Instrument landing System: **1938**

VOR (Airways): **1960s**

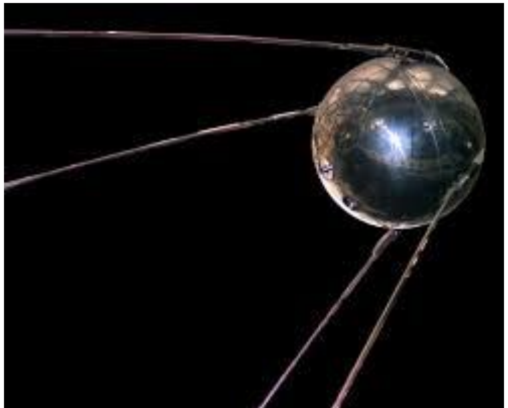
Failed Introduction of RNAV: **1983**

GPS navigation: **1994** RNP: **1996**

PBN ICAO mandate: **2016**

Navaids not always suitable in terrain challenging environment and expensive to maintain

Some history



Sputnik - **1957**

First GPS (Block 1) launch - **1978**

USA President Reagan makes GPS widely available - **1983**

GPS SA turned off – **2000**

US/EU agreement for GPS/Galileo - **2004**

PBN ICAO mandate: **2016**

Ground based Navaids do not provide coverage and accuracy needed for todays airspace.

ICAO Annex 10 definitions

ICAO ANNEX 10

GNSS: Global Navigation Satellite System

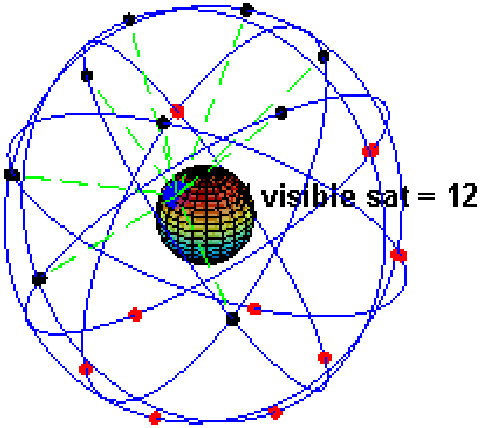
A worldwide position and time determination system that includes one or more ***satellite constellations, aircraft receivers*** and system integrity monitoring, ***augmented*** as necessary to support the required navigation performance for the intended operation.

GPS: Global positioning system

The satellite navigation system operated by the United States.

GPS (Global Positioning System)

Accuracy of 12 meters



Worldwide coverage

- Position computed in WGS84
- A 24 minimum satellite constellation
- Mass market GPS receiver are not expensive

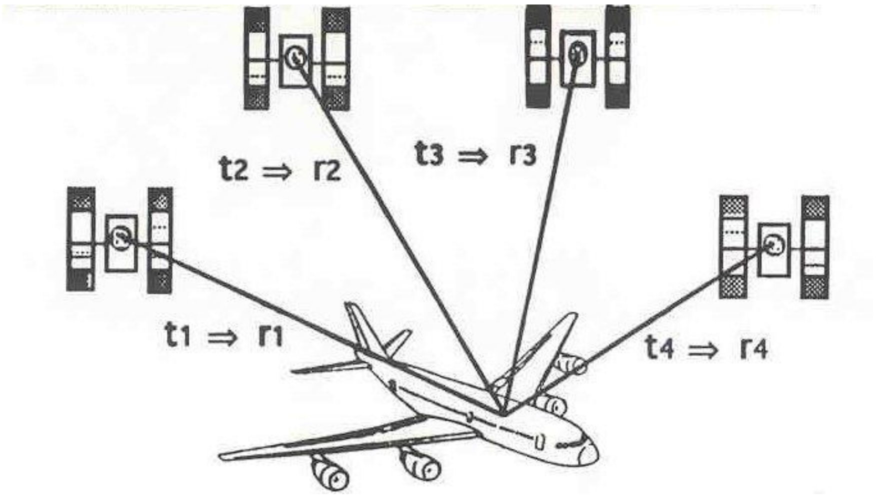
How it works?

GNSS concept

PVT computation

GPS SUPPLIED DATA:

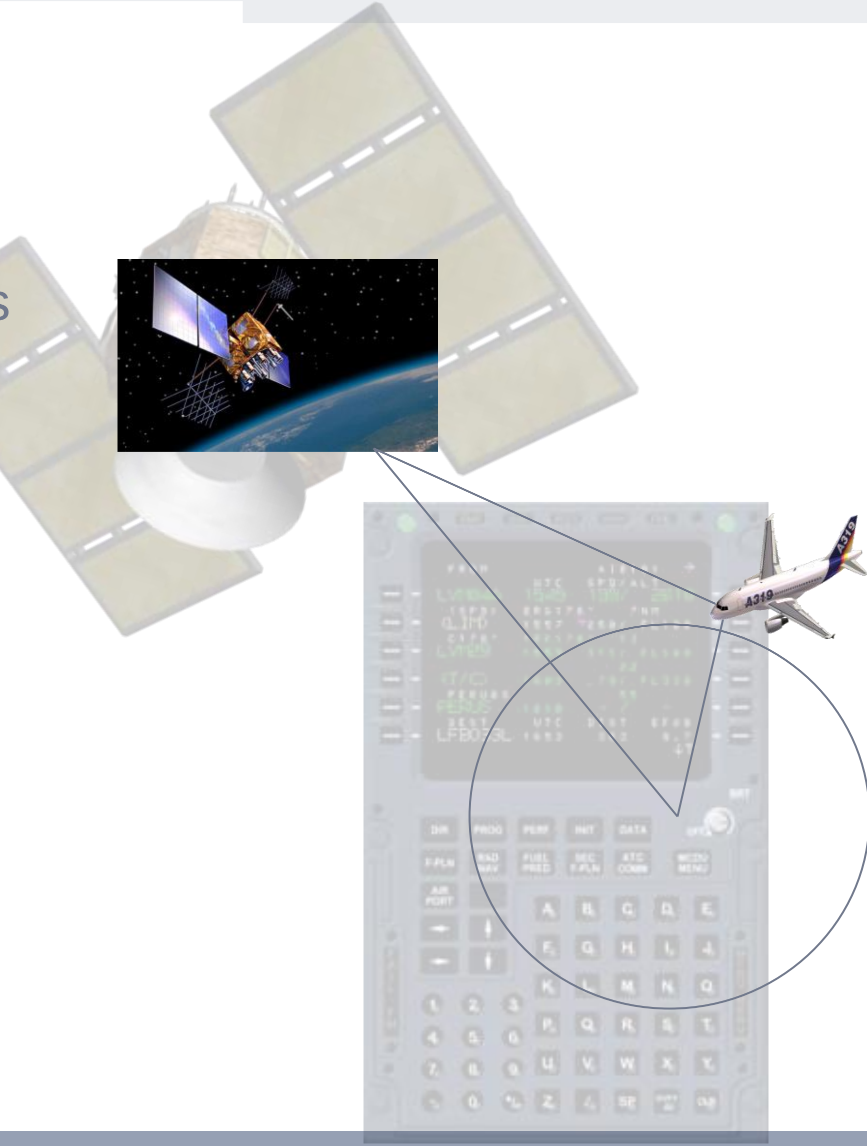
The GPS is a system combining space, ground based and airborne segments which provides, with a worldwide coverage, 3D position (with respect to an Earth Centered Earth Fixed referential), velocity, and time



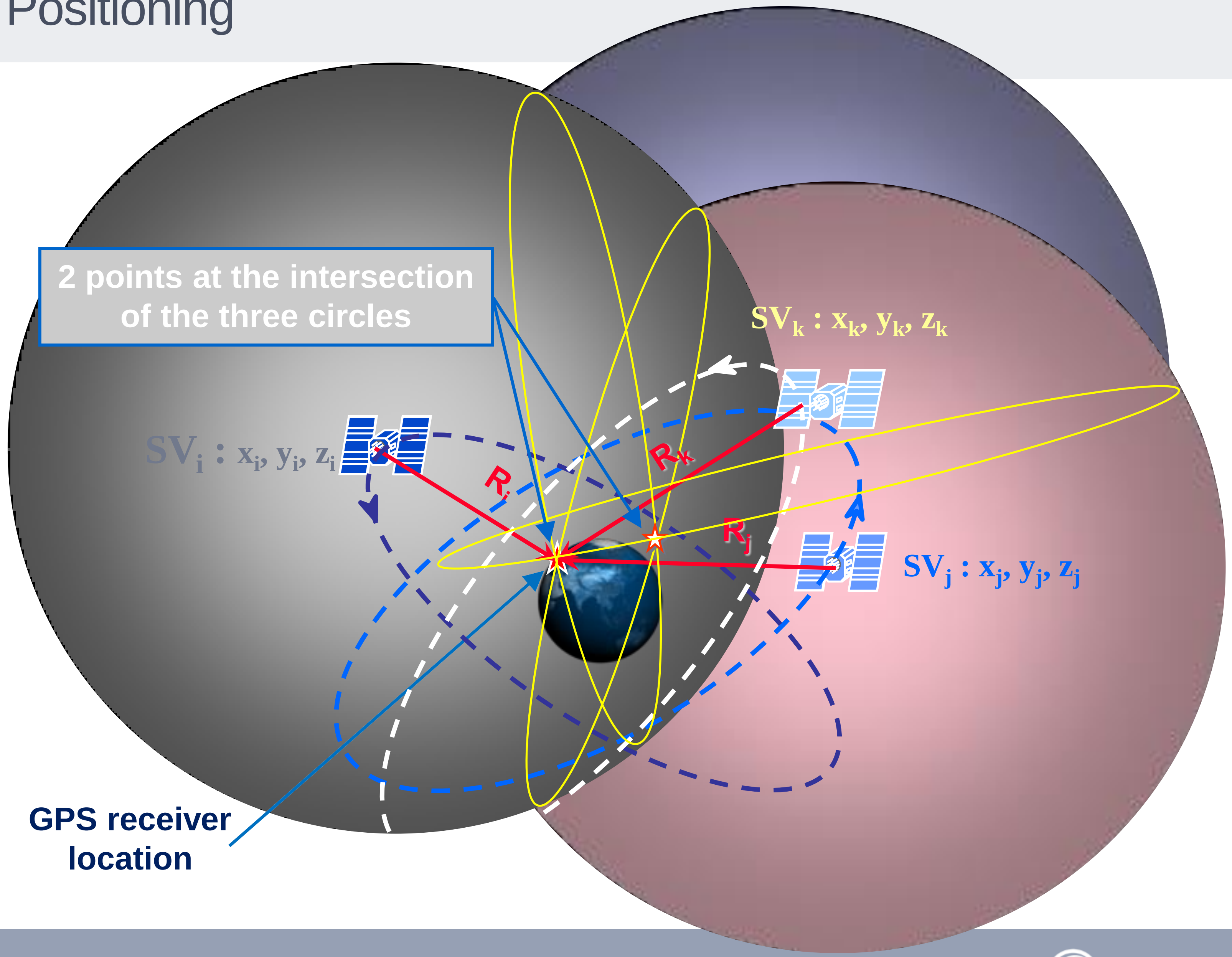
PVT (Position Velocity Time) determination by triangulation after propagation delay measurement

Basic Principles

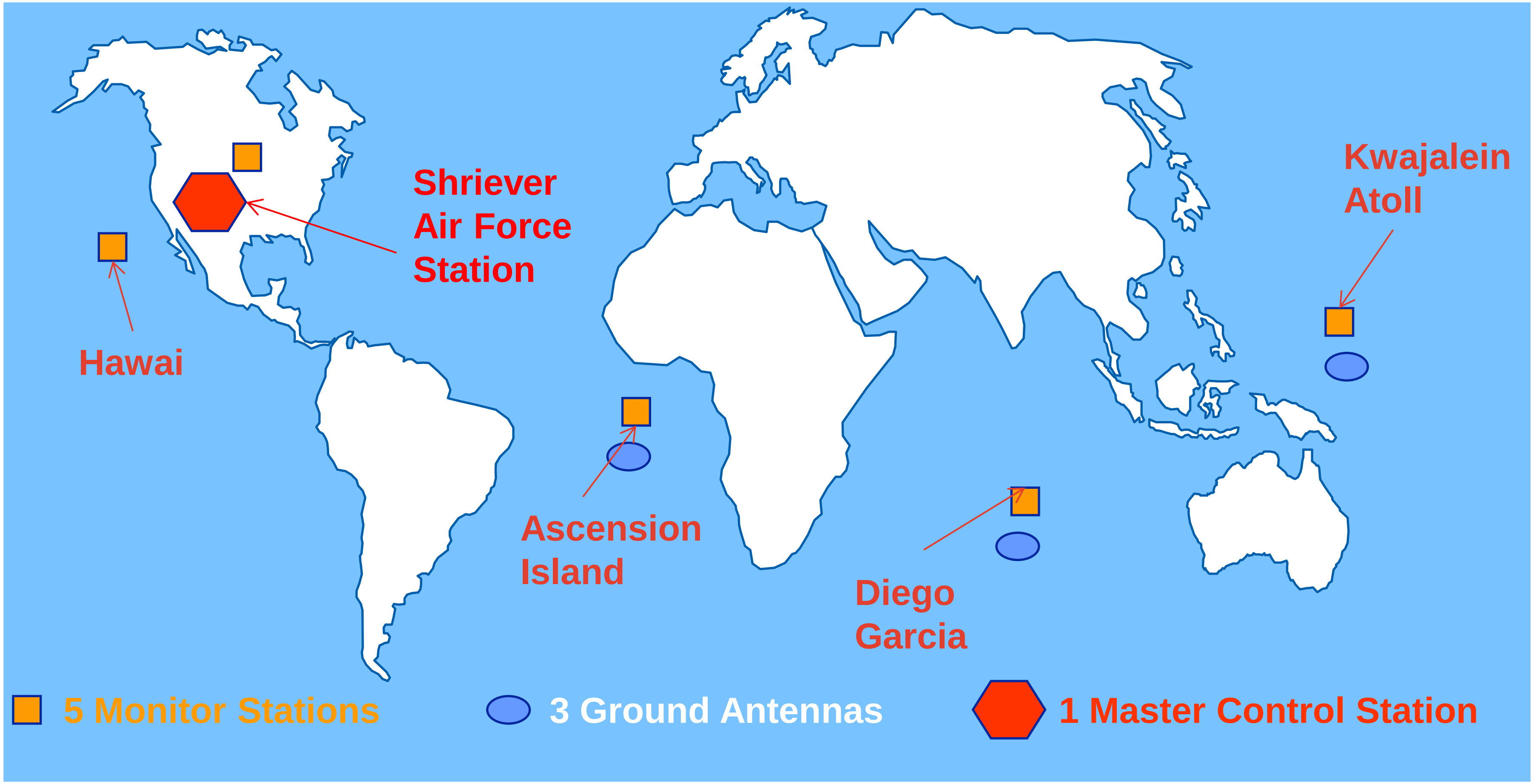
- ✓ Based on Time of Arrival concept
- ✓ Each SV generate a unique PseudoRandom code periodically
- ✓ Receiver acquires and tracks Satellites
- ✓ Receiver measures pseudoranges
- ✓ Receiver demodulates Navigation Messages
  - Almanac, Ephemeris
  - Ionospheric corrections
  - Clock corrections
  - Health status
- ✓ Receiver resolves navigation solution identifying four unknowns x, y, z and t thus needing four satellites as a minimum to compute a PVT solution



GPS Positioning



Ground segment: CONTROL SEGMENT



Requirements

In order to guarantee Signal In Space (SIS) for safe and reliable operations, four parameters are used:

- **Integrity**
- **Accuracy**
- **Availability**
- **Continuity**

ICAO Annex 10 Definitions

Integrity:

A measure of the ***trust*** that can be placed in the correctness of the information supplied by the total system.

Includes the ability of a system to provide ***timely and valid*** warnings to the user (***alerts***).

Accuracy:

GNSS position error is the difference between the ***estimated*** position and the ***actual*** position. For an estimated position at a specific location, the probability should be at least ***95 per cent*** that the position error is within the ***accuracy requirement***.

ICAO annex 10 Definitions

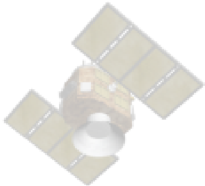
Continuity :

Continuity of service of a system is the capability of the system to perform its function without ***unscheduled*** interruptions during the intended operation.

Availability :

Availability of GNSS is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft.

GPS Std. Positioning Service accuracy

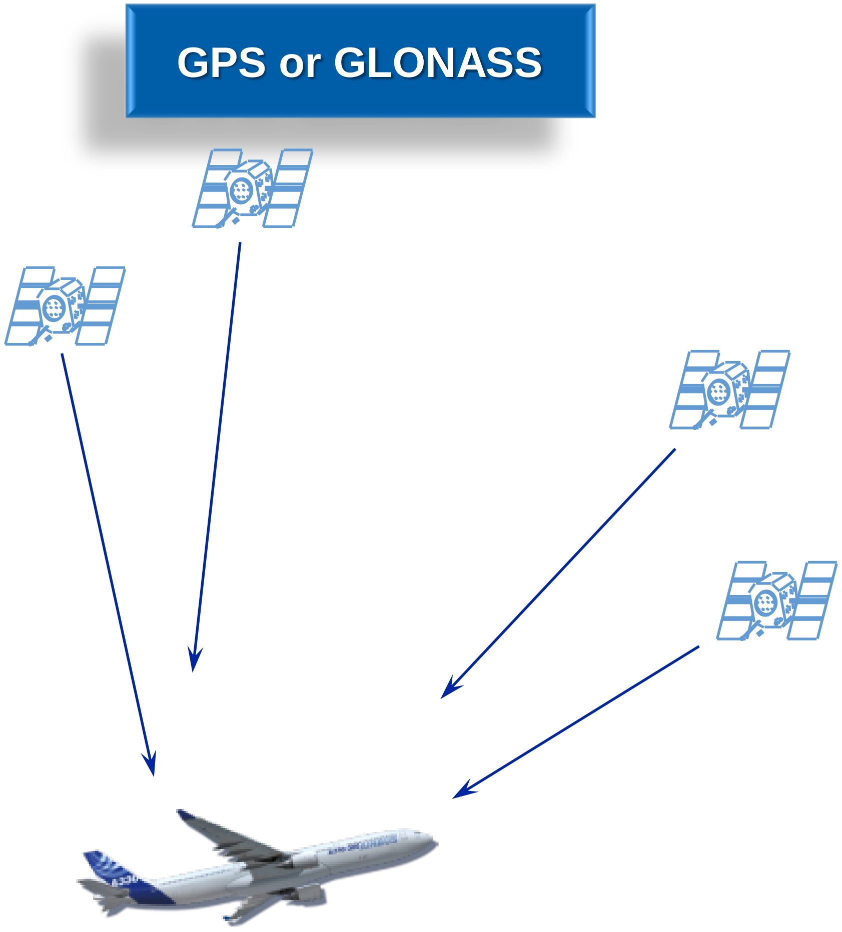


	GPS SPS positioning accuracy 95% of time, Global average
Horizontal position error	**13 m (43 ft)**
Vertical position error	**22 m (72 ft)**

GNSS Augmentation Means and Signal prediction

Can I trust this position ?

A need to trust “SIS” for safe operation



Satellites may broadcast

- ✓ Erroneous signal for hours
- ✓ Distance errors

Erroneous clock or ephemeris data

- ✓ Positioning errors

Users needs

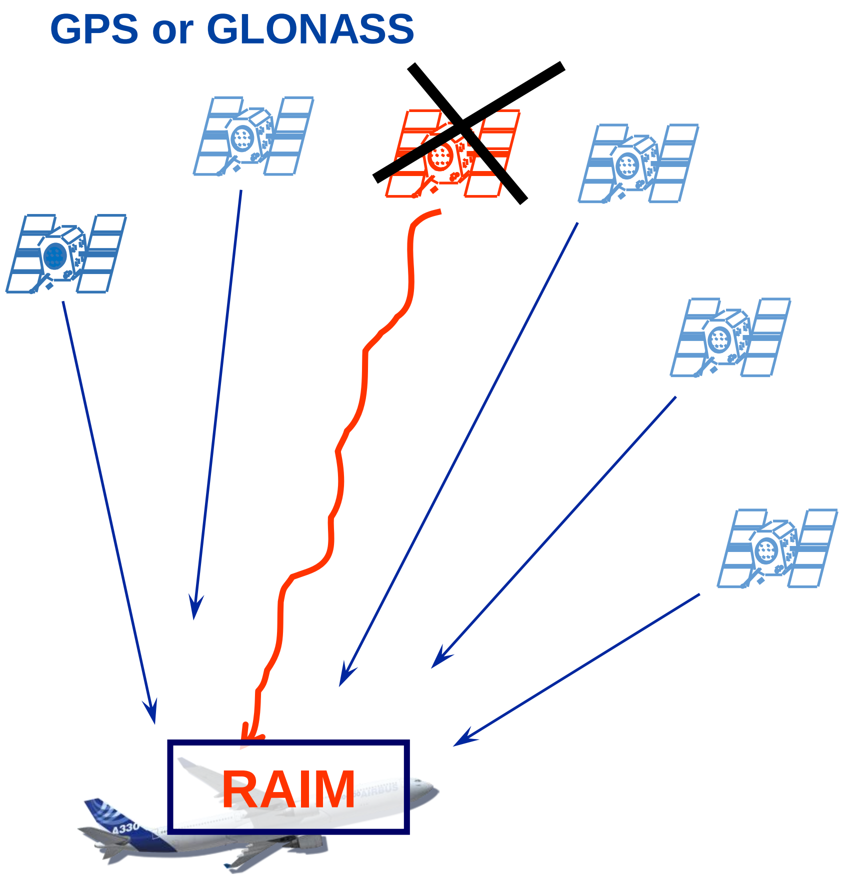
- ✓ To know quality of computed position
- ✓ To be warned if anything goes wrong

This is checking integrity of SIS

GNSS integrity monitoring

- GNSS integrity monitoring techniques aim at monitoring the quality of GNSS positioning
- Large variety of techniques:
  - In an autonomous manner (ABAS) :
    - Using the redundancy of GNSS measurements only (RAIM)
    - Using additional information from other sensors (AAIM)
  - Using a ground station (GBAS)
  - Using a network of ground stations (SBAS)
- All these systems can include Fault Detection (FD) or Fault Detection and Exclusion (FDE)

A need to trust "SIS" for safe operation



- ✓ 4 satellites to determine 3D position and time
- ✓ Usually more satellite are available (6 to 12)
- ✓ RAIM uses
  - ➢ 5 satellites for fault detection (FD)
  - ➢ 6 satellites for fault detection and exclusion (FDE)
- ✓ RAIM provides integrity and warning

RAIM on board function to guarantee integrity

Availability of Autonomous Integrity

- ✓ Depends on phase of flight
  - Better in En Route than in Approach

- ✓ Can be predicted based on satellite almanac data at a specific location and time
  - Predictions tools

- ✓ RAIM/ABAS is not sufficient for APV (Except Baro VNAV) or precision approach operations

Other Augmentations

- ✓ Complements the core satellite constellation(s) by increasing quality of positioning

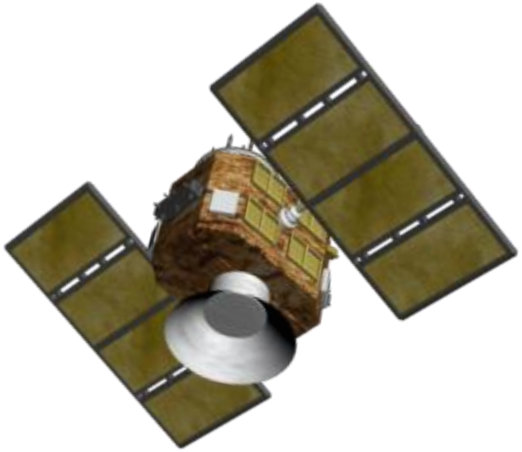
- ✓ Through space segment and ground segment : SBAS
  - WAAS, EGNOS, GALILEO, MSAS, GAGAN, COMPASS
  - Area service including multiple aerodrome

- ✓ Through ground segment : GBAS
  - Multiple companies develop versions of GBAS

Positioning Error and Errors Analysis

Unlike *ILS and VOR*, GNSS errors change over time :

- ✓ The orbiting of satellites
- ✓ The error characteristics of GNSS
- ✓ The satellite geometry



For GNSS

- ✓ Position errors can change over a period of hours
- ✓ No continuous measure of the system accuracy
- ✓ But high level of reliance on analysis and characterization of errors.

GPS Prediction Tools

- Based on constellation status information issued by US Coast Guard
- Assessment of availability and continuity

- Based on RAIM concept

- More or less sophisticated
  - ✓ Include one or more points (2D or 3D)
  - ✓ Include or not mask due to terrain

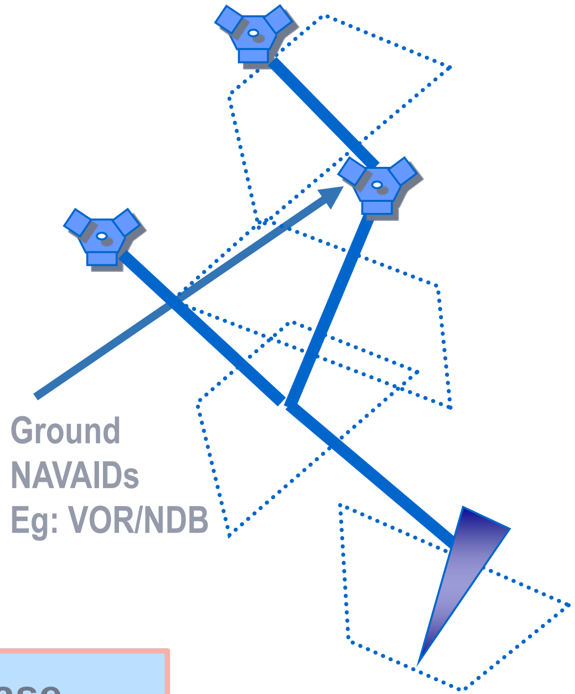
PBN Generalities

Conventional routes

- **Defined based on old aircraft capabilities and use of conventional navigation means**
  - ✓ Large protection areas and separation criteria to cope with limited accuracy of position estimation

- **Based on Ground Navigation Aids**
  - ✓ Overfly
  - ✓ Relative position

- **Limited design flexibility**
  - ✓ Leading to traffic saturation

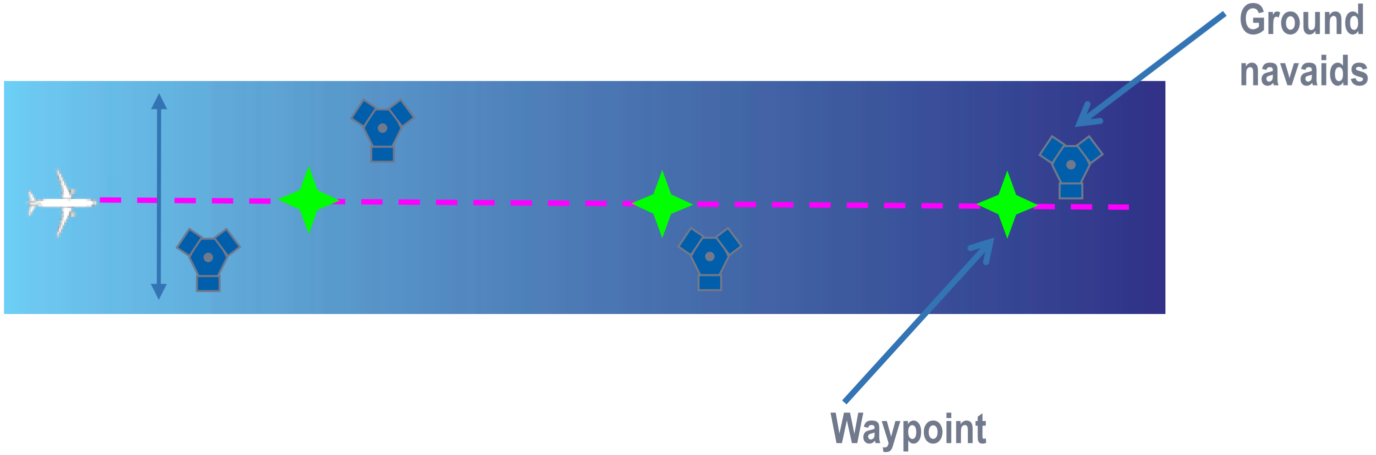


Widely used but no more suitable due to traffic increase and high fuel cost

RNAV Definition

RNAV stands for **Area Navigation**

RNAV: Capability to fly any desired flight path, defined by waypoints such as geographic fixes (LAT/LONG) and not necessarily by ground navaids



RNAV capability is linked to aircraft on-board equipment (RNAV systems)

"RNAV X" capability represents the linear lateral Accuracy of the Navigation system expected to be achieved 95% of the flight time

RNAV is a method of navigation allowing for the definition of more direct routes

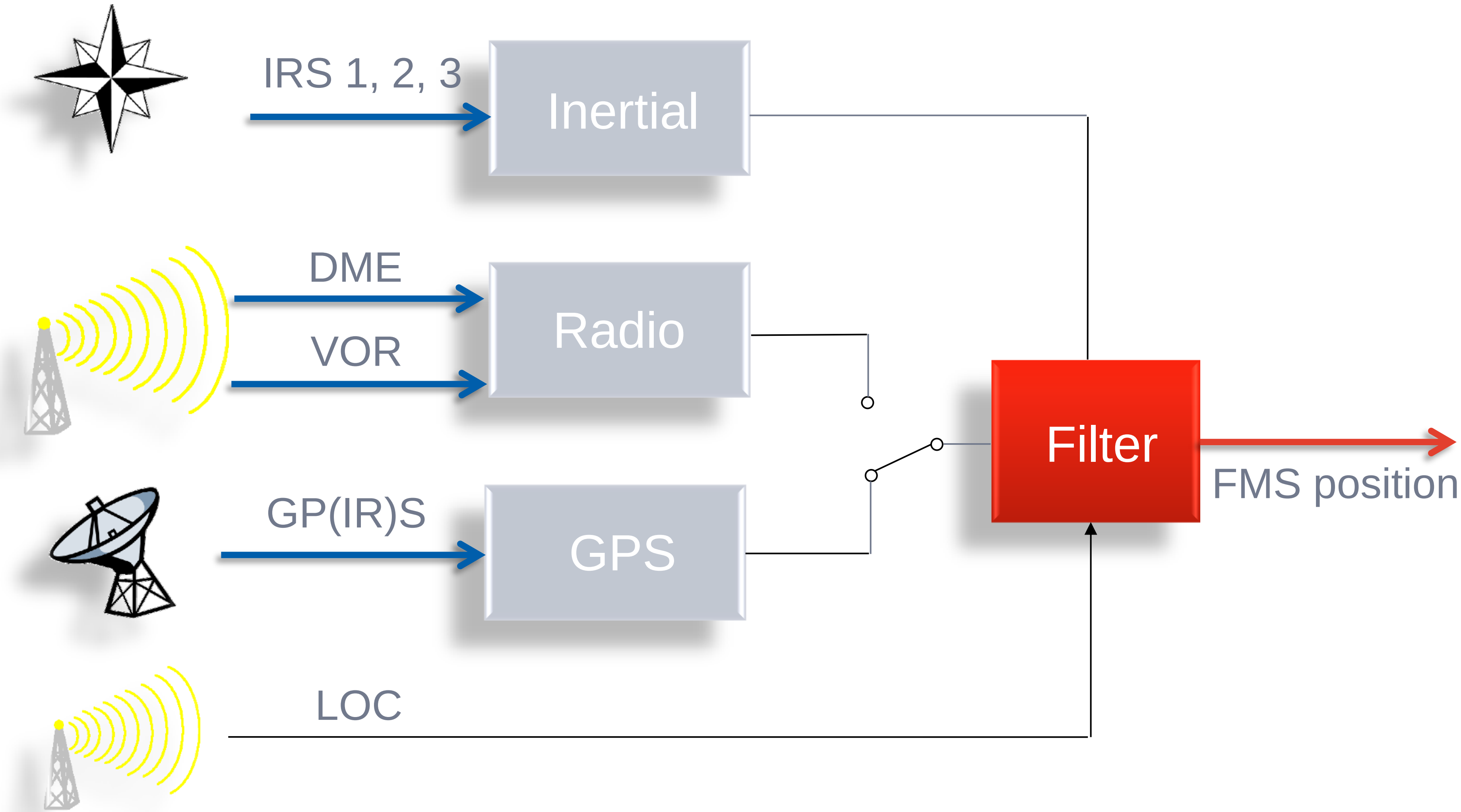
RNAV SYSTEM: A/C Position

NAV mode

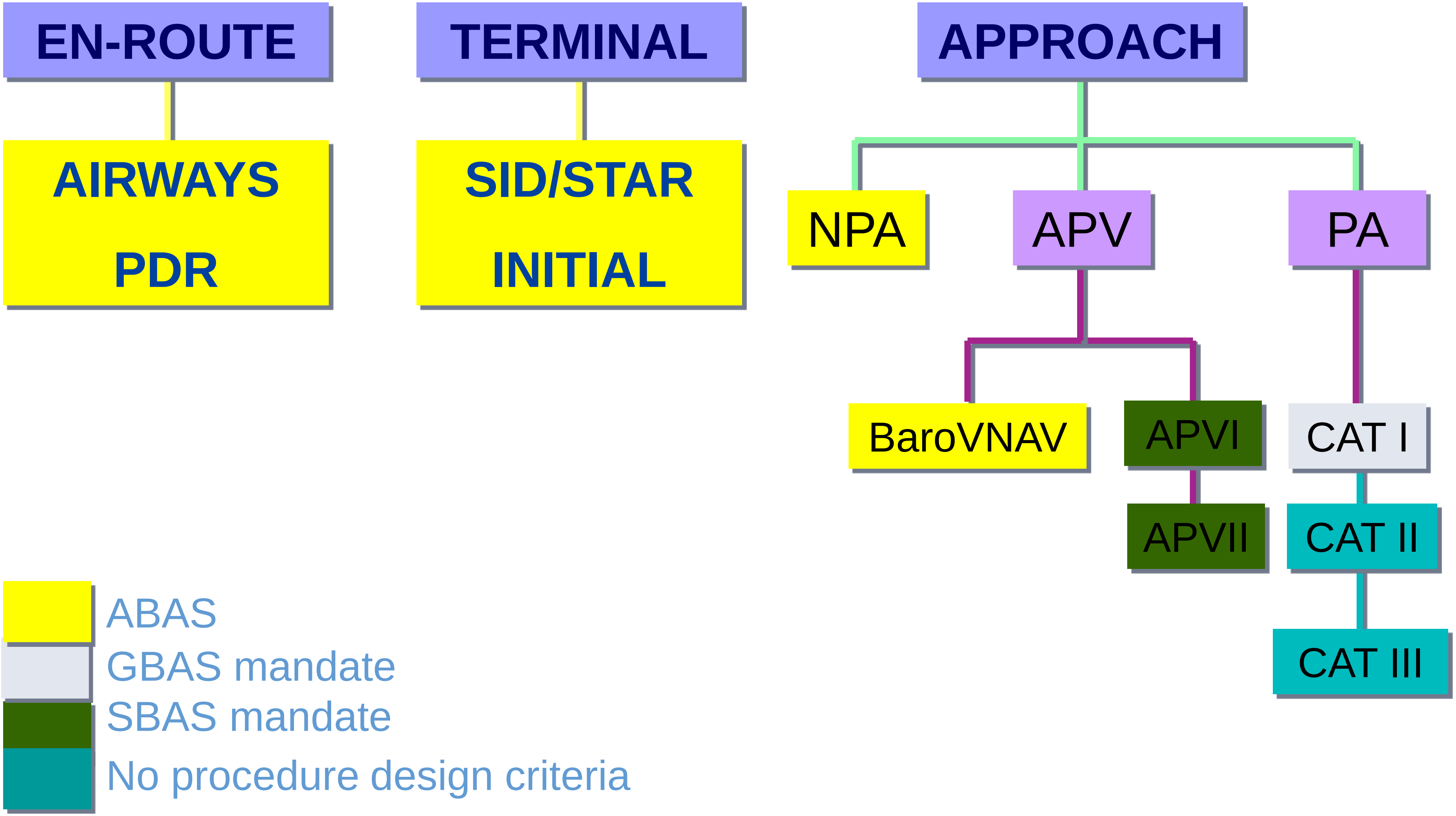
IRS drift

Available positions

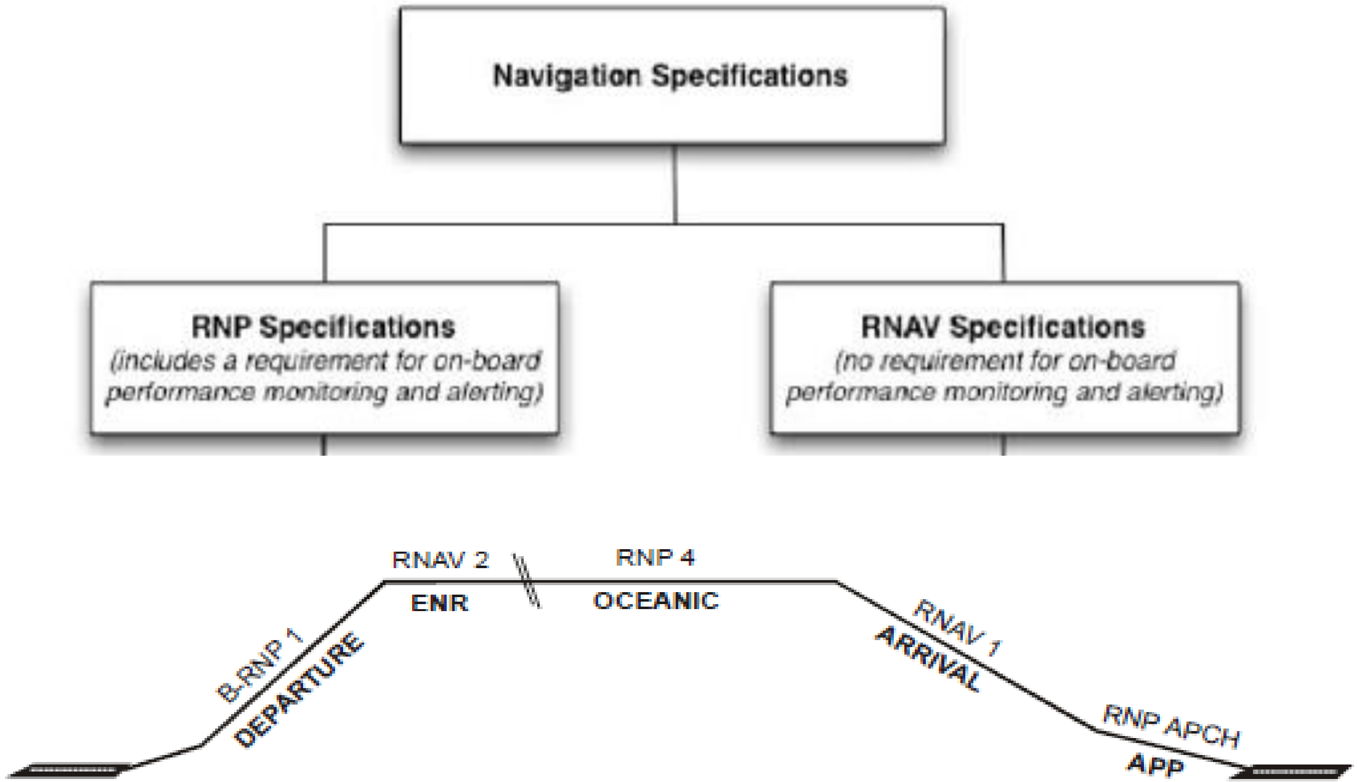
RNAV SYSTEM


IRS 1, 2, 3
Inertial
DME
VOR
Radio
GP(IR)S
GPS
LOC
Filter
FMS position

RNAV Operations



Performance Based Navigation implementation is strongly promoted by ICAO



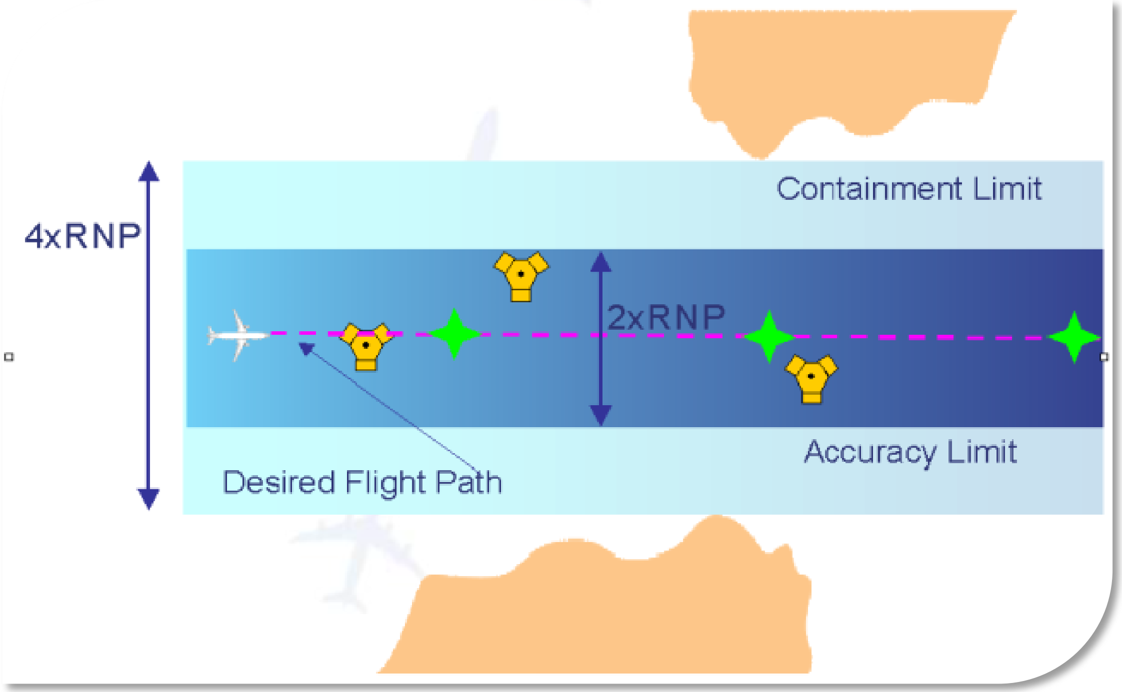
ICAO Resolution A36-23, 36th Session, September 2007, urges States to implement :

- ✓ Performance-Based Navigation (PBN)
- ✓ Approaches with Vertical Guidance (APV)
- ✓ Part of Block 0 (Short Term) Upgrade

RNP ensures trajectory containment

RNP =
- Navigation **accuracy**
- On board containment **integrity**
- **Continuity** of RNP capability

+ On Board **Performance Monitoring** and **Alerting (OBPMA)**



RNP X = +/- X NM corridor for the accuracy limit,
+/- 2*X NM corridor for the containment limit

RNP Approaches: RNAV (GNSS)

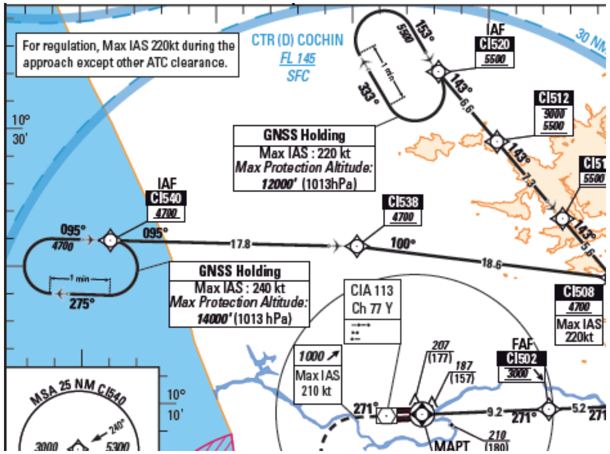
RNP APCH (with or without Baro-VNAV) characteristics:

- ✓ Straight-in approach on runway axis: 7-10Nm straight final segment
- ✓ Based on 0.3NM
- ✓ Large obstacle clearance area with buffers
- ✓ ICAO Charting: RNAV (GNSS)
- ✓ With Baro VNAV

  I. Decision Altitude instead of MDA

  II. Stabilized approach coded in the FMS down to 50ft above runway threshold

  I. Final path with constant descent angle

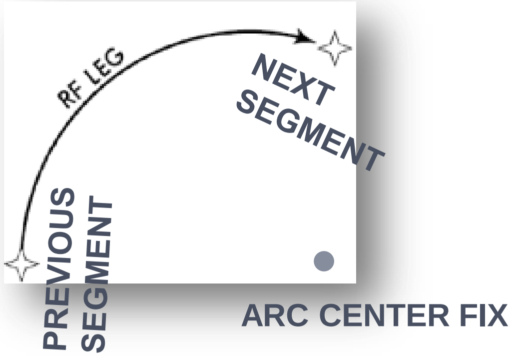


RNP AR Definition

RNP AR stands for **A**uthorization **R**equired (ICAO wording), equivalent to RNP SAAAR (ex-FAA wording)

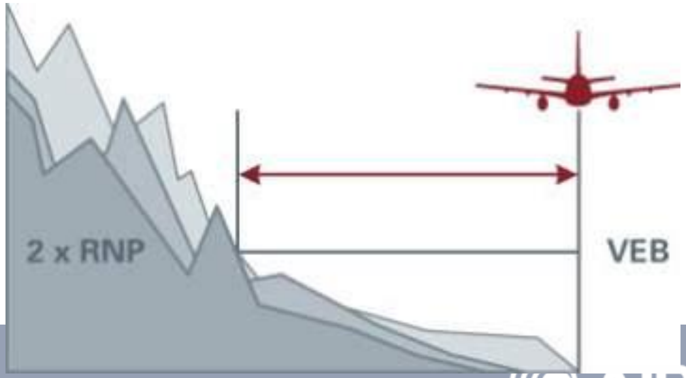
An RNP AR procedure has one of the following characteristics:

- ✓ Reduced RNP values lower than 0.3 NM in approach (down to 0.1 NM) or lower than 1 NM in missed approach and/or departure;



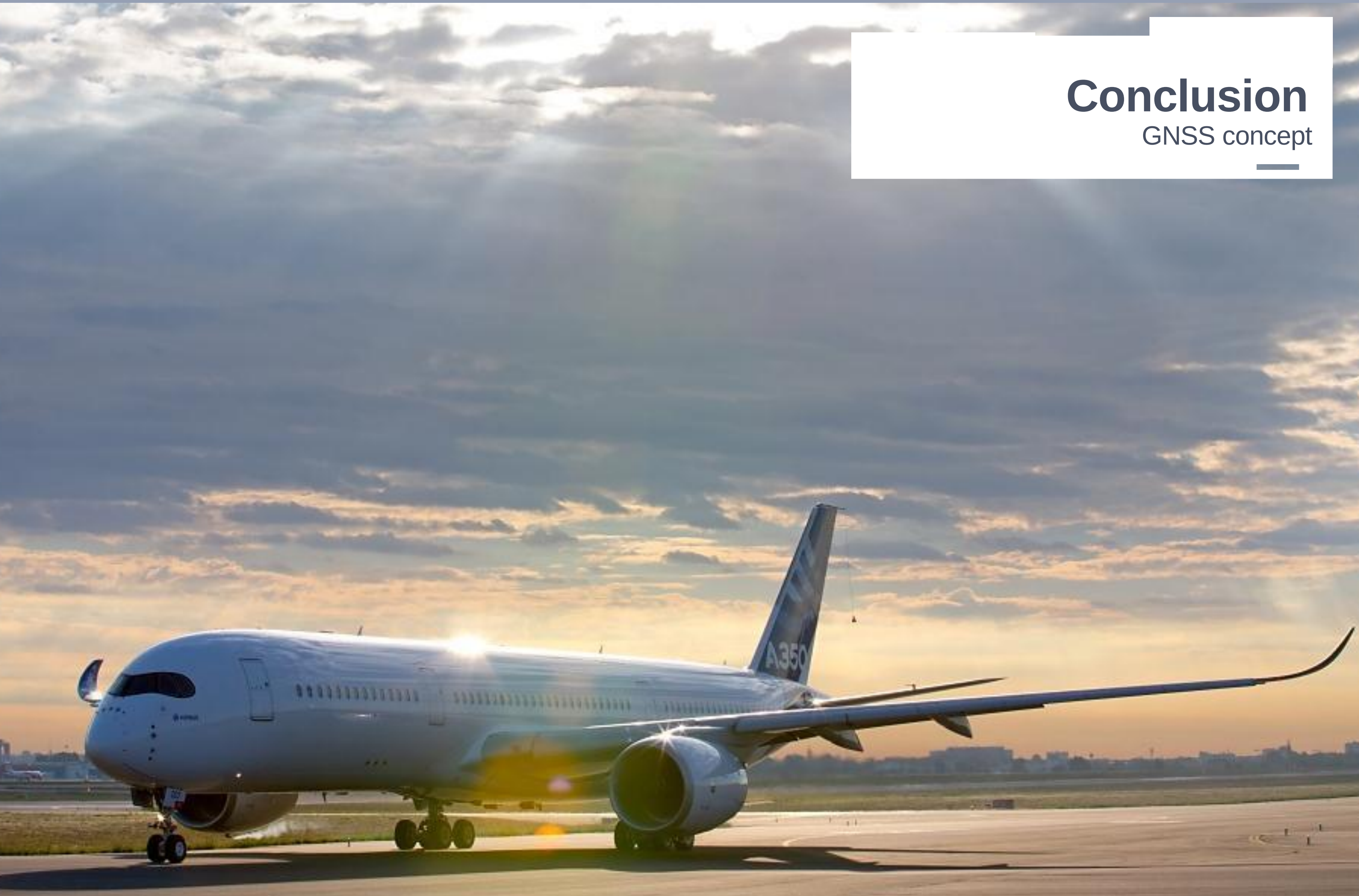
- ✓ Curved flight path after FAF (RF legs);

- ✓ Reduced obstacle protections, at 2xRNP, without buffers laterally and using a VEB vertically



Conclusion

GNSS concept



Summary

- GNSS provide global navigation coverage
- RNP = RNAV + Onboard monitoring and alerting
- Different methods to compute aircraft position.
- ABAS already provide huge operational benefits (Baro VNAV down to 250ft DH).
- Most of the > 100 seats aircraft do not have SBAS capabilities.
- Appropriate predictions means should be available before starting the operations.

Performance Based Navigation (PBN) Solution

Any Questions?