ICAO PBN Workshop
Tanzania

Introduction to RNAV

Outlines

- Introduction to RNAV
  - Introduction
  - Conventional vs RNAV
  - RNAV positioning
  - RNAV calculator

« ***Area navigation (RNAV).*** A method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained navigation aids, or a combination of these. »

RNAV System - History

Some history

Visual References (Stars…)

Instrument landing System: **1938**

VOR (Airways): **1960s**

Introduction of 2D RNAV VOR/DME: **1975**

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

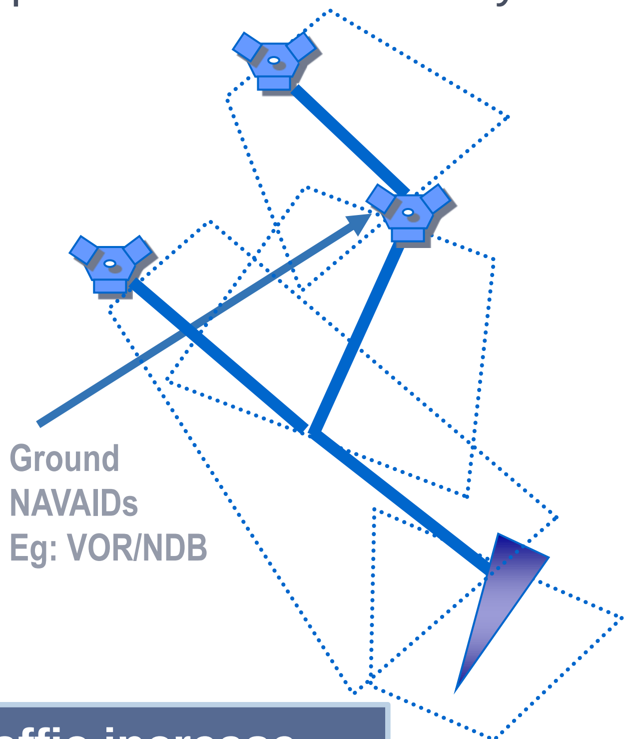
PBN ICAO mandate: **2016**

RNAV System - History

- RNAV began in the US in the 1970's and the certification/approval requirements followed evolutions of this concept and of its associated technologies.
  - AC 90-45 « Approval of area navigation systems for use in the US NAS » issued in 1969.
  - AC 90-45A issued in 1975
    - 2D RNAV with vertical guidance for advisory
    - Positioning based on VOR/DME
  - AC 20-130 Approval of multi-sensor navigation system for use in the US NAS » issued in 1988.
    - Positioning based on VOR/DME, DME/DME and/or Inertial
  - AC 20-130A issued in 1995 addressing FMS and GPS systems.
  - AC 90-100A (RNAV for Enroute and Terminal area) and AC 90-101 (RNAV for specific approaches: RNP AR) issued in 2007
  - …

Conventional navigation versus RNAV

- 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



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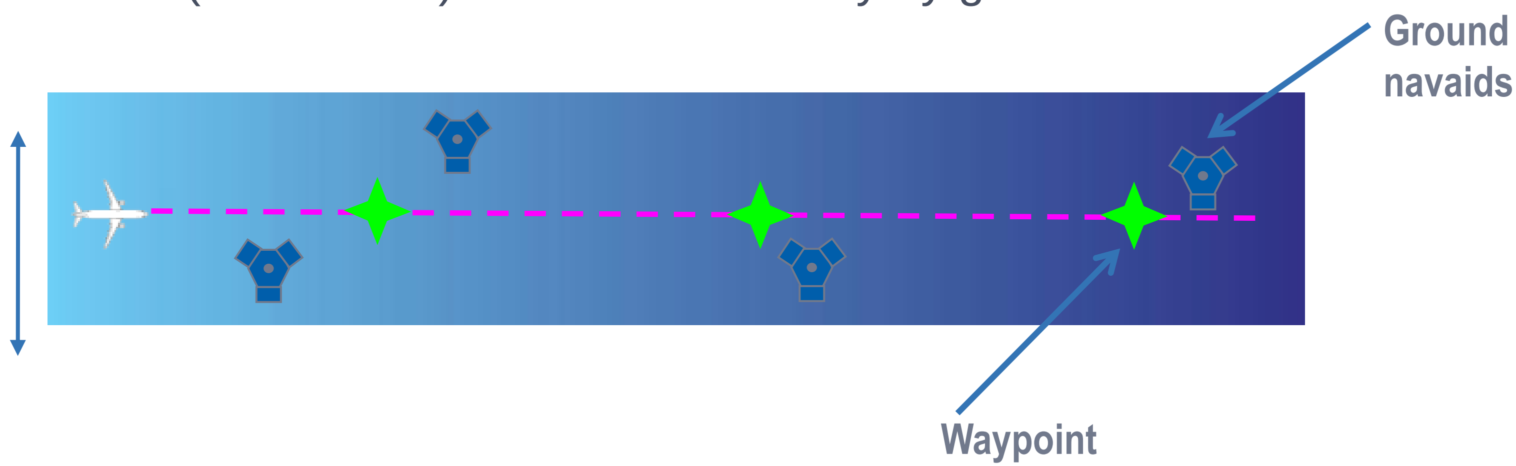
Widely used but no more suitable due to traffic increase and high fuel cost

RNAV Definition

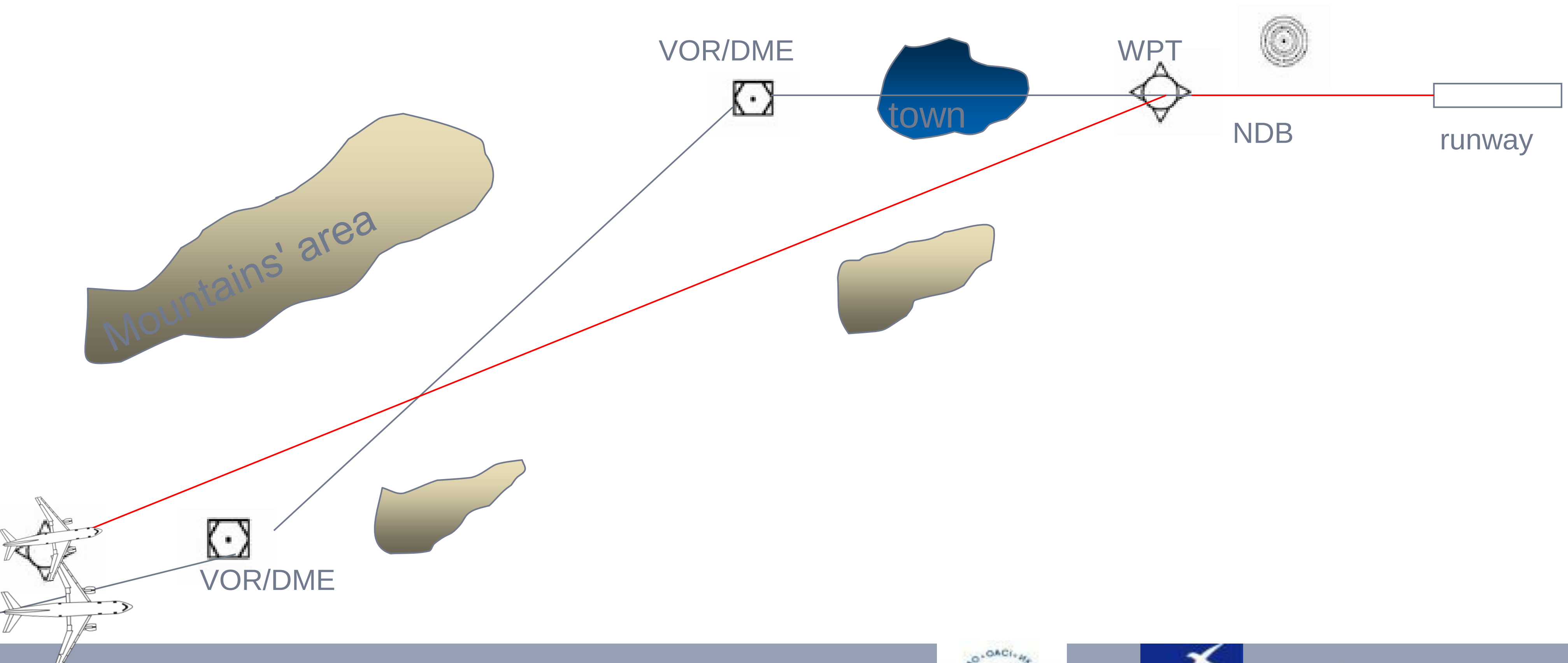
- **RNAV** stands for Area Navigation
- **RNAV** : Capability to fly any desired flight path, defined by waypoints such as geographic fixes (LAT/LONG) and not necessarily by ground navaids



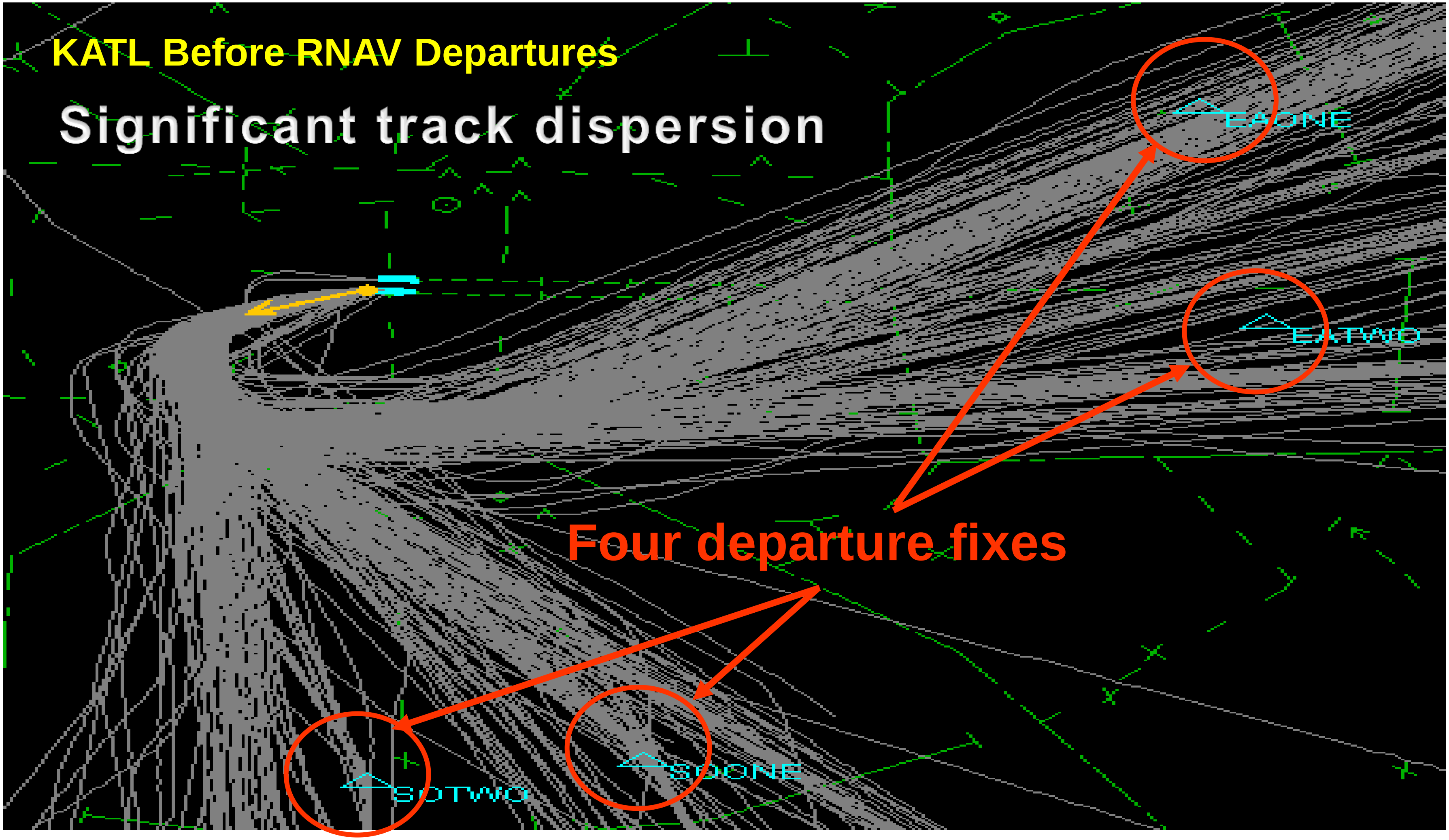
RNAV capability is linked to aircraft on-board equipments (RNAV systems)

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

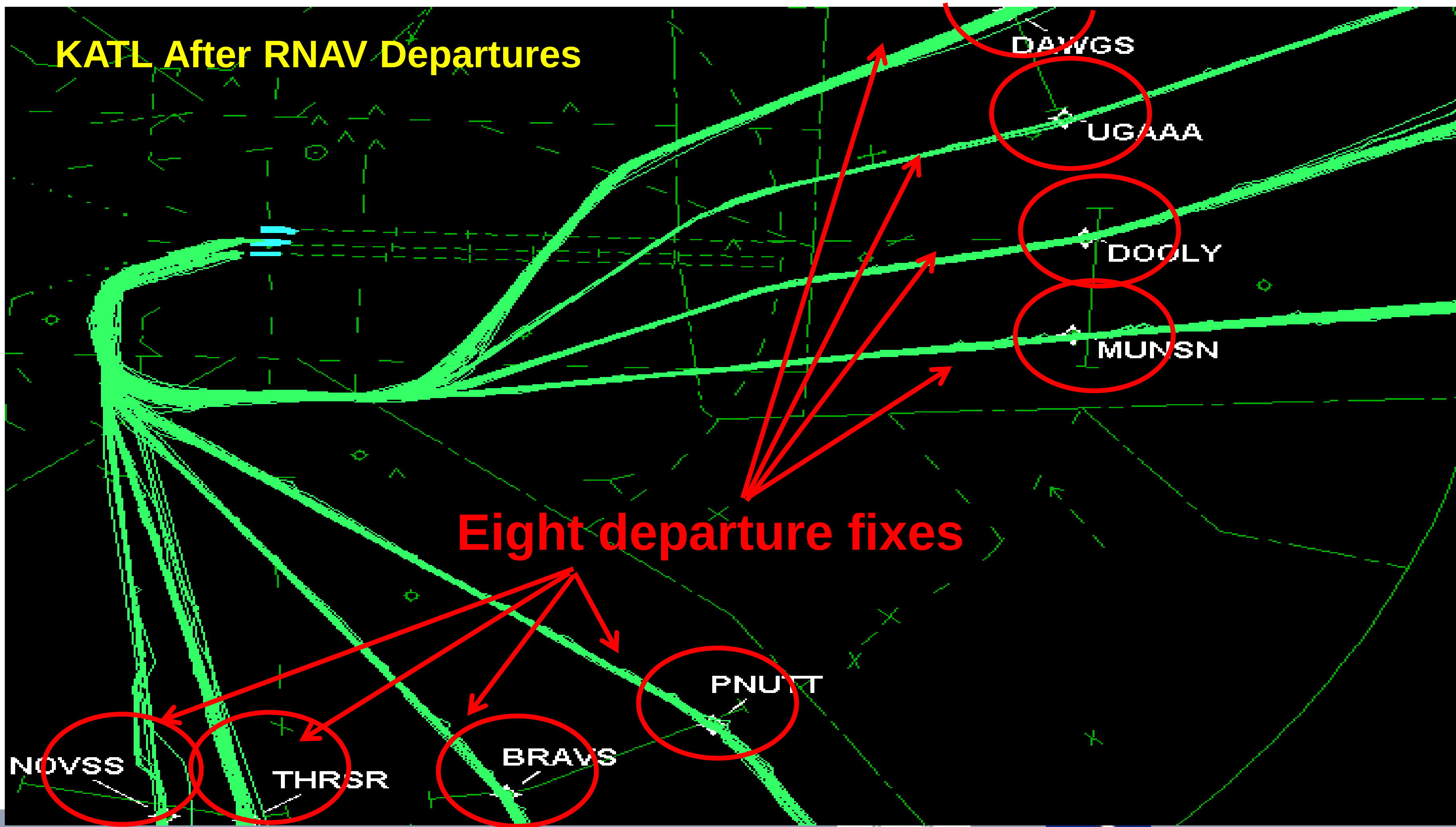
RNAV advantage



PBN Predictability

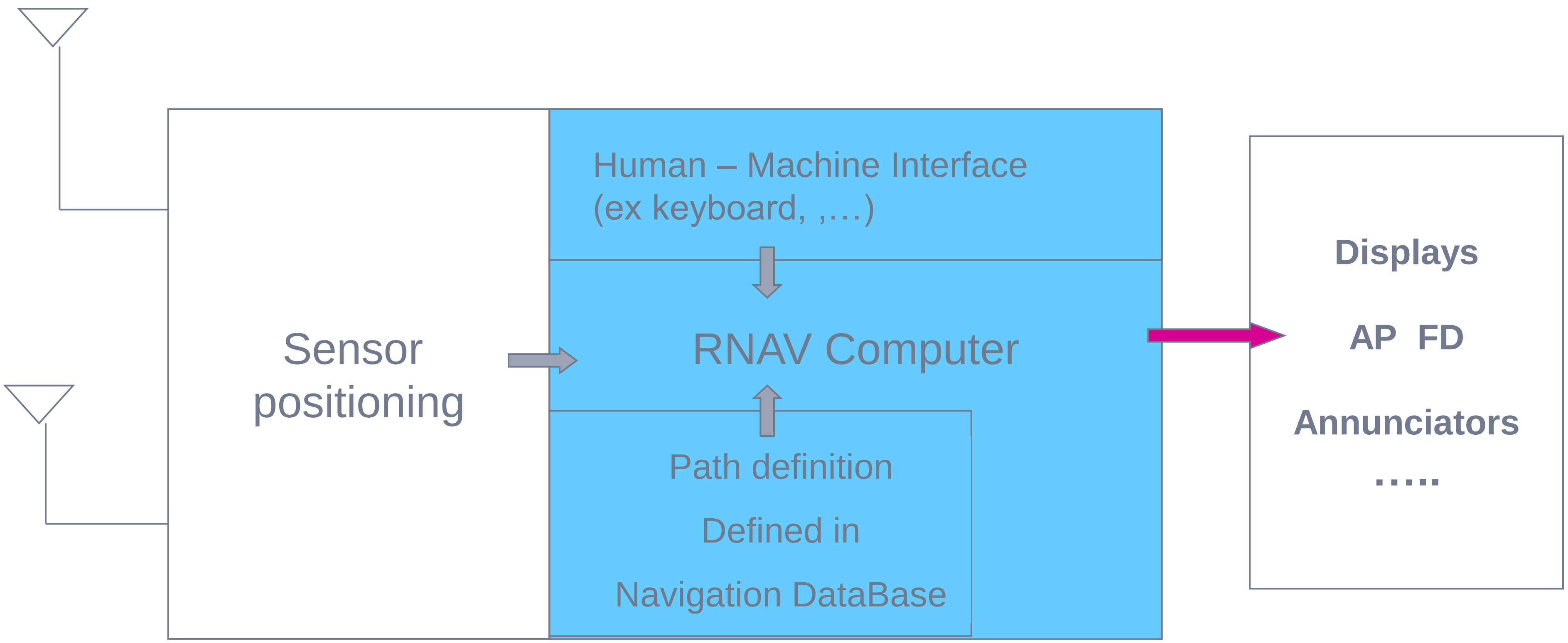


PBN Predictability

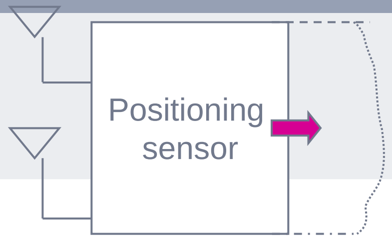


The RNAV system

RNAV system - Basic principle



RNAV positioning



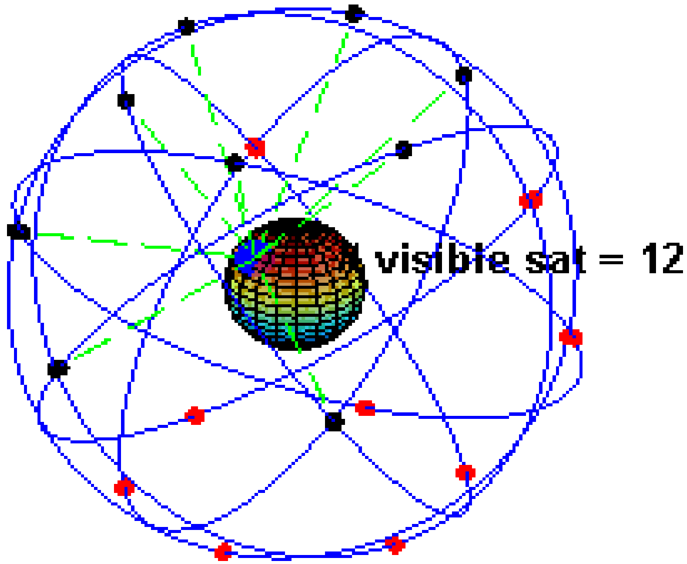
- Determine the aircraft position (latitude and longitude)
- The aircraft can determine its position on the following sensors:
  - GNSS
  - DME/DME
  - VOR/DME
  - Inertial

Positioning : GNSS

- Based on GPS constellation
- A constellation of 24 satellites* into 6 orbital planes

Position calculated in the WGS84 reference system

Actual accuracy within about ten meters



Worldwide coverage

Usable all phases of flight

* USA engagement on the minimal GPS constellation

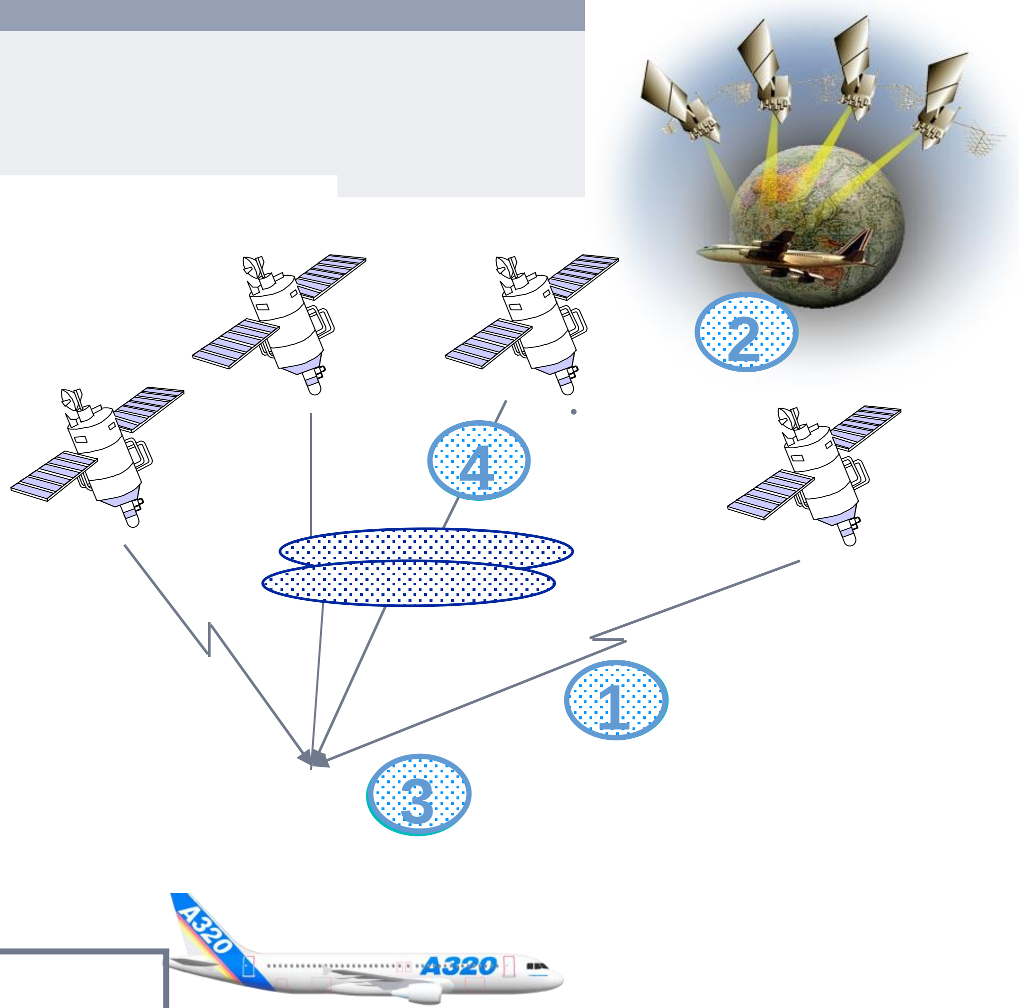
Positioning : GNSS

1. Measurement of the distance user – satellite from time information (satellite and user clocks)

2. GPS signal contains satellite position

3. Determination of the navigation solution by triangulation

4. Error calculation



	GPS user positioning accuracy (95% of time, global average) Annexe 10 – attachement D
Horizontal position error	33 m (108 ft) SA ON – 13m (43 ft) SA OFF
Vertical position error	73 m (240 ft) SA ON – 22m (72ft) SA OFF

Positioning : GNSS

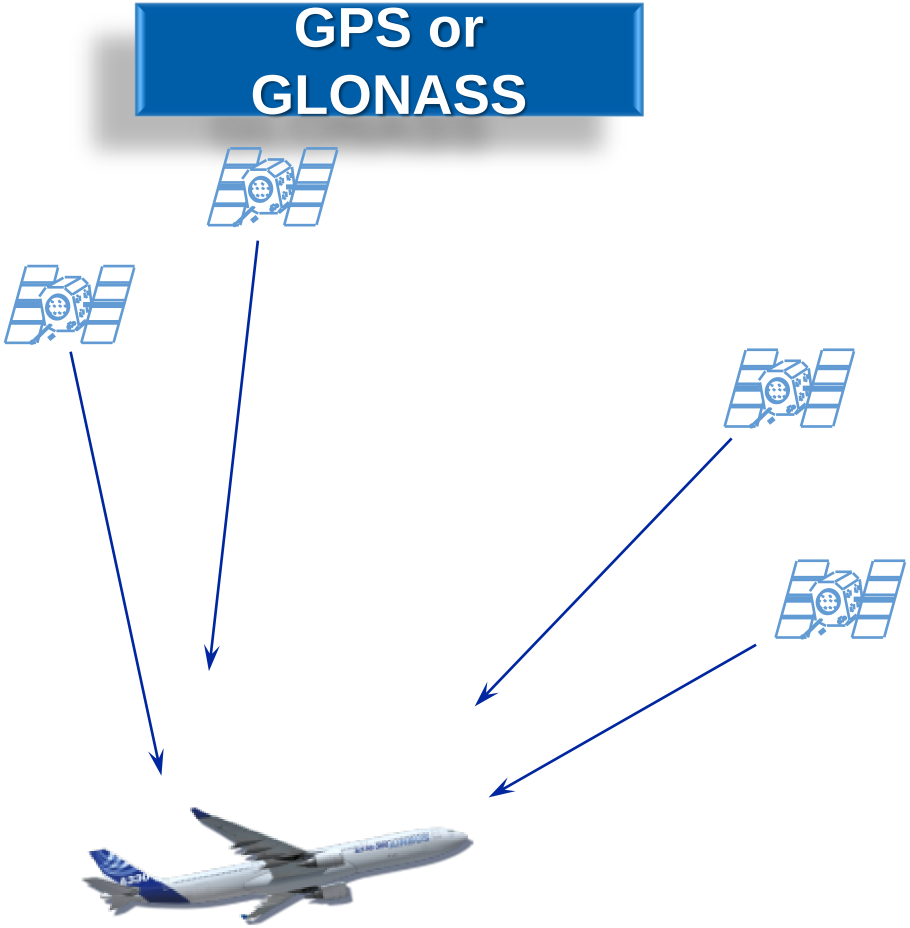
- GPS alone performance does not meet ICAO requirements for navigation
- ABAS Autonomous Based Augmentation System is required to check integrity of the GPS data
  - Horizintal Alarm Limit (HAL)
  - 2 Nm (En route), 1 Nm (Terminal area) and 0.3 Nm (Final Approach)
- Two techniques:

RAIM	AAIM
Stand-alone integrity control by the receiver	Stand-alone integrity control by the aircraft
Stand-alone GNSS receiver Multi-sensors system	Multi-sensors system
Based on the redundancy and the geometry of GPS satellites	Based on the combination of GNSS signal with other sensors (example: inertial system)

- Accuracy (NSE) (on board – TSO C129 performance requirements)
  - 0.124 Nm (95%) in En-route and Terminal area
  - 0.056 Nm (95%) in Approach

RAIM : Receiver Autonomous Integrity Monitoring
AAIM : Aircraft Autonomous Integrity Monitoring

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

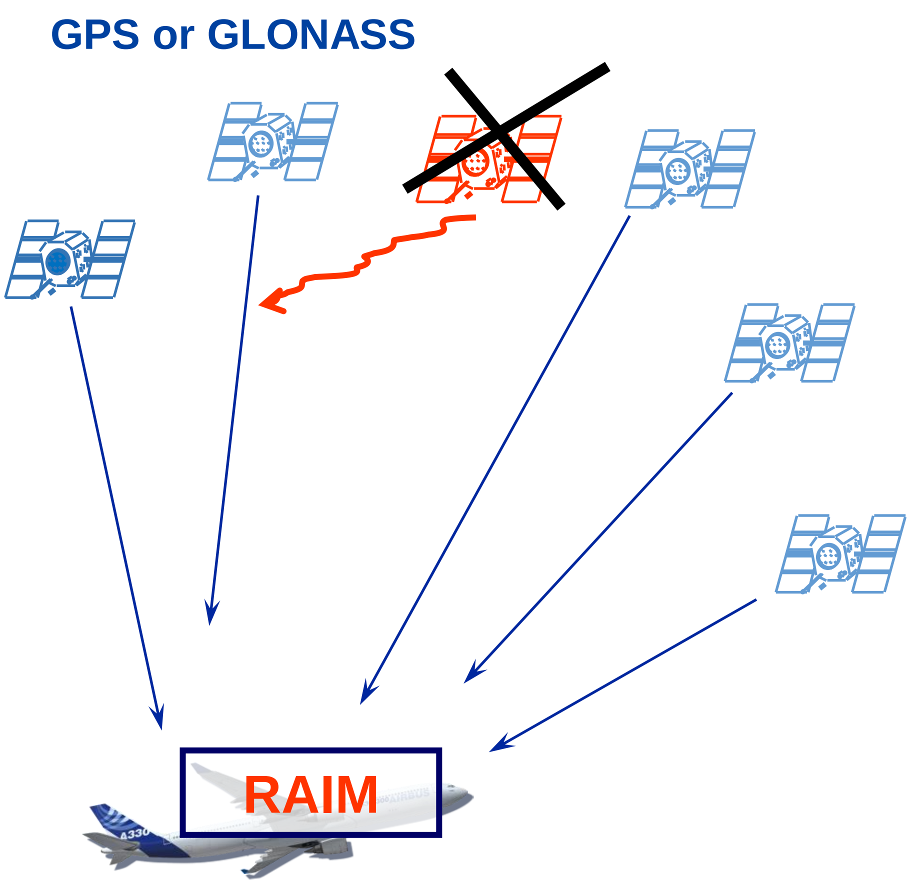
- ✓ To know quality of computed position
- ✓ To be warned if anything goes wrong

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

Positioning : GNSS

Note that : for approach the GPS can be completed with

- a satellite based augmentation signal SBAS (ex WAAS, EGNOS)
  - Increase precision and integrity => used for Approach with vertical guidance (part of PBN)
- A ground based augmentation signal – GBAS
  - Used for precision approach (not part of PBN)

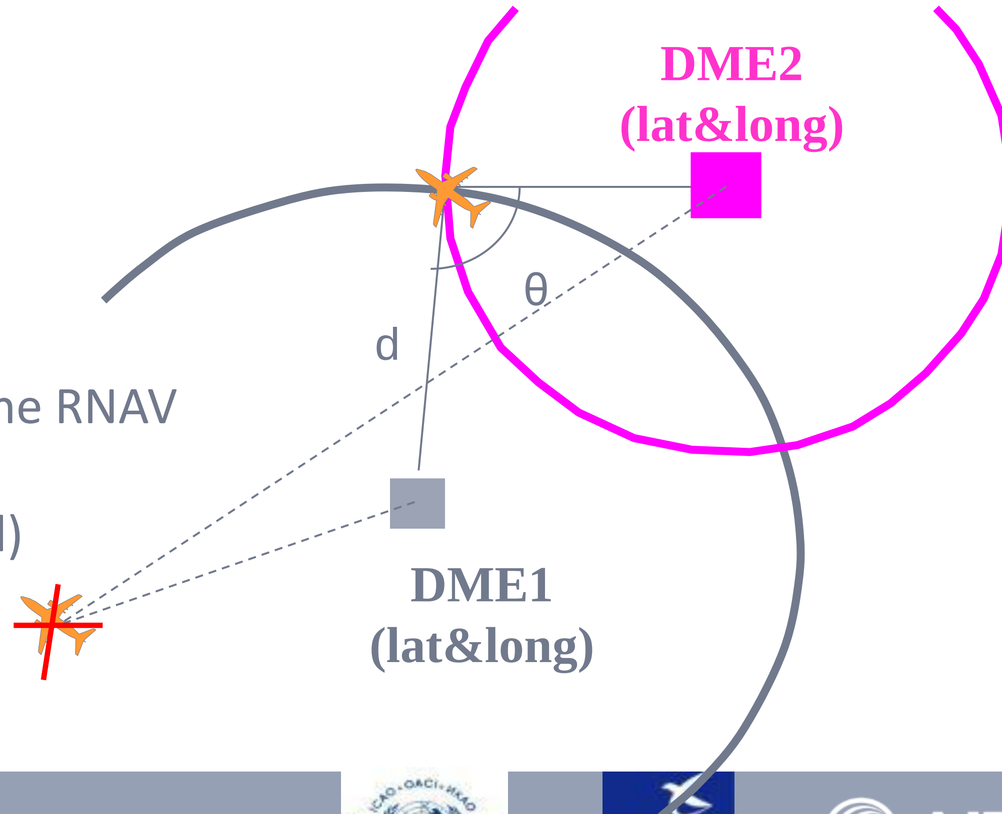
Positioning : DME/DME

- Position calculated (lat&long) from 2 DME distances
- To have the accuracy performance within 1NM:

  $30° \leq \theta \leq 150°$

- FMS constraints:

  $3NM < d < 160NM$



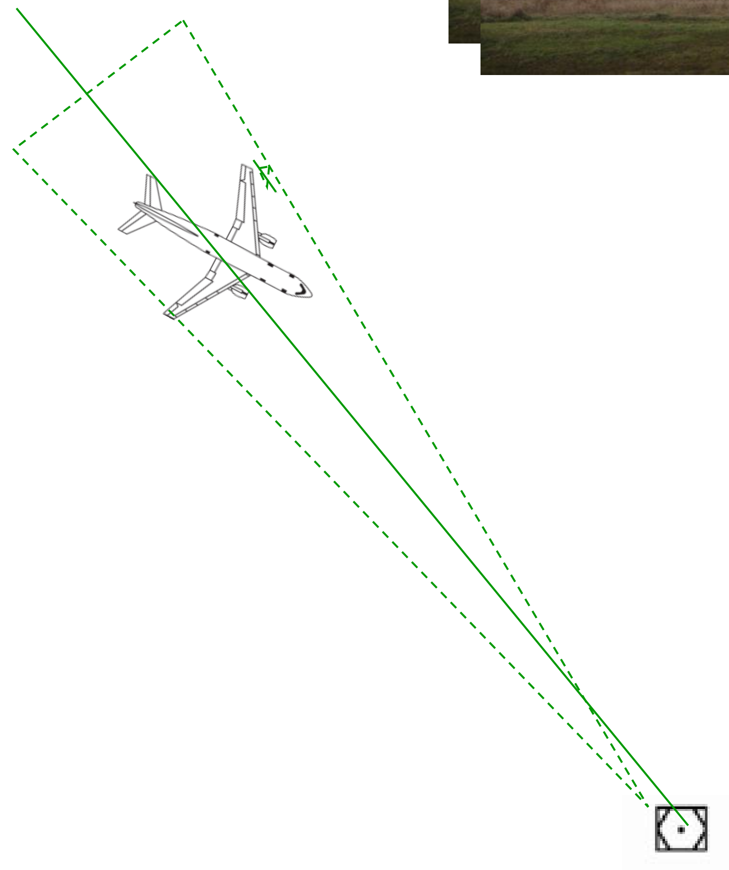
•The DME is selected and tuned by the RNAV system
•Scanning DME (with multiple chanel)

Positioning : RNAV Inertial

- Autonomous Navigation
- Positioning
  - Position determined through computations based on accelerometer and laser gyro sensed signals
  - IRU senses accelerations along and rotation about each of the three axis.
  - Inertial drift
    - 2Nm/hour
    - High drift rate the first ½ hour of navigation (8Nm/hour)
- Alignment of IRS is required before the flight
  - IRS alignment consists of determining local vertical and initial position and angles.
- with / without automatic radio updating of aircraft position
- Inertial data can be used to update GPS data and provide an Hybrid GPIRS position (e.g Airbus aircraft).

Positioning : VOR/DME

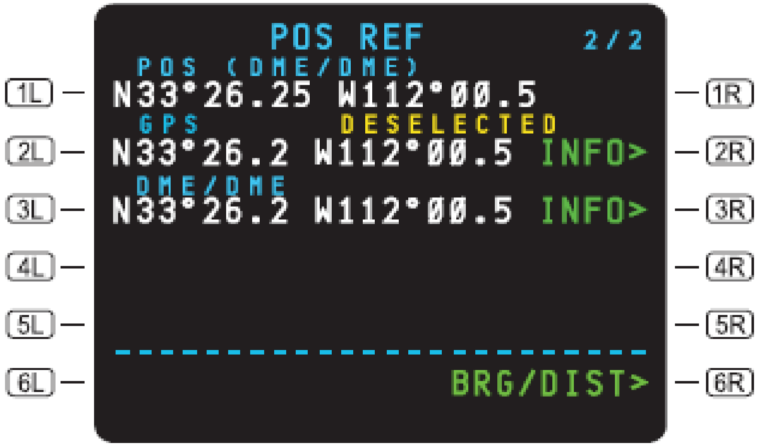
- Use of VOR/DME
- Position computed from a DME distance and a VOR angle (bearing)
- Accuracy
  - Depend on the distance from the station
- The VOR/DME is selected and tuned by RNAV
- Positioning not accurate enough (no future)



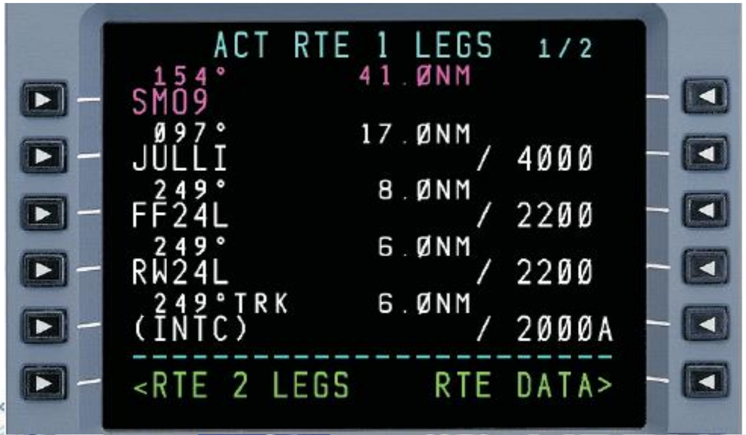
RNAV calculator

- Compute a guidance to follow the required path
  - Based on the positioning
  - Based on a selected trajectory

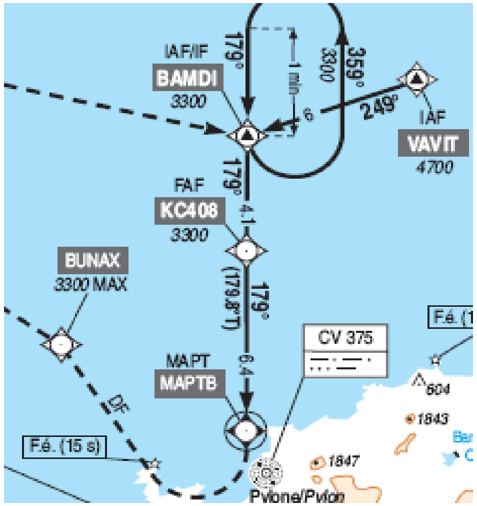
- Positioning can use one or several positions
  - Simple (ex GPS),
  - Hybridization (ex GPIRS),
  - IRS Radio update (ex IRS/DME),
  - Blended position (ex w_1IRS+ w_2 Radio+ w_3 GPS)



- Selected Trajectory
  - By the pilot
  - Flight Plan, route, procedure,…



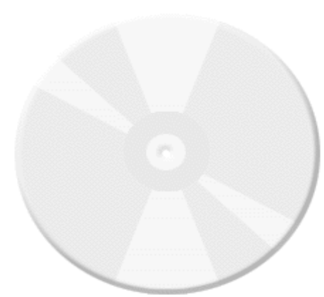
RNAV computer and the coding cycle



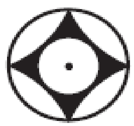
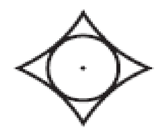
REPERES *FIXES*	IDENTIFICATION *IDENTIFICATION*	COORDONNEES *COORDINATES*	CODAGE PROPOSE *PROPOSED CODING*	STATUT *STATUS*
IAF	VAVIT	42° 48' 38.6"N - 008° 55' 09.4"E	IF	Fly By
IAF/IF	BAMDI	42° 46' 34.5"N - 008° 47' 30.4"E	IF/TF	Fly By
FAF	KC408	42° 42' 28.4"N - 008° 47' 31.7"E	TF	Fly By
MAPT	MAPTB	42° 36' 01.31"N - 008° 47' 33.54"E	TF	Fly Over
MATF	BUNAX	42° 39' 16.0" N - 008° 39' 11.0" E	DF	Fly By
MATF	CALNO	42° 47' 58.0" N - 008° 21' 52.0" E	TF	Fly Over
MATF	BAMDI	42° 46' 34.5" N - 008° 47' 30.4" E	DF	Fly Over

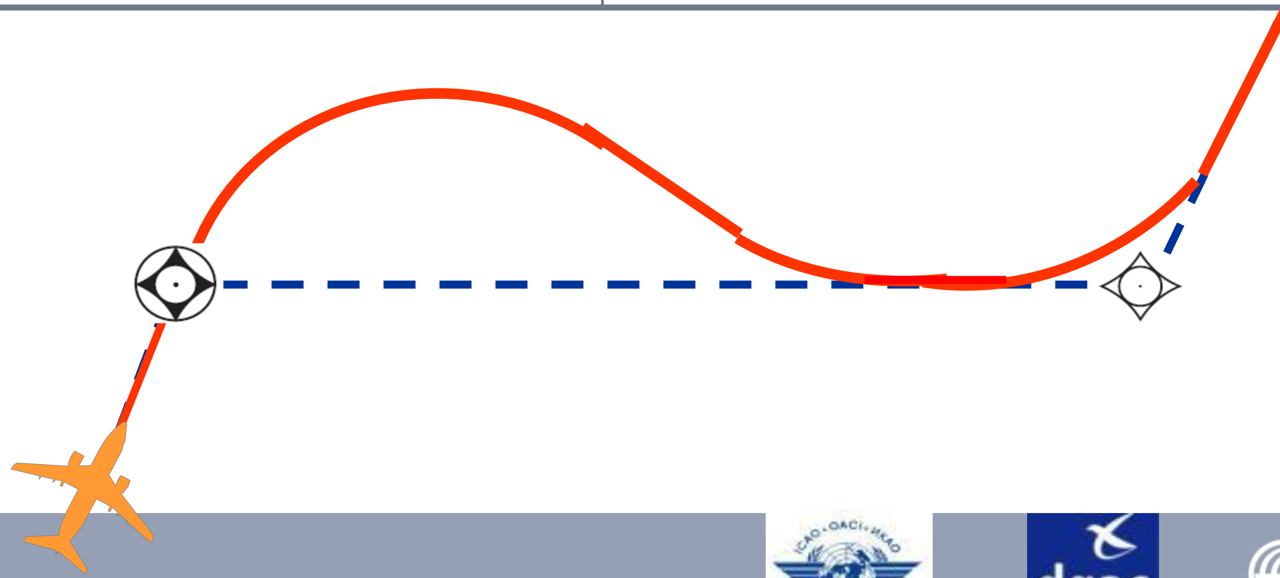
ARINC 424 : standardizes waypoints path terminators and routes « depiction »

Translation of the route or the procedure from the paper chart into an electronic format



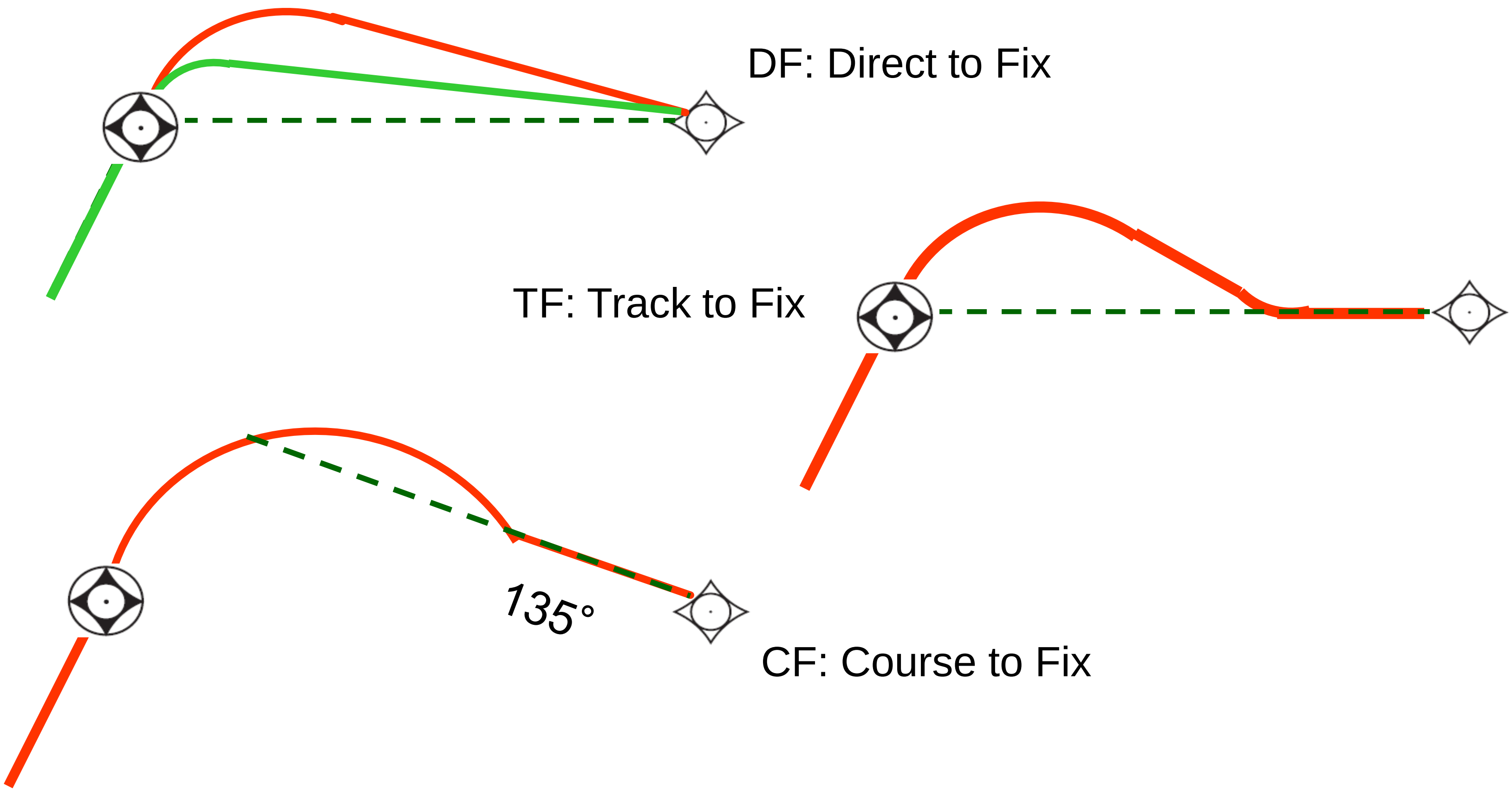
Two types of waypoints for two different trajectories :

Fly-over waypoint	Fly-by waypoint
	



Example of ARINC 424 path terminator

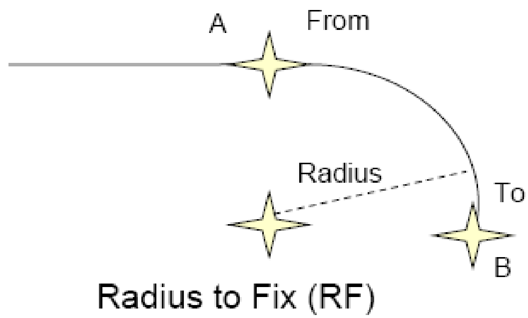
Several different trajectories may exist to reach the same point



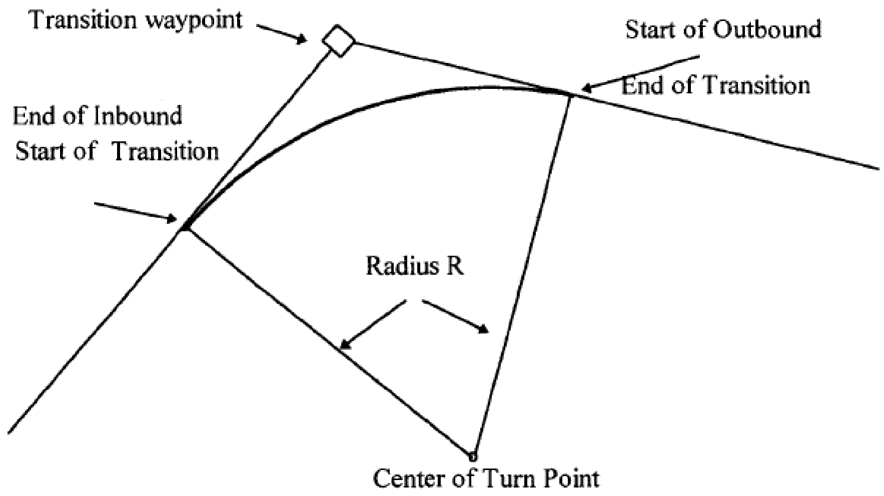
According to the path terminator, the trajectory is more or less predictable

Other example of ARINC 424 path terminator

- Transition with repeatability of the path



RF leg can be used in terminal area and Approach



For routes R will depend on the level of the transition

Radius to Fix (RF leg)

Fixed Radius Turn (FRT)

Examples of RNAV Avionics Architecture

RNAV architecture for General aviation example – Stand alone

Display system slaved to the route to be flown

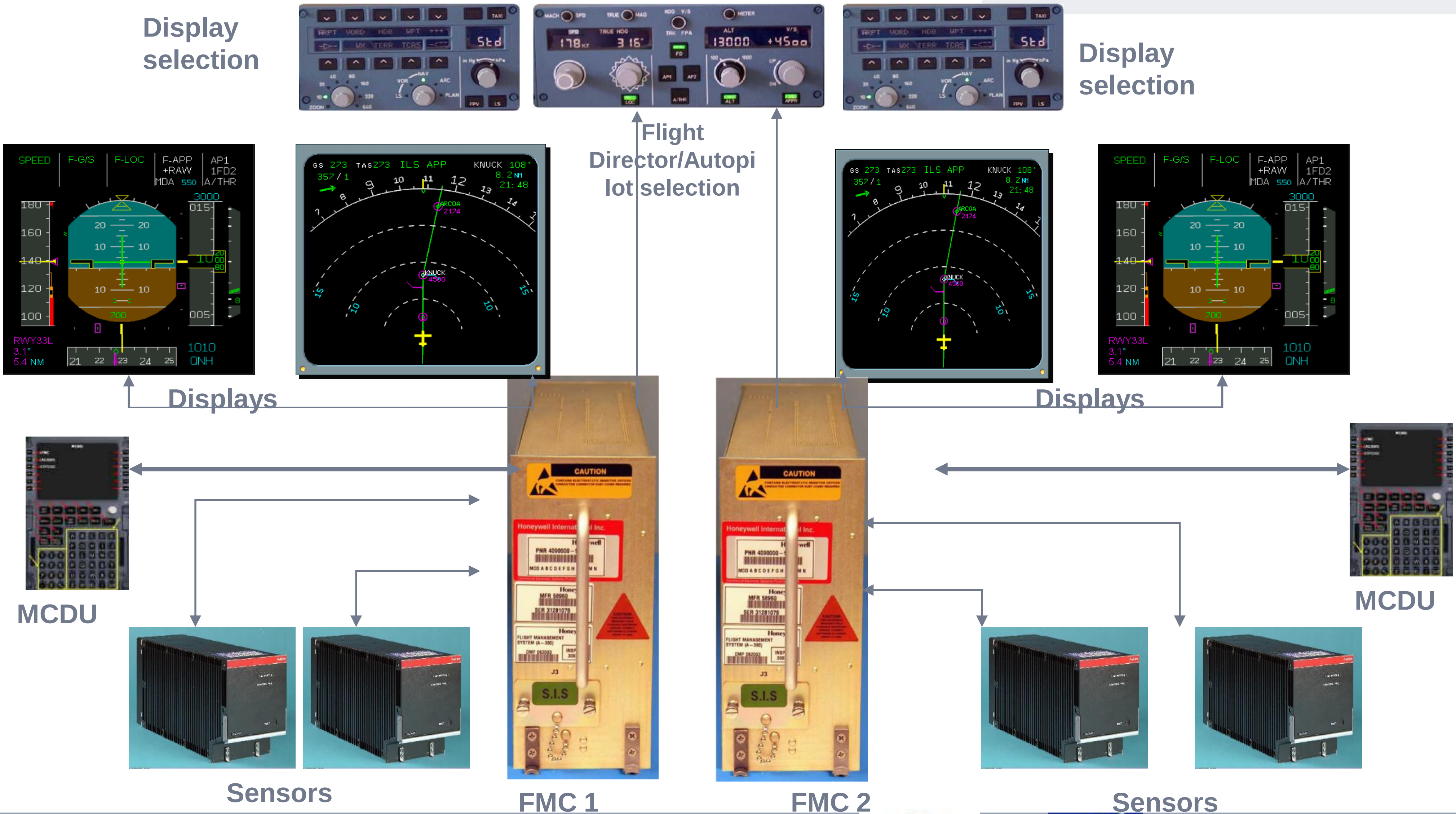
Flight Technical Error (FTE)

Remote annunciator and selection

NSE

Standalone RNAV system

RNAV architecture for air transport aircraft – Multisensors



End of the presentation

Thank you for your attention – Any question ?