ICAO PBN Workshop
Tanzania

Introduction to RNAV
Outlines

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

« 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. »
Some history

RNAV System - History

Visual References (Stars…)

Instrument landing System: 1938

VOR (Airways): 1960s

Introduction of 2D RNAV VOR/DME: 1975


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
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** 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
KATL Before RNAV Departures

Significant track dispersion

Four departure fixes
PBN Predictability

KATL After RNAV Departures

Eight departure fixes
The RNAV system
RNAV system - Basic principle

Sensor positioning

Human – Machine Interface (ex keyboard, …)

Path definition
Defined in Navigation DataBase

RNAV Computer

Displays
AP FD
Annunciators

…..
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

* USA engagement on the minimal GPS constellation

Position calculated in the WGS84 reference system

Worldwide coverage

Usable all phases of flight

Actual accuracy within about ten meters
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

<table>
<thead>
<tr>
<th></th>
<th>GPS user positioning accuracy</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(95% of time, global average)</td>
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<tr>
<td></td>
<td>Annexe 10 – attachement D</td>
</tr>
<tr>
<td>Horizontal position error</td>
<td>33 m (108 ft) SA ON – 13m (43 ft) SA OFF</td>
</tr>
<tr>
<td>Vertical position error</td>
<td>73 m (240 ft) SA ON – 22m (72ft) SA OFF</td>
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</tbody>
</table>
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:

<table>
<thead>
<tr>
<th>RAIM</th>
<th>AAIM</th>
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<tbody>
<tr>
<td>Stand-alone integrity control by the receiver</td>
<td>Stand-alone integrity control by the aircraft</td>
</tr>
<tr>
<td>Stand-alone GNSS receiver</td>
<td>Multi-sensors system</td>
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<tr>
<td>Multi-sensors system</td>
<td></td>
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<tr>
<td>Based on the redundancy and the geometry of GPS satellites</td>
<td>Based on the combination of GNSS signal with other sensors (example: inertial system)</td>
</tr>
</tbody>
</table>

• 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

GPS or GLONASS

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 satellites 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
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)
• Position calculated (lat&long) from 2 DME distances

• To have the accuracy performance within 1NM:

\[30^\circ \leq \theta \leq 150^\circ\]

• FMS constraints:

\[3 \text{NM} < d < 160 \text{NM}\]

• The DME is selected and tuned by the RNAV system

• Scanning DME (with multiple channel)
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 $\frac{1}{2}$ 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 w₁IRS + w₂ Radio + w₃ GPS)

• Selected Trajectory
  – By the pilot
  – Flight Plan, route, procedure,…
RNAV computer and the coding cycle

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:

<table>
<thead>
<tr>
<th>Fly-over waypoint</th>
<th>Fly-by waypoint</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Fly-over Waypoint" /></td>
<td><img src="image2" alt="Fly-by Waypoint" /></td>
</tr>
</tbody>
</table>
Several different trajectories may exist to reach the same point.

- **DF**: Direct to Fix
- **TF**: Track to Fix
- **CF**: Course to Fix

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

**Radius to Fix (RF)**

RF leg can be used in terminal area and Approach

**Fixed Radius Turn (FRT)**

For routes R will depend on the level of the transition
Examples of RNAV Avionics Architecture
RNAV architecture for General aviation example – Stand alone

Remote annunciator and selection

Display system slaved to the route to be flown

Flight Technical Error (FTE)

Standalone RNAV system

NSE
RNAV architecture for air transport aircraft – Multisensors

Display selection

Flight Director/Autopilot selection

Displays

MCDU

Sensors

FMC 1

FMC 2

MCDU

Sensors
End of the presentation

Thank you for your attention – Any question?