PBN Airspace Design Workshop

Area Navigation

Asia and Pacific Regional Sub-Office
Beijing, China
Learning Objectives

By the end of this presentation, you will be:

- Aware of the evolution of Navigation System
- Understand the concept of area navigation
- Identify the main components required to perform area navigation
Evolution of Navigation System

- Navigation at the beginning
  - Flight during the day
  - Follow roads, rivers, railroads, buildings, telephone lines and other things can be recognized in the air

- Early days – Try to overcome night and weather
  - 1910s – Bonfires and Beacons
  - Early 1920s – lighted airport boundaries, Spot-lit windsocks, Rotating lighted beacons on towers, Lighted airways, etc.
    - First lighted airways(1923) : Dayton to Columbus, Ohio (USA) – 72Km
Evolution of Navigation System

- **Late 1920s ~ 1930s – Begin to use Radio**
  - Radio for Two-Way communication
    - Weather Updates
    - Request help with navigation
  - Radio for Navigation
    - Radio Maker Beacons
    - 4 Course Radio Range System
  - Pilot listen for Navigation Signals

- **1930s ~ 1940s – Use of VOR**
  - Static-free VHF Omni-directional Radio Range
    - Pilot navigate by instrument
  - VOR (with improvements) becomes a primary NAVAID for decades
    - Define routes
    - Supports approach procedures
Evolution of Navigation System

- **1940s ~ 1950s – Introduction of ILS**
  - 1929: First system tested
  - 1946: (Provisional) ICAO selects ILS as primary landing system for international “trunk’ airports
  - Today, ILS has the capability to support CAT I, CAT II and CAT III precision approaches and will be used more

- **From 1950s – Use of DME**
  - 1961: first regular civil use (pilot tuned)
  - In PBN, DME use is based on automatic tuning

- **From 1970s ~**
  - Development of long range navigation system, etc. INS, LORAN, OMEGA
  - Introduction of FMS with database
  - Use of GPS (GNSS)
Conventional Navigation

- Ground based navigation aids (NAVAIDs)
  - Aircraft overfly NAVAID or intersection

- Display accuracy is a function of distance
  - Protection area grows, in other words “Splayed”
    - Limited Design Flexibility
**First Generation Digital Avionics**

- **Appeared in early 1970s**
  - Basic ‘cruise control’
  - Capable of storing 4 manually inserted ‘waypoints’
  - Provided guidance on Course Deviation Indicator (CDI)
  - Flew to waypoint before switching to next leg

- **Conventional ATS Routes**
  - Defined by NAVAIDs
  - NAVIAD coordinates loaded into computer
  - Automatic route guidance provided from computer
Evolution to Area Navigation

- Long Range Navigation (LORAN)
  - US system terminated in 2010

- Omega Radio Navigation System
  - Terminated in 1997

- Inertial Navigation

- VOR/VOR and VOR/DME

- Multi sensor Flight Management System (FMS)

- GPS, GLONASS and Augmentations
Definition of Area Navigation

- **Area Navigation (RNAV)** is a method of navigation which permits aircraft operation on any desired flight path:
  - Within the coverage of station-referenced NAVAIDs, or
  - Within the limits of the capability of self-contained system, or
  - A combination of these capabilities

- **Area navigation is the key enabler for the Performance Based navigation (PBN)**
Benefits of Area Navigation

- Ground or Space Based NAVAIDs
  - Aircraft fly “Waypoints”

- Protected area is constant (“Linear”)
  - Increased Design Flexibility
How is Area Navigation enabled?

- Through the use of a navigation computer
- Waypoints (coordinates) are input into computer
  - Manual entry permitted but limits capabilities
  - Automatically with an integrated database
- Pilot creates route (series of waypoints), i.e. flight plan
- Computer estimates position using navigation sensors fitted, i.e. VOR/DME, DME/DME, GNSS, and compares estimation to defined route
- Deviation between the position and defined path will create guidance information
Aircraft Functionality

- Database
  - Route
  - NAVAIDs
  - Airspace constraints

Range and/or Bearing Information

- Performance Management (Climb/Descent/Turns)
- Position Estimation
- Path Comparison & Path Correction
Navigation Database

- Most navigation applications require a database
- Contains pre-stored information as requested by the AO such as:
  - NAVAIDS
  - Waypoints
  - ATS Routes
  - Terminal Procedures
  - Related information
- The navigation computer will use this information for flight planning and cross-checking of sensor information
- Databases are compiled by a specialist of ‘data house’ and updated, i.e. Annex 15 AIRAC cycle
- Today, the size of the database is cause for concern
Navigation Computer Functionality

- Computers built by different OEMs
  - Operating system differences – just like Microsoft, Apple, Linux
  - Industry Standard: ARINC 424

- Functionality defines what the computer is capable of:
  - Turn performance
  - Path terminators
  - Automatic leg sequencing
  - Offset
  - Database
  - Alerting
  - Outputs (Display)
Flight Segments

- For the navigation computer, the flight consists of different elements known as ‘segments’
- Each segment is held in a different part of the database
- The segment must be connected together by the pilot
- ‘Route Discontinuity’ occurs when segments are not linked
Turn Performance : En-route

- Aircraft flies from **waypoint to waypoint**
- Track between waypoints are known as ‘leg’
- Aircraft flies ‘legs’ as ‘To-To-To’
- At, or abeam, the waypoint, the computer steps to the next one in the flight plan
- **Computer will initiate turn** approaching waypoint to be turn complete on next leg
- **Turn anticipation is not always the same**
  - Creates track dispersion
Instrument Flight Procedures

- IFPs define the departure and arrival paths of the aircraft
- Links terminal airspace to the ATS route
  - Responsibility of procedure designers
- Computer limitations
  - Only one STAR allowed per procedure
- So ‘Transition’ connects STAR to Approach segment
- Additional functionality enabled for IFPs, such as:
  - Waypoint Transitions
  - Path Terminators
Waypoint Transition : IFP

- A specified geographical location expressed in WGS84 coordinates
- Used to define an area navigation route or flight path of an aircraft employing area navigation
- A flight path is defined by waypoints and/or by specific condition as altitude
  - Fly-over waypoint
  - Fly-by waypoint
- Fly-by waypoint is preferred but MAPt, MAHF and HWP are always Fly-over waypoint
Path Terminators: IFP

History of Path Terminator

- The advent of airborne data base, new method is required to store and manage instrument flight procedures which have been published in charts and text forms in the data base
- Since 1970s, ARINC-424 standard has been used to codify IFR procedures and put into electronic databases
- A key concept in ARINC 424 is that of the “Path-Terminator” a specific way of defining a leg or segment of an IFR procedure

Path Terminator

- Transform procedures into coded flight path
- Set of two alphabetic characters that define the flight path along the leg, and the terminator or end-point of the leg
- Instruct to navigate from a stating point to a specific point of terminating condition
- Only ONE Path Terminator associated with a WP, but additional constraints (altitude or speed) are possible
Path Terminators: IFP

- TF: Track between Fixes (Fly-Over)

Navigate towards the ending waypoint on the track between the two waypoints.
Path Terminators : IFP

- TF : Track between Fixes (Fly-By)

Navigate towards the ending waypoint on the track between the two waypoints.
Path Terminators : IFP

- DF : Direct to Fix

From the actual position navigate direct to the ending waypoint whatever the track is.
**Path Terminators : IFP**

- **CF : Course to Fix**

Navigate towards the ending waypoint on a specified track.
Path Terminators: IFP

- RF: constant Radius arc to a Fix

- Circular path about a defined turn center.
- Radius: distance from turn center to termination point
- Turn range: between 2° and 300°
Area Navigation Systems

- **Legacy systems**
  - VOR/DME or DME/DME navigation
  - INS
  - Few aircraft still operating this type of equipment

- **Stand-alone GNSS**
  - Common in GA
  - Often used in commuter/feederliner operations
  - Sometimes installed in jet transport aircraft
  - Automatic mode switching
  - Human factors considerations
  - Functionality limitations
  - Proper installation required
Area Navigation Systems

Flight Management Systems
- With/Without GNSS updating
- With/without IRS
- Dual/single FMS
- Variations in functionality
- Variations in displays
Modern Navigation Aids

- 2 PFD
  (Primary Flight Display)
- 2 ND
  (Navigation Display)
- 1 EWD
  (Engine warning Display)
- 1 SD
  (System Display)
- 2 EFCP
  (EFIS Control Panel)
- 2 MCDU
  (Multipurpose Control & Display Unit)
FMS and Navigation

- **Navigation Computer**
  - Positioning
  - Flight planning
  - Trajectory prediction
  - Navigation radio tuning
  - Information display management

- **Aircraft Performance Management**
  - Optimized information on speed, altitude, vertical profile, etc.

- **Save cost for commercial airlines by aviation technology and precision instrument flight**
FMS and Navigation

- Pilot’s EFIS
- Controls and Displays (3)
- Radio Altimeter
- Air Data Computer
- VOR/ILS DME (2)
- Digital Clock
- IRS (3)
- Compass (2)
- Fuel System
- Autopilot/Flight Control Computer
- Thrust Management Computer
- Selectors and Annunciators
- ADS
- GNSS (2)
- TCAS
- EGPWS
FMS integrated Navigation Computer
Path Steering

Navigation Sensors
- GNSS
- DME
- VOR
- IRU

Database Identification, Fixes, Navaid Idents, etc

Selected FP & Nav Mode
Path Deviation
Steering Command

Display & Sys Alerting

A/C Flight Control Sys

User Interface
Path Steering

Path Definition

Position Estimation

Position Data & Sensors in Use

Sensor Control

Sensor Data

Estimated Position

Path Definition

Navaid Position & Elevation

Stored FP Data

NAV Computer

Navigation Database
In PBN, the lateral track accuracy required for a navigation application is dependent on:

- Navigation sensors
- Geometry of the NAVAIDs
- Quality of navigation data
- How the aircraft is flown
  - Automatic (AFCS)
  - Manually (following CDI)
- Display information
- Human error (manual input into computer)
Flight Profile with FMS

- Before T/O, the Flight Plan Route is loaded into the FMS.
- After T/O, the FMS captures the assigned Flight Plan Route.
- The FMS commands speed and thrust for optimum economy, calculating optimum altitude for the weight as the flight progresses.
- The FMS provides continual guidance along Flight Plan route including great circle routing.
- FMS calculates TOD for fuel efficient descent, i.e. idle thrust descent.
- Automatically complies with speed and altitude restrictions.
- Provides transition to automatic landing system.
- Advises pilot of correct landing speed.
Thank You