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, rives, 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

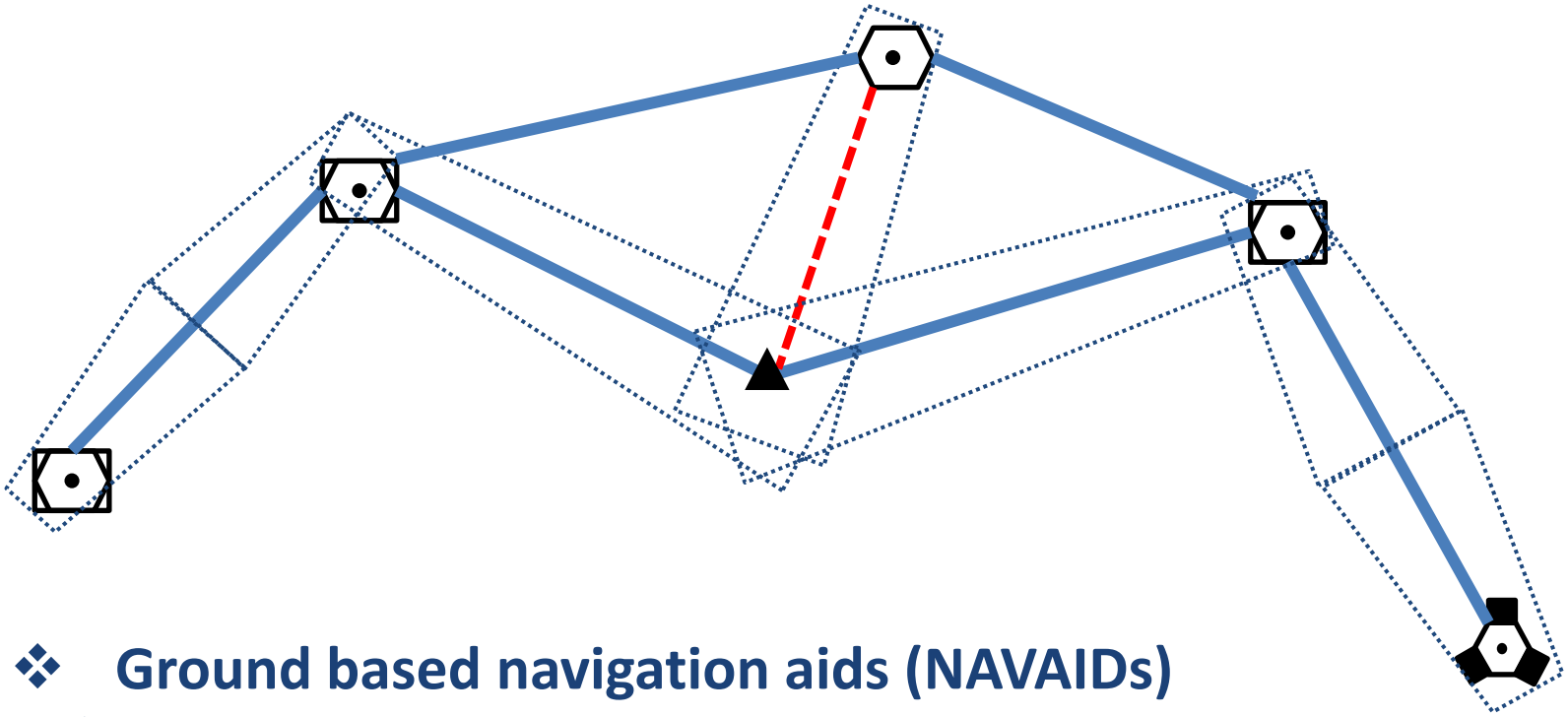
Evolution of Navigation System

- **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



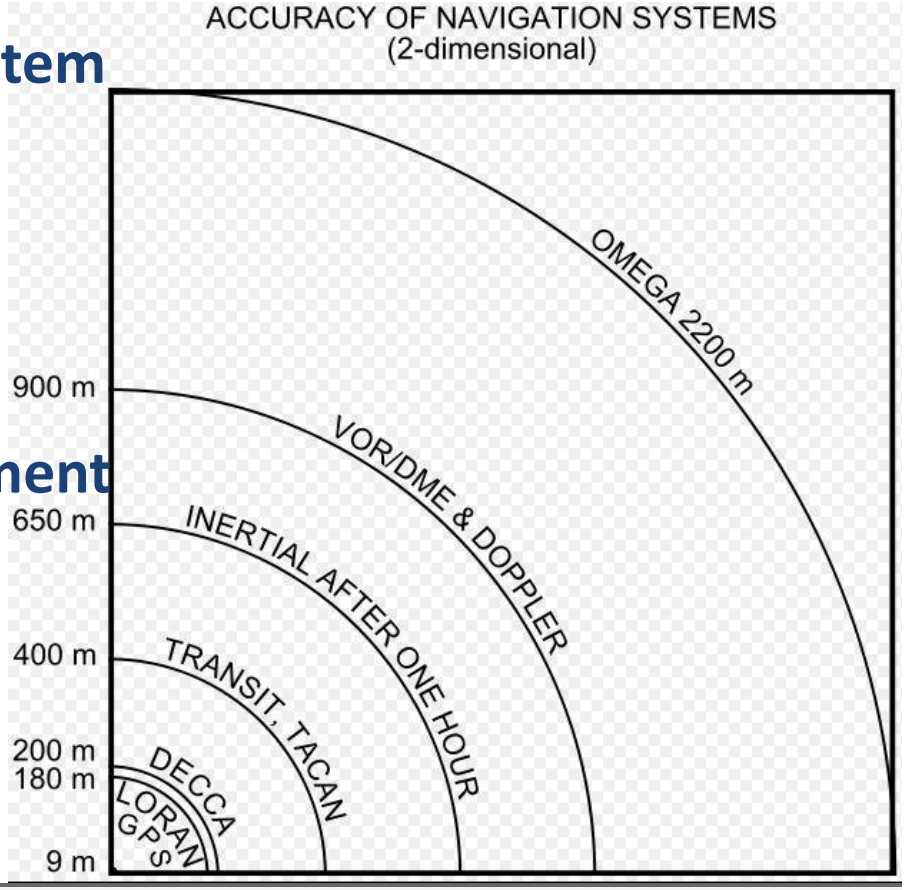
- **Ground based navigation aids (NAVAIDs)**
  - Aircraft overfly NAVAID or intersection
- **Display accuracy is a function of distance**
  - Protection area grows, in other words “Splayed”
    - ⇨ Limited Design Flexibility

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

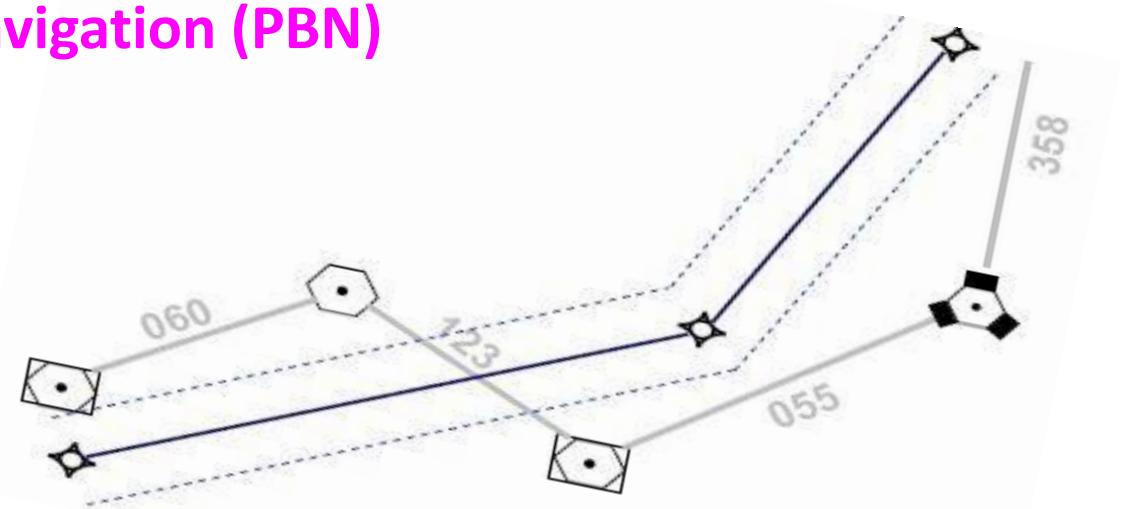
Evolution to Area Navigation

- **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**

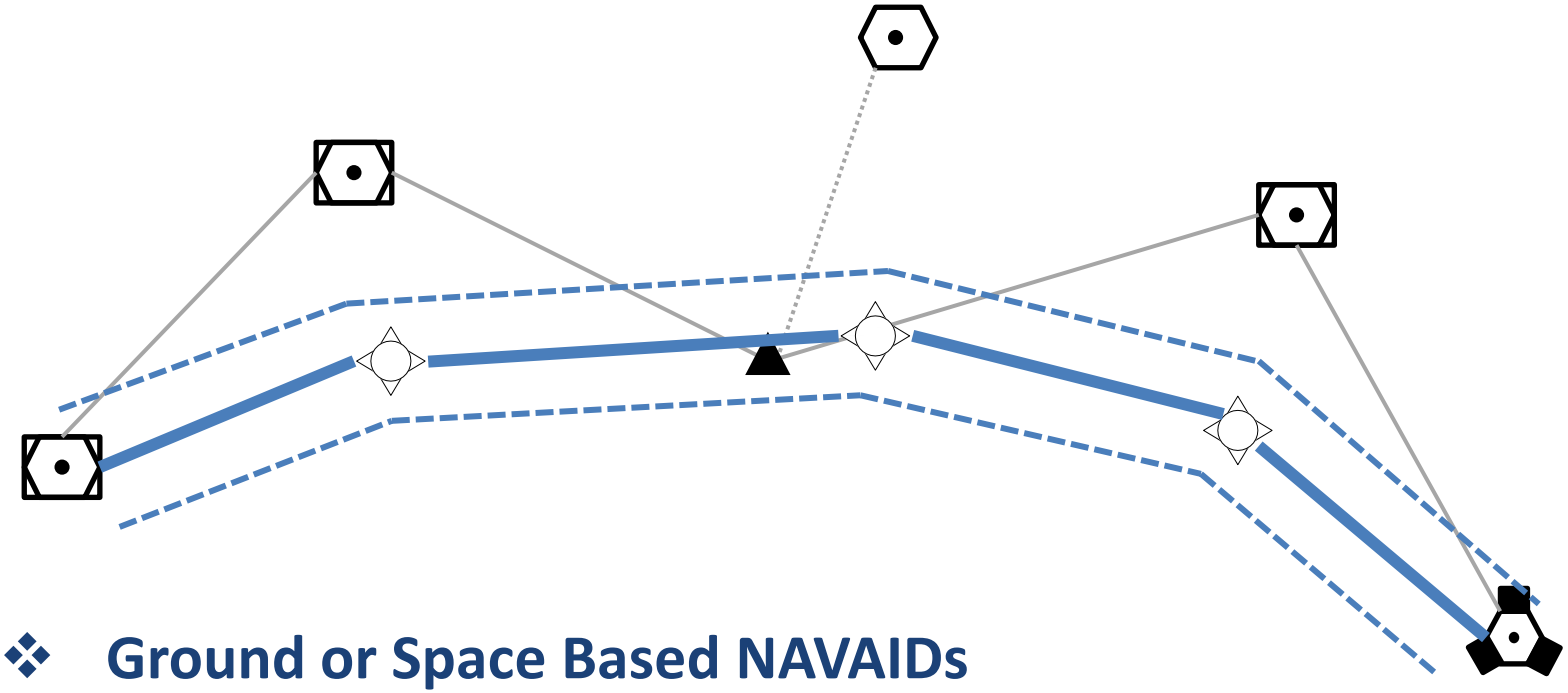


Definition of Area Navigation

- **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

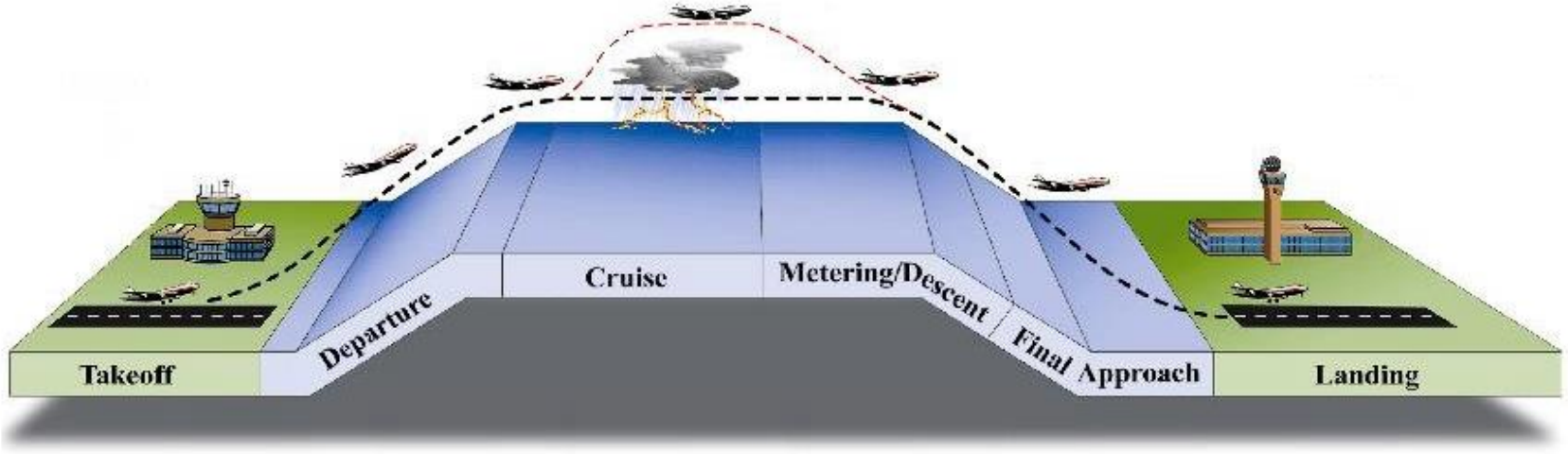
- Most navigation applications require a database
- Contains pre-stored information as requested by the AO such as:
  - NAVAIDS
  - Waypoints
  - ATS Routes
  - Terminal Procedures
  - Related information
- The navigation computer will use this information for flight planning and cross-checking of sensor information
- Databases are complied 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)

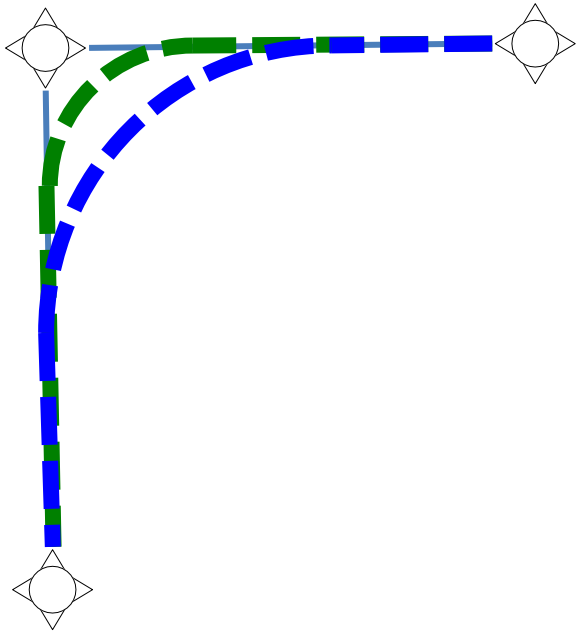
Flight Segments

- 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



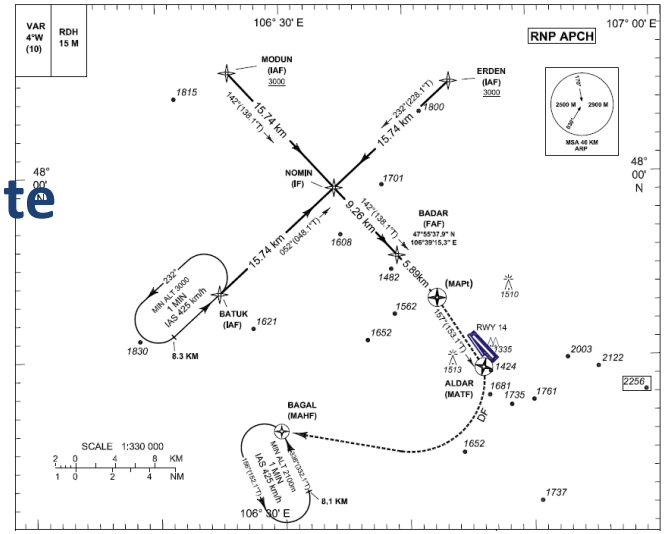
Turn Performance : En-route

- 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



RNAV (GNSS) RWY14-via NOMIN-MATF

Serial number	Path descriptor	Fix identifier	Flyover	Course °M(°T)	Dist,km	Turn direction	Altidute,m	Speed, (km/h)	Coordinates	VPA/RDH	Navigation performance	Reamarks
1	TF	NOMIN	–	142(138.1)	15.74	–	2300	–	47 59 20.88N 106 34 16.57E	–	PNP APCH	IF
2	TF	BADAR	–	142(138.1)	9.26	–	1860	–	47 55 37.99N 106 39 15.25E	–	PNP APCH	FAF
3	TF	MAPt	Y	142(138.1)	5.89	–	1550	–	47 53 16.10N 106 42 24.90E	3.0	PNP APCH	MAPt
4	–	THR14	–	142(138.1)	–	–	–	–	47 51 10.25N 106 45 12.72E	–	PNP APCH	THR14
5	CF	ALDAR	Y	157(153.1)	8.37	R	–	–	47 48 43.90N 106 45 50.10E	–	PNP APCH	–
6	DF	BAGAL	Y	–	–	R	–	–	47 46 10.84N 106 29 40.79E	–	PNP APCH	–

HOLDING PROCEDURE

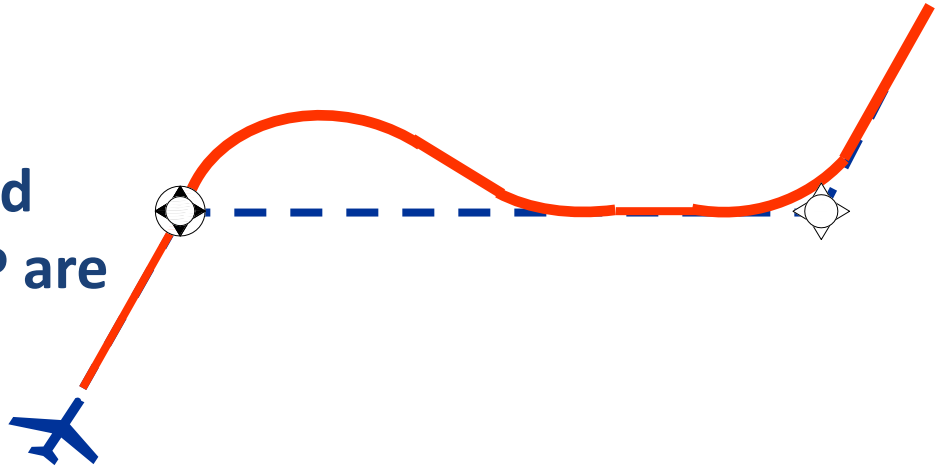
Holding Identification	Path descriptor	Fix identifier	Inbound course °M(°T)	Leg distance (KM)	Turn direction	Minimum altidute	Speed limit, (km/h)	Coordinates	VPA/RDH	Navigation performance	Reamarks
RNVAV (GNSS)RWY 14	HOLD	BATUK	052/(048.1)	8.33	L	3000	425	47 53 39.23N 106 24 53.42E	–	PNP APCH	1min (Outbound timing)

HOLDING PROCEDURE

Holding Identification	Path descriptor	Fix identifier	Inbound course °M(°T)	Leg distance (KM)	Turn direction	Minimum altidute	Speed limit, (km/h)	Coordinates	VPA/RDH	Navigation performance	Reamarks
RNVAV (GNSS)RWY 14	HM	BAGAL	336/(332.1)	8.10	L	2100	425	47 46 10.84N 106 29 40.79E	–	PNP APCH	1min (Outbound timing)

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

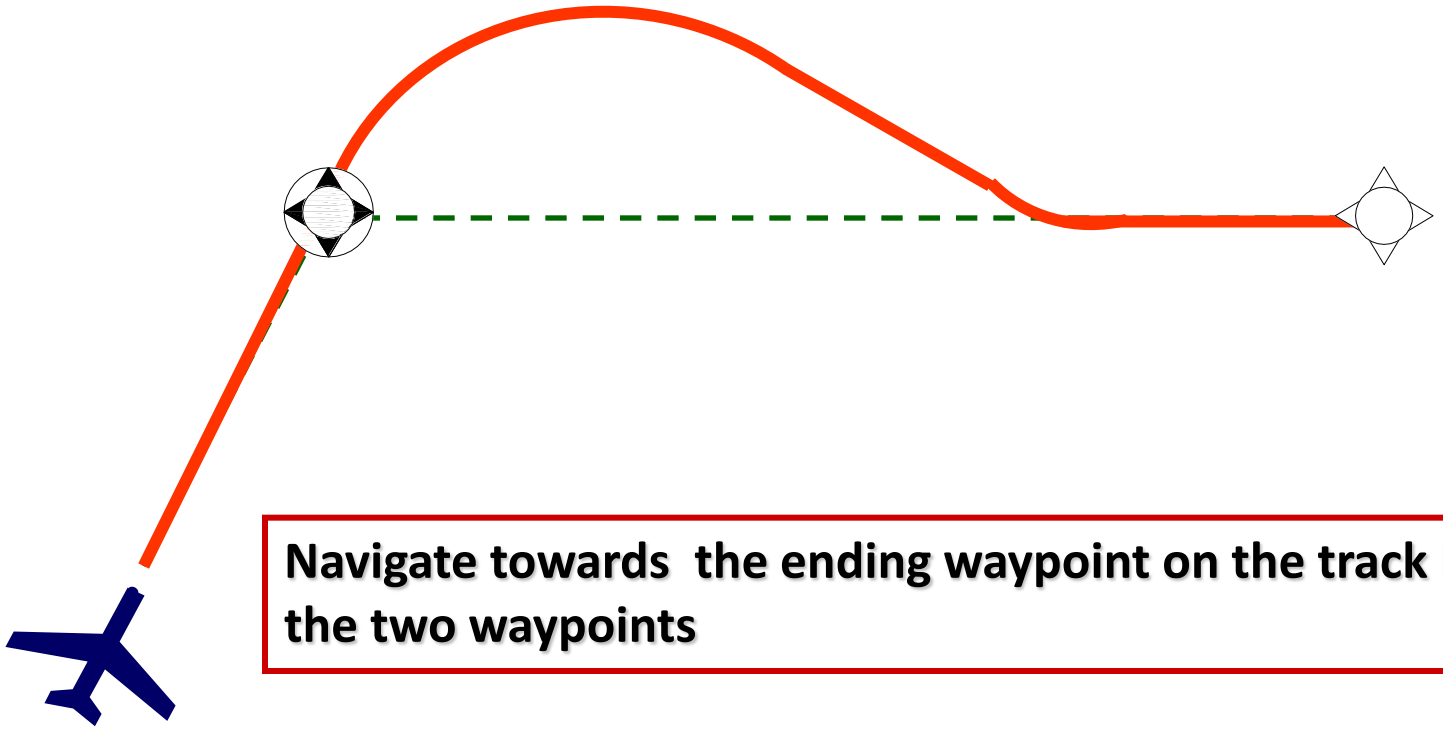


Path Terminators : IFP

- **History of Path Terminator**
  - The advent of airborne data base, new method is required to store and manage instrument flight procedures which have 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

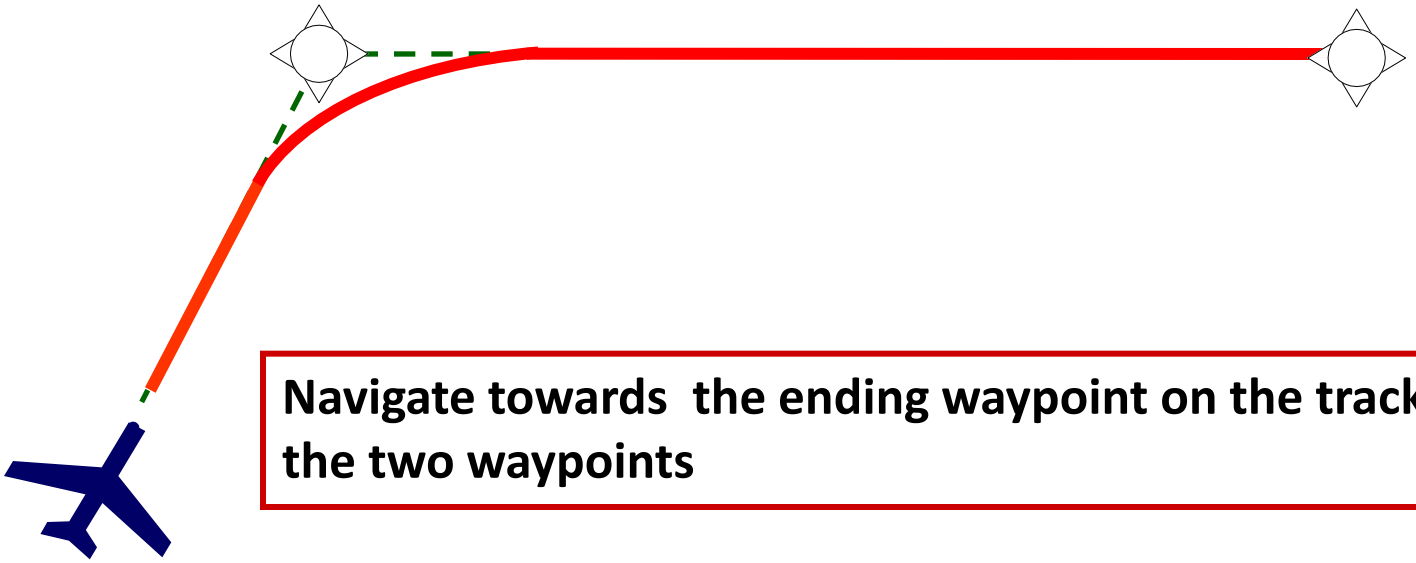
- TF : Track between Fixes (Fly-Over)



Navigate towards the ending waypoint on the track between the two waypoints

Path Terminators : IFP

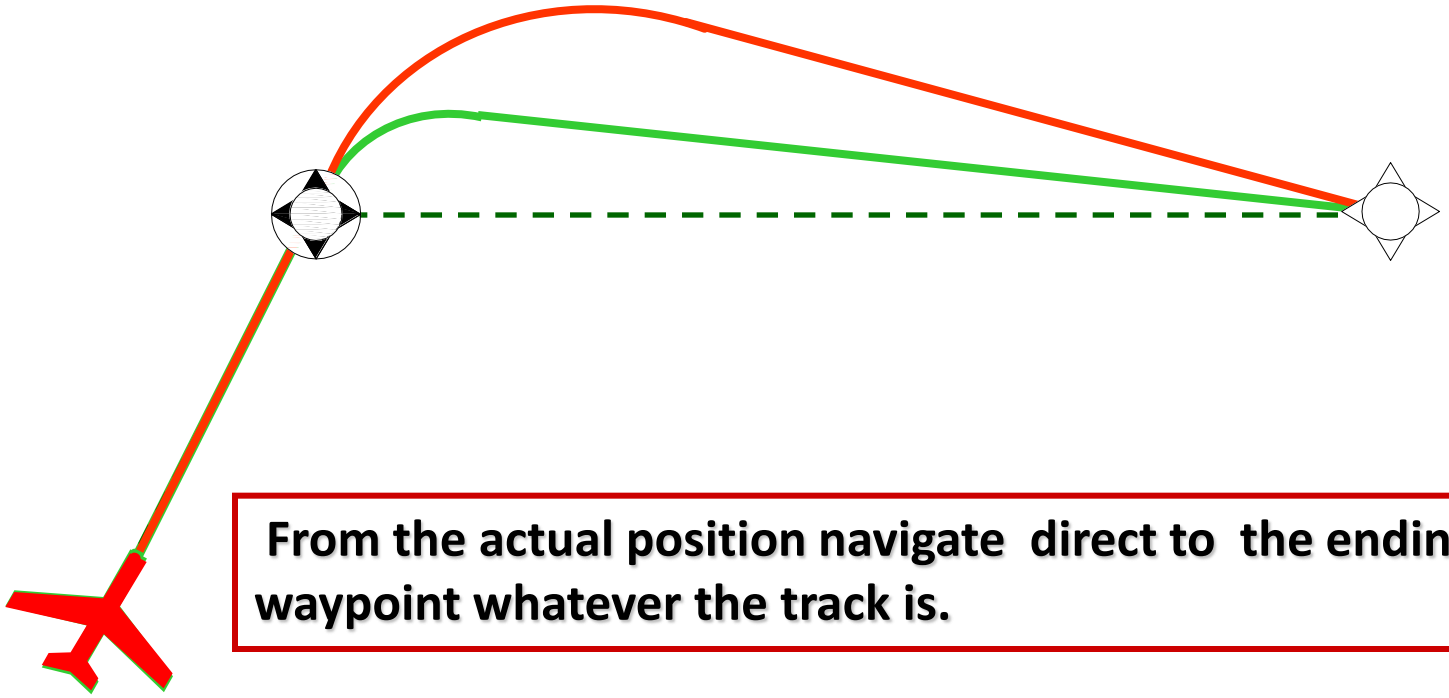
- **TF : Track between Fixes (Fly-By)**



Navigate towards the ending waypoint on the track between the two waypoints

Path Terminators : IFP

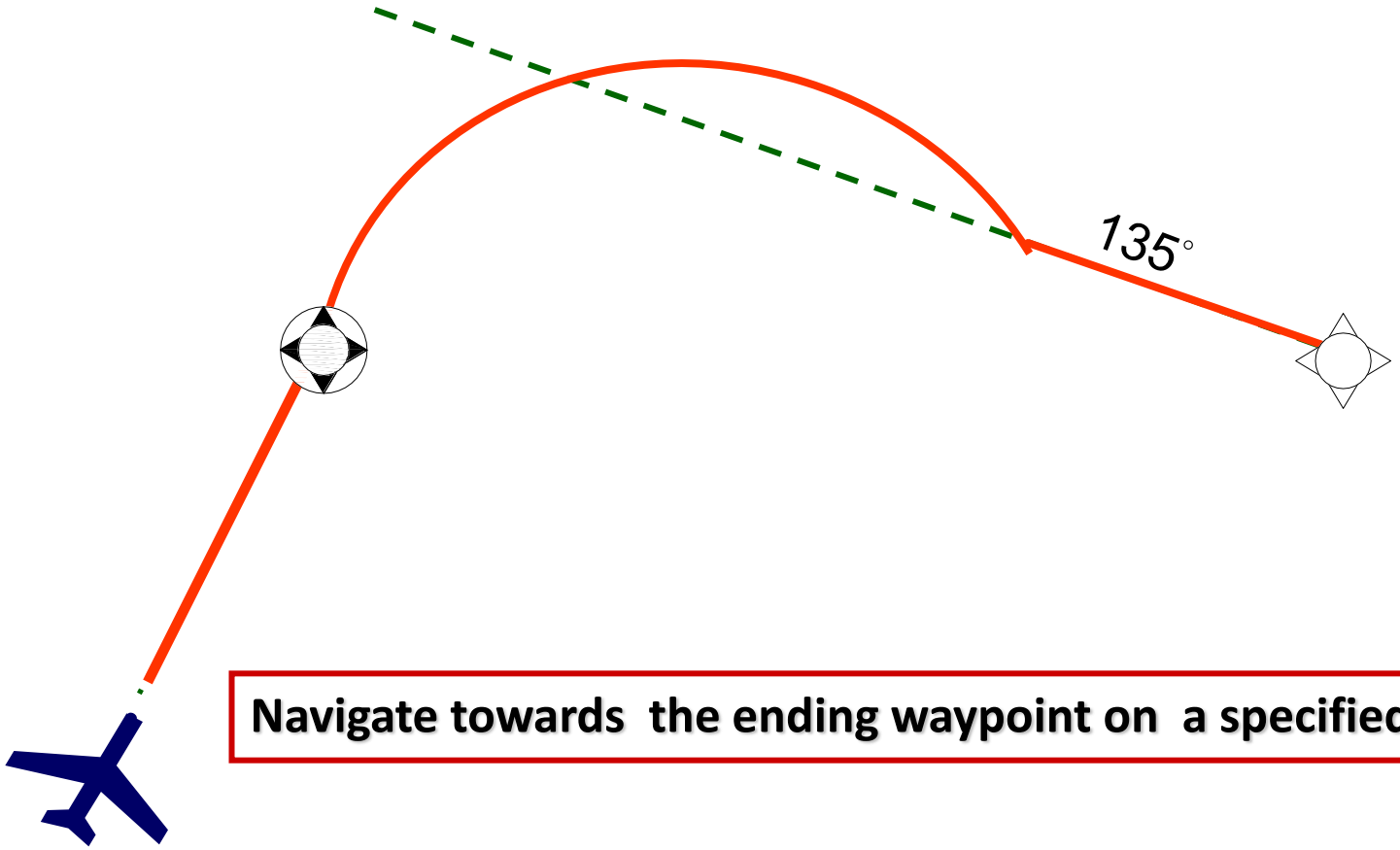
- **DF : Direct to Fix**



From the actual position navigate direct to the ending waypoint whatever the track is.

Path Terminators : IFP

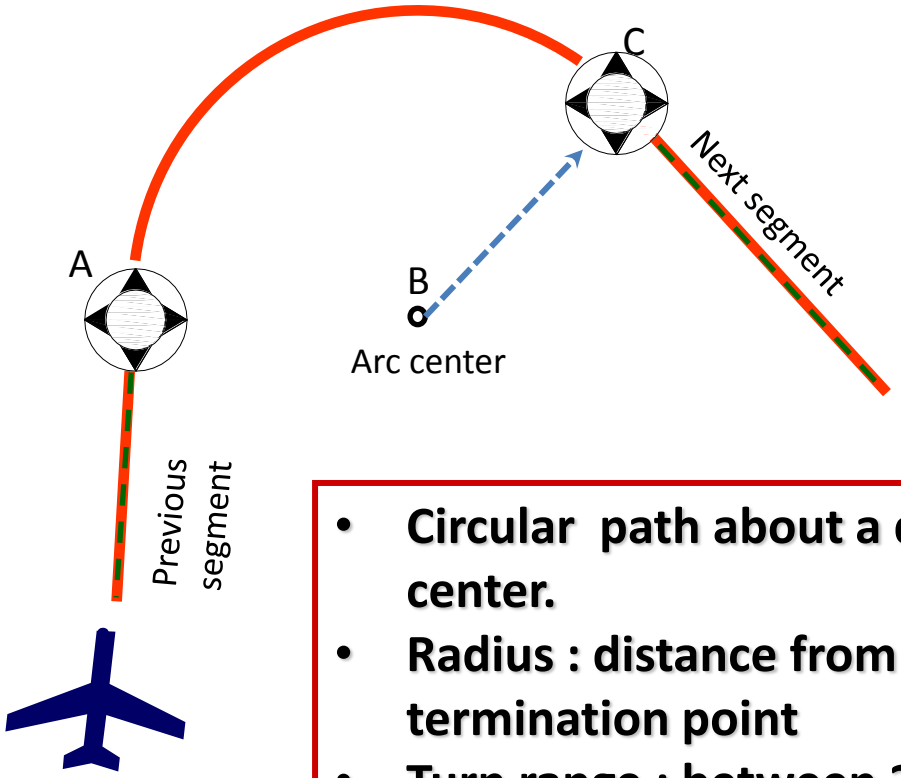
- **CF : Course to Fix**



Navigate towards the ending waypoint on a specified track.

Path Terminators : IFP

❖ **RF : constant Radius arc to a Fix**



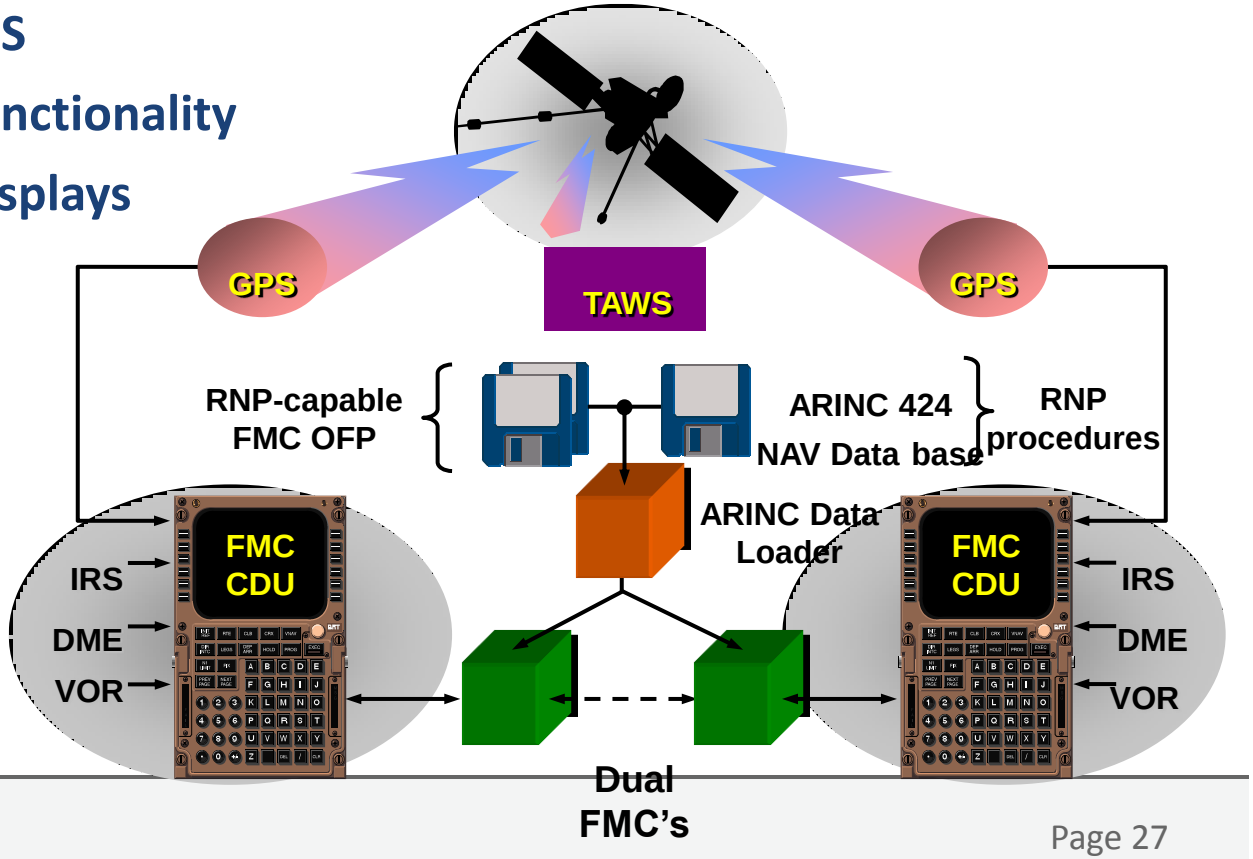
- **Circular path about a defined turn center.**
- **Radius : distance from turn center to termination point**
- **Turn range : between 2˚ and 300 ˚**

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/feed
  - Sometimes installed in jet trar
  - 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



Cockpit : 1970s vs. Todays

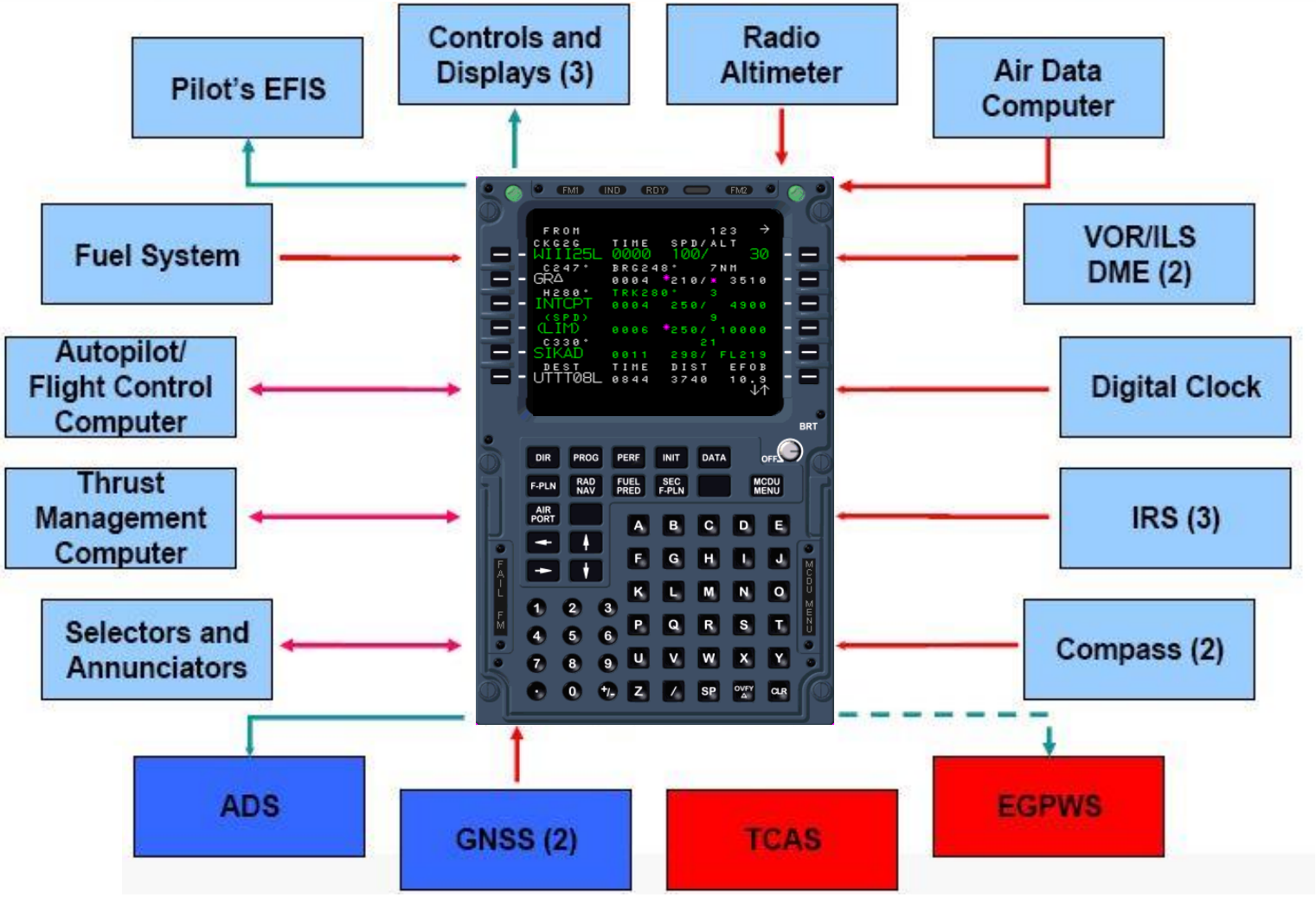
Modern Navigation Aids

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

FMS and Navigation

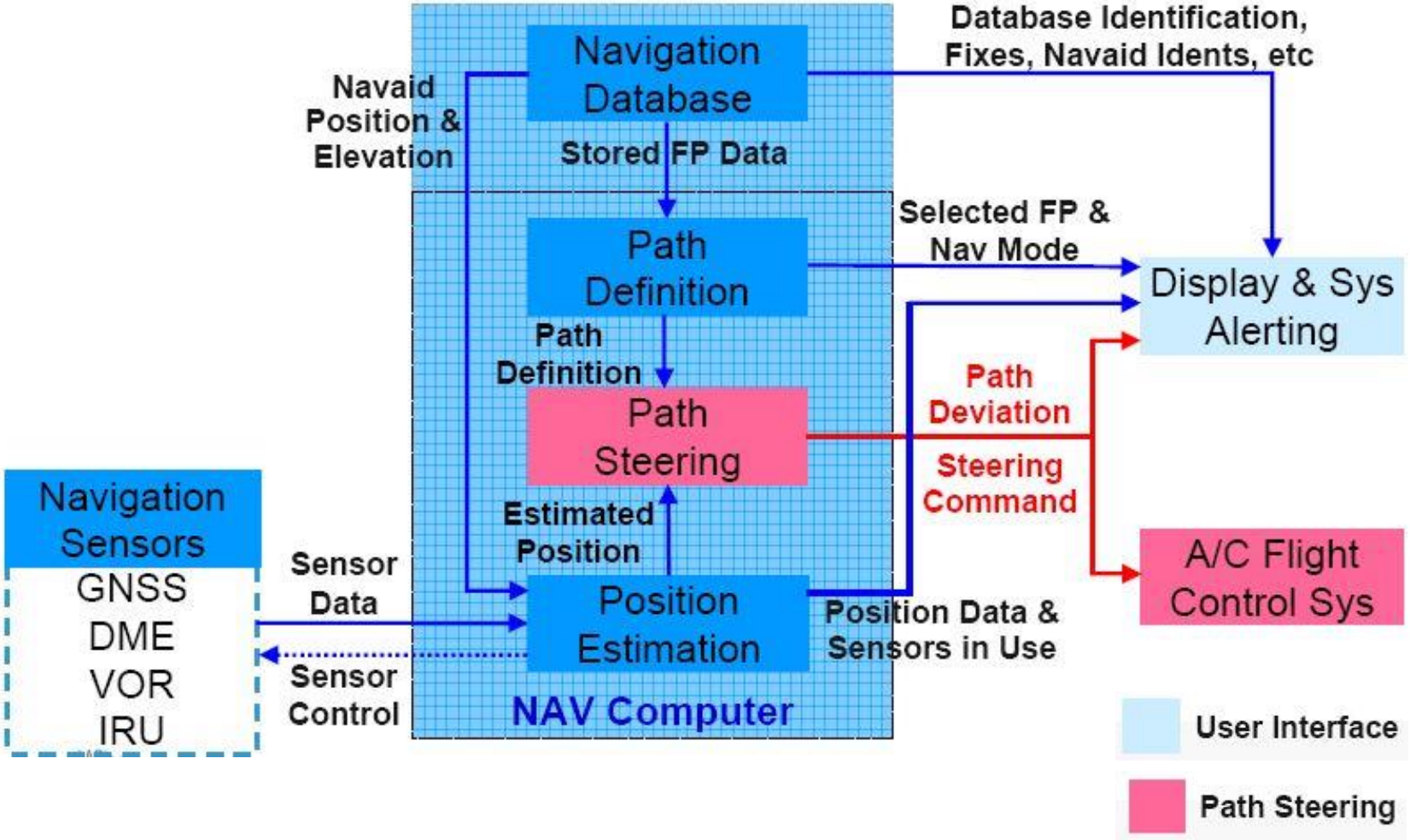
- **Navigation Computer**
  - Positioning
  - Flight planning
  - Trajectory prediction
  - Navigation radio tuning
  - Information display management
- **Aircraft Performance Management**
  - Optimized information on speed, altitude , vertical profile, etc.
- **Save cost for commercial airlines by aviation technology and precision instrument flight**

FMS and Navigation



FMS integrated Navigation Computer

Path Steering



Navigation Accuracy

- 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 progress
- 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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Thank You