Flight Management System
Lateral Navigation

Presented by
Arnaud de SOUQUAL (AIRBUS)

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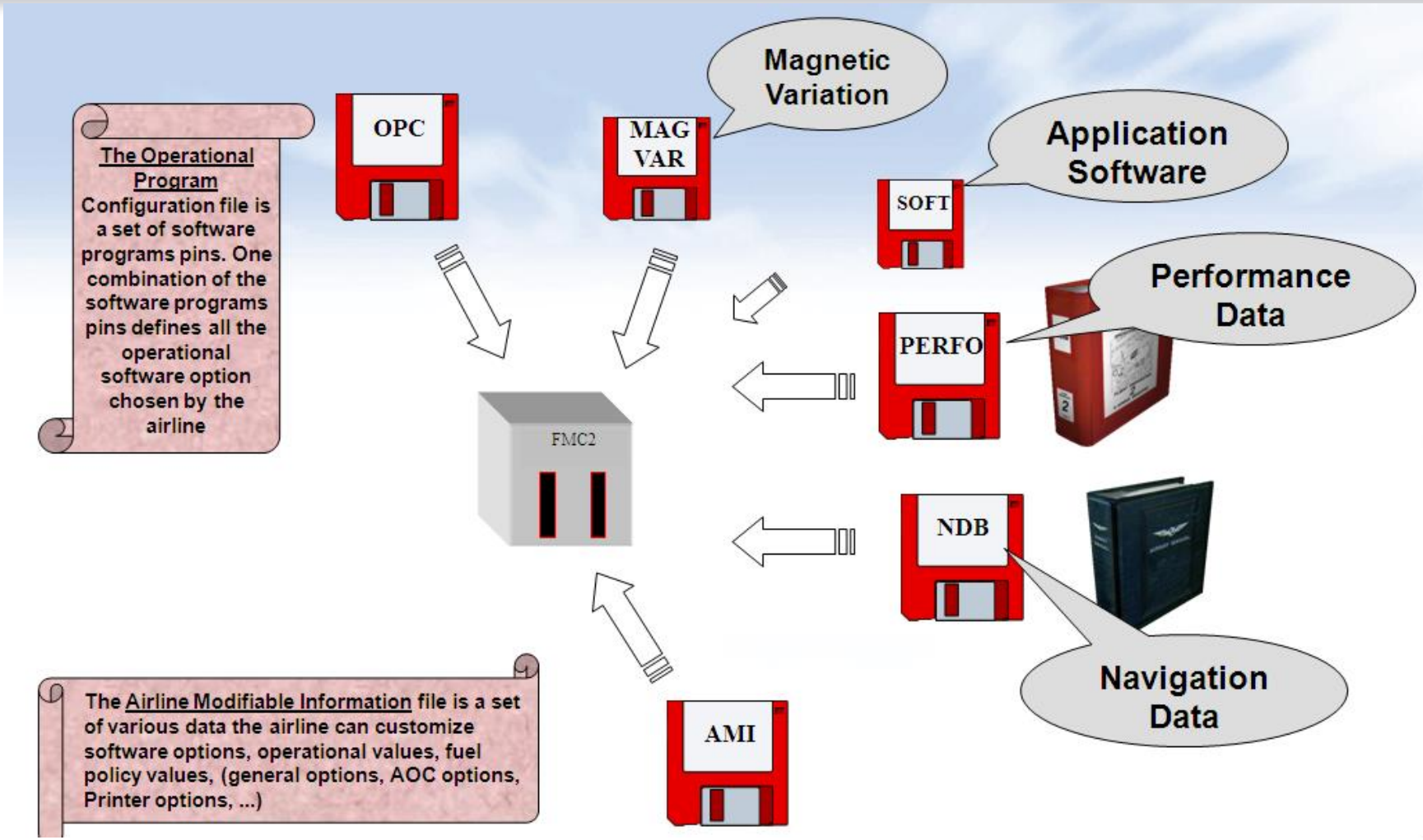
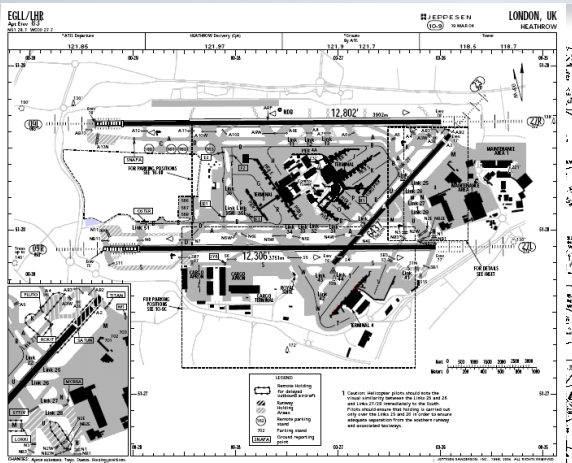
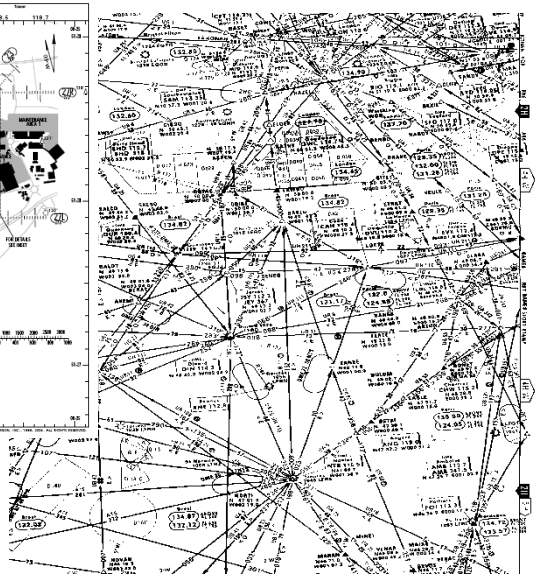
1 Navigation Database

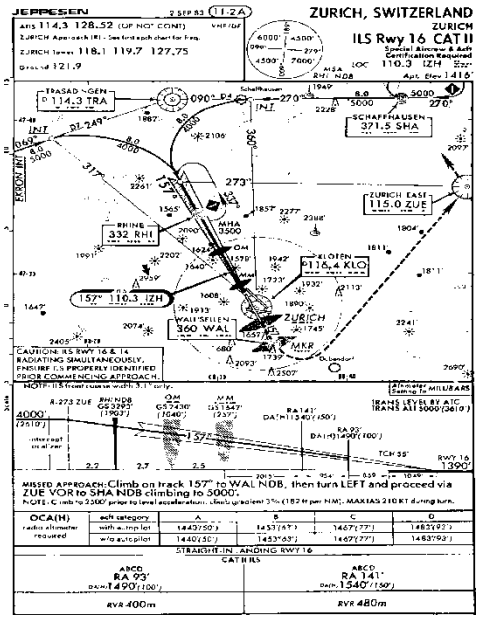


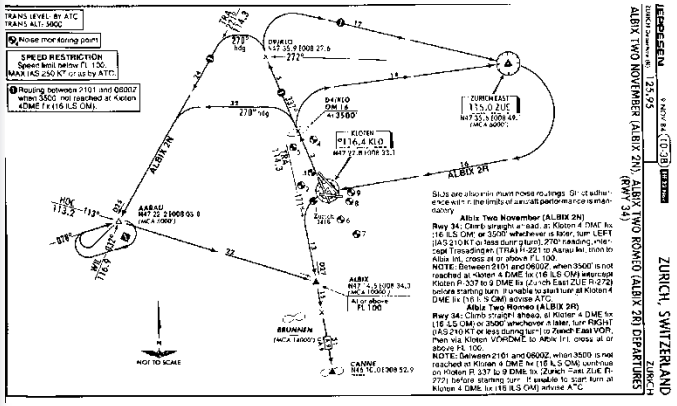
1 Navigation Database

Airport charts









En route charts

Approach charts

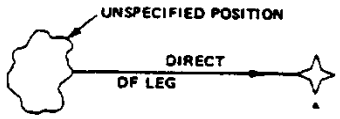
Departure and Arrival charts

Format A424

1 Navigation Database

Examples of A424 legs

DF

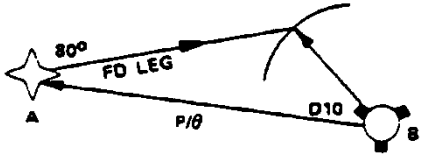


Computed track direct to a fix

FA

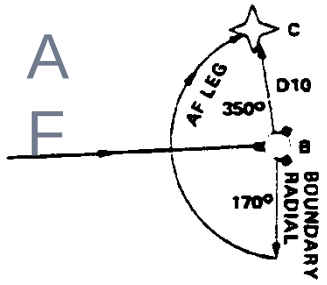
Course from a fix to an altitude

FD



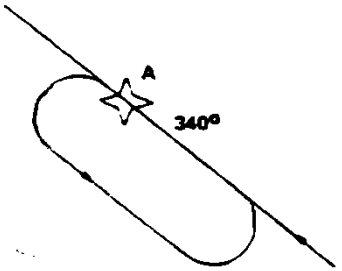
Course from a fix to a DME distance

A F



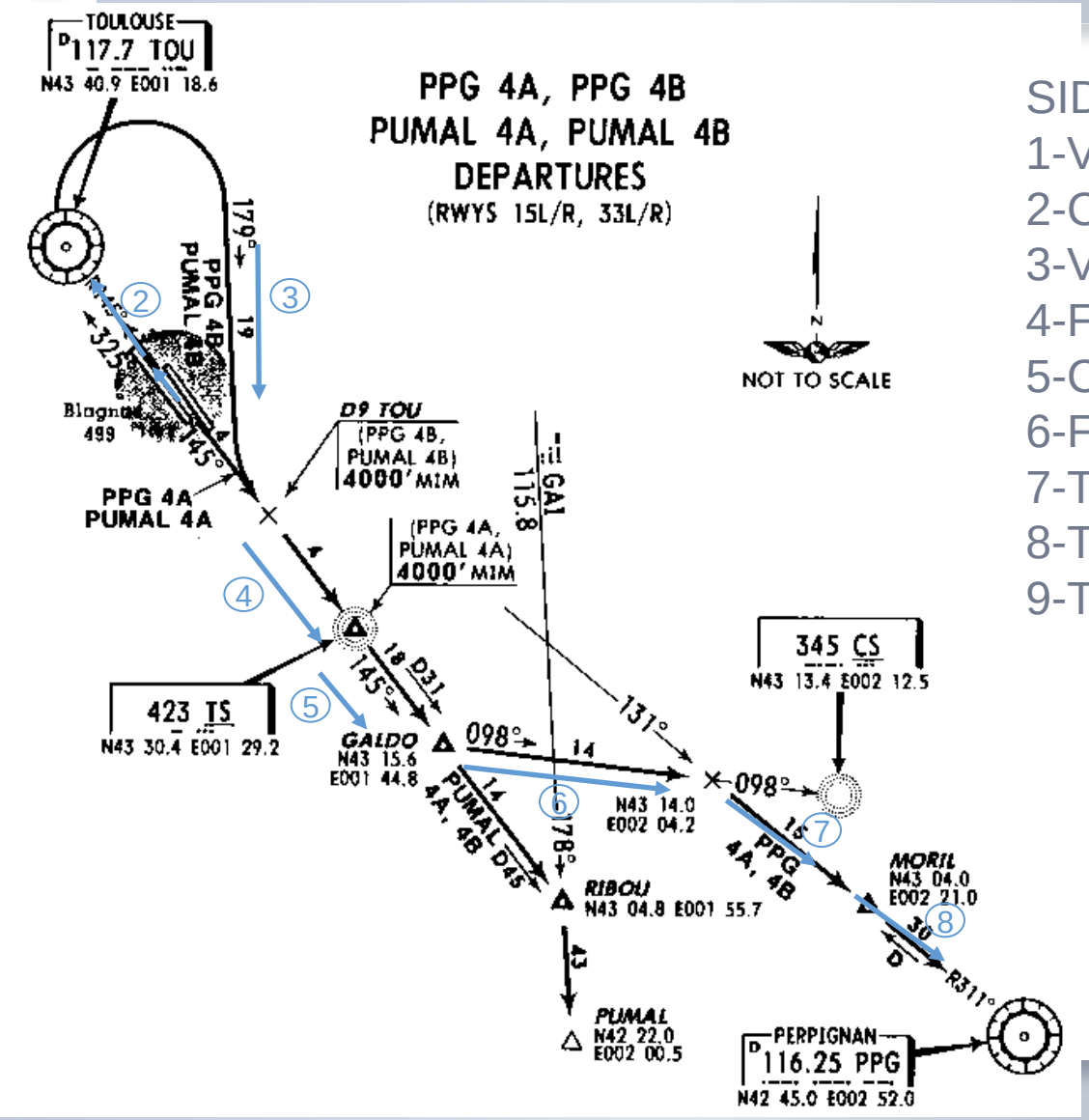
A constant DME arc to a fix

HX



Holding patterns

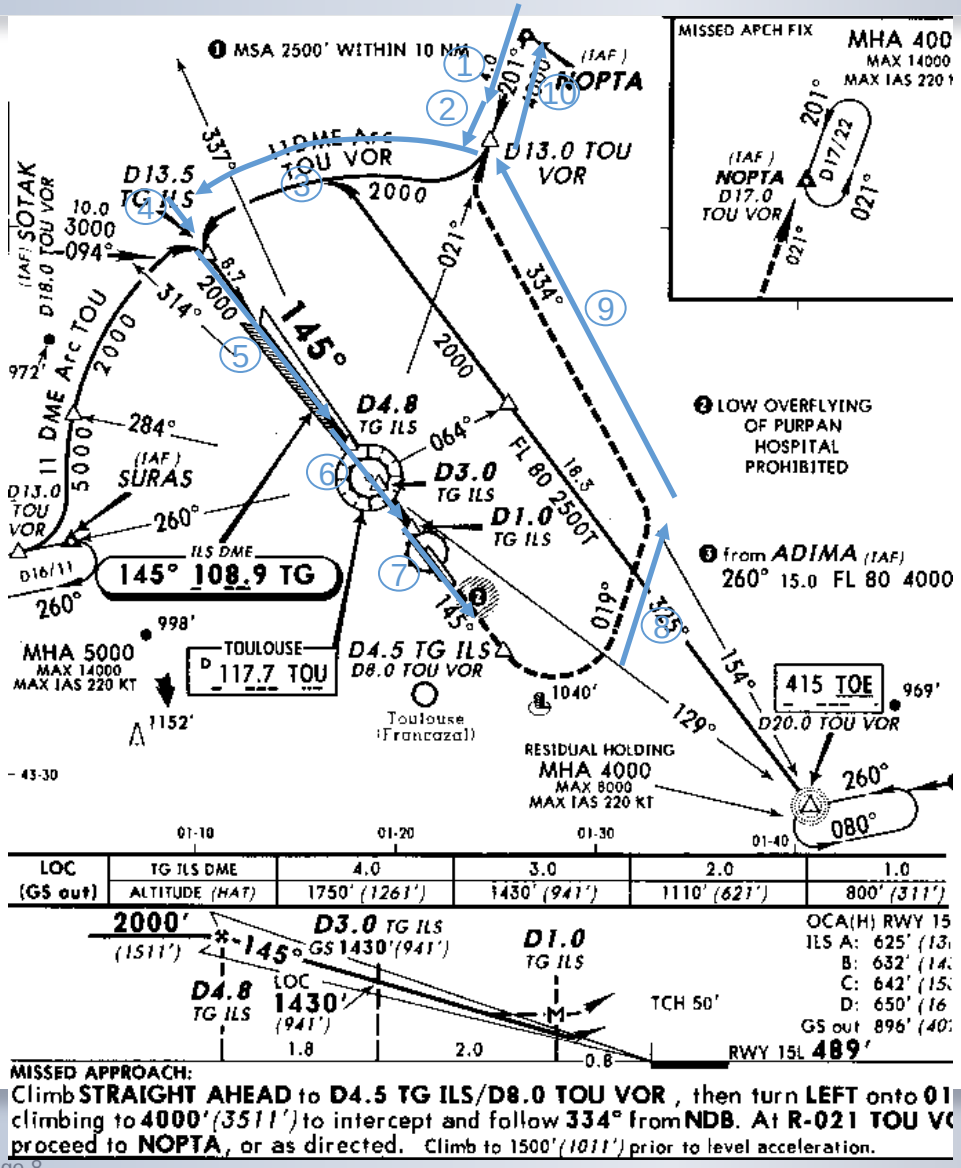
1 Navigation Database



SID PPG 4B coding example

1-VA	324.9°	900ft	
2-CF	324.9°	TOU	
3-VI	178.9°	Right turn	
4-FD	144.9°	TOU	+9000ft
5-CF	144.9°	TS	
6-F		GALDO	
7-TF		TOU43	
8-TF		MORIL	
9-TF		PPG	

1 Navigation Database



Appr Trans NOPTA coding example

1-FD	200.9°	NOPTA
2-VI	200.9°	
3-AF	Left	D337K
4-CF	144.9°	CI15R

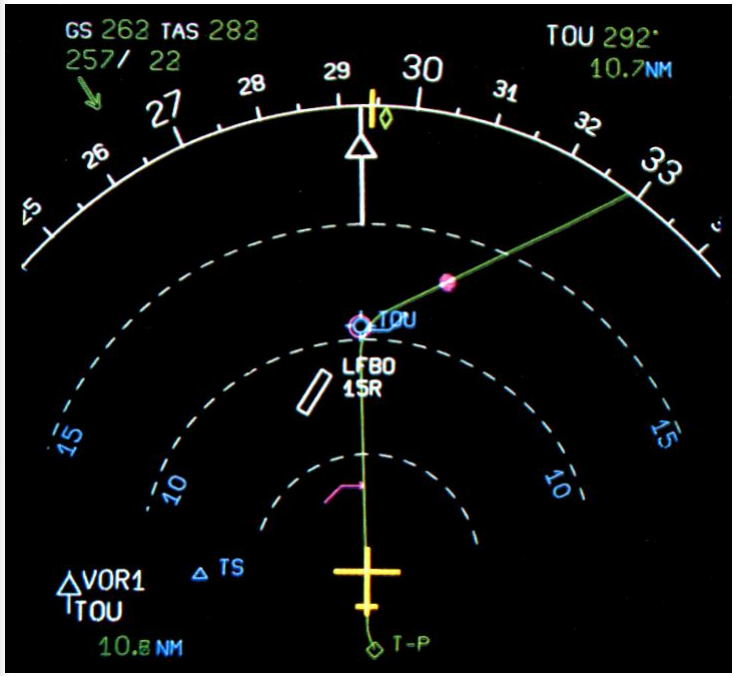
App ILS15Rcoding example

4-IF		CI15R
5-CF	144.9°	FI15R
6-CF	144.9°	RW15R
7-CF	144.9°	D145E
8-VI	19°	
9-CF	334°	D334Z
10-CF	20.9°	NOPTA

1 Navigation Database

MFD A380 : A/C Status page

1 Navigation Database



Information available on

ND for trajectory

Information available on

MCDU for runway,
route, waypoint, navaid

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2 What is a Flight plan?

A flight plan is a combination of elementary elements:

- Departure airport
  Arrival airport

Each airport is identified by an ICAO four-letter code

Examples:
LF - FRANCE
LFBO (**TLS**) – Toulouse / Blagnac Airport
LFPG (**CDG**) – Paris / Charles de Gaulle Airport (Roissy Airport)
LFPO (**ORY**) – Paris / Orly Airport
EG – UNITED KINGDOM
EGKK (**LGW**) – London / Gatwick Airport
EGLL (**LHR**) – London / Heathrow Airport

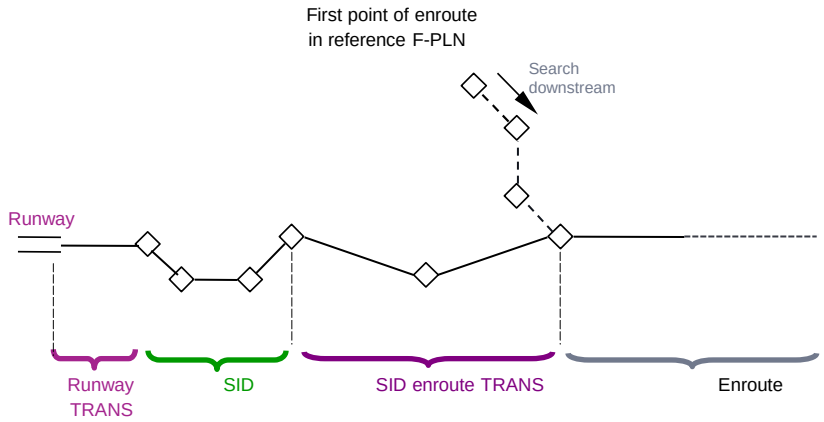
The **three-letter** code (IATA code) is more commonly known to the public.

2 What is a Flight plan?

A flight plan is a combination of elementary elements:

- Departure airport
- Arrival airport
- Departure procedure

A Departure procedure contains 3 optional elements :
- RWY (runway and runway transition)
- SID (Standard Instrument Departure)
- TRANS (SID enroute transition)

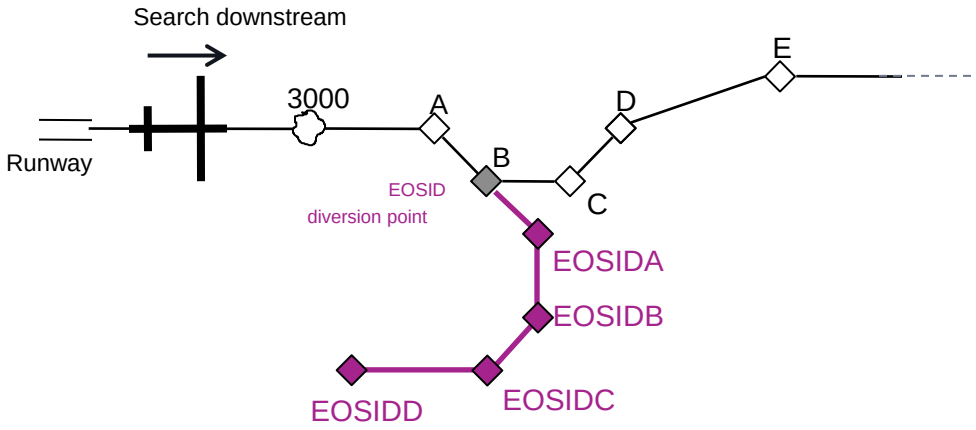


2 What is a Flight plan?

A flight plan is a combination of elementary elements:

- Departure airport
- Arrival airport
- Departure procedure
- Engine Out Procedure

An Engine Out procedure or EOSID is a standard procedure to use if an engine fails just after take off.

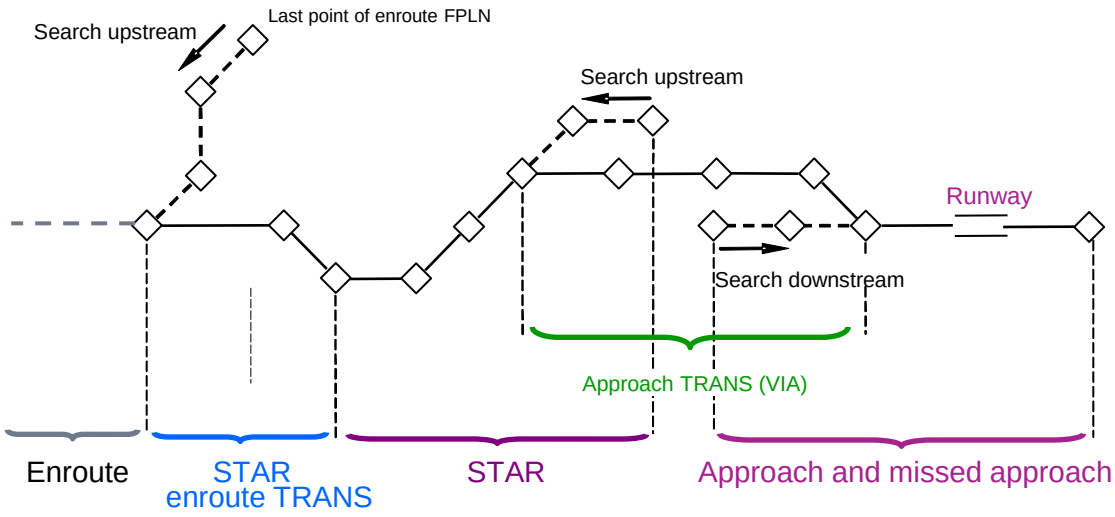


2 What is a Flight plan?

A flight plan is a combination of elementary elements:

Departure airport
Arrival airport
Departure procedure
Engine Out Procedure
Arrival Procedure

An Arrival procedure contains 4 optional elements :
- **APPR** (Final approach including runway & missed approach)
- **VIA** (Approach transition)
- **STAR** (Standard Terminal Arrival Route)
- **TRANS** (STAR enroute transition)



2 What is a Flight plan?

A flight plan is a combination of elementary elements:

- Departure airport
- Arrival airport
- Departure procedure
- Engine Out Procedure
- Arrival Procedure
- Waypoints

5 means to identify a waypoint :

→ An Ident
ex : BEROK

→A Latitude/longitude
ex : 44°09.9N/010°21.1E

→A place/bearing/distance (PBD)
ex : BEROK/100/10

→A place-bearing / place-bearing (PB/PB)
ex : BEROK-090/SIPLO-045

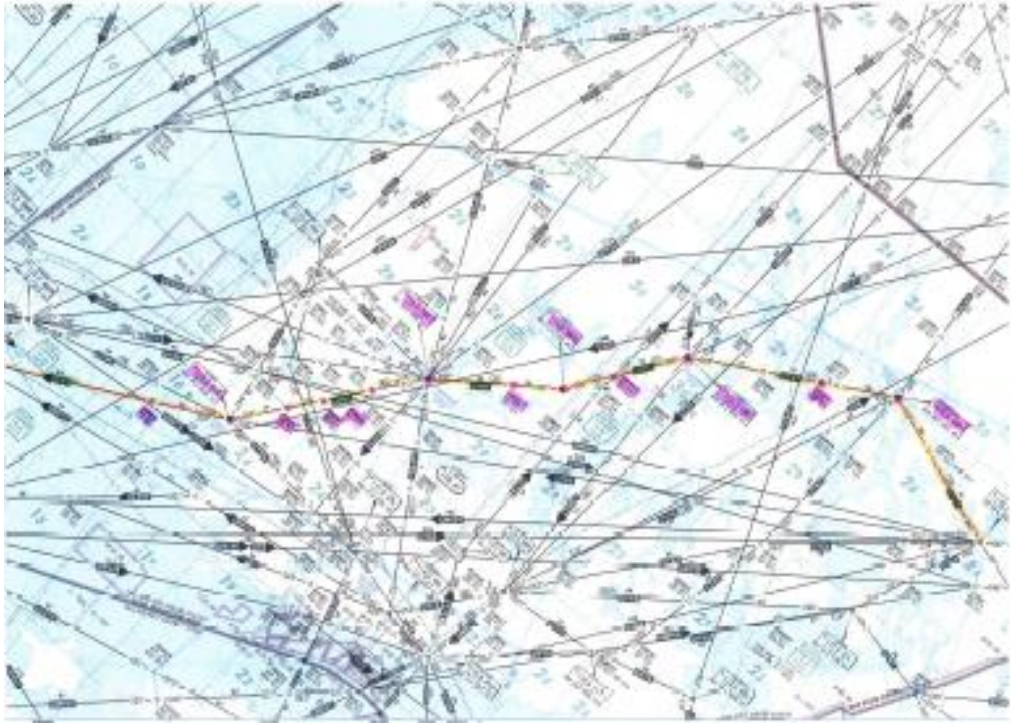
→A place-distance or Along Track Offset (ATO)
ex : BEROK/10

2 What is a Flight plan?

A flight plan is a combination of elementary elements:

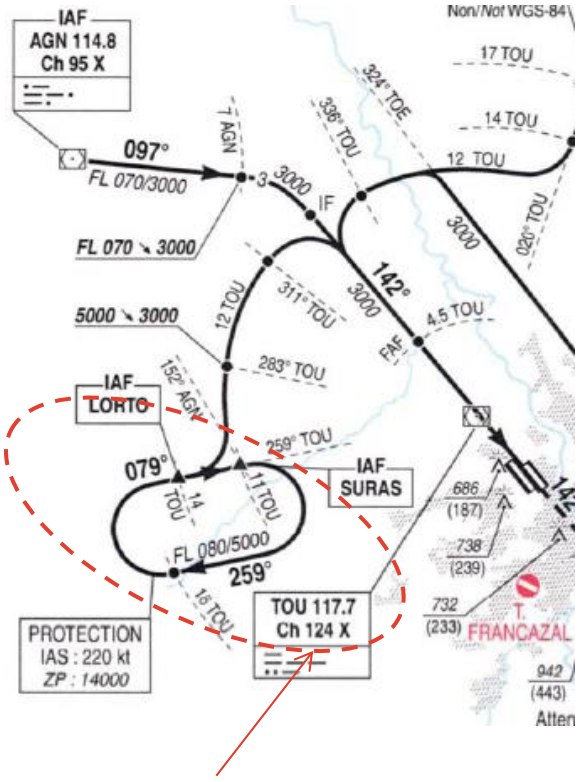
- Departure airport
- Arrival airport
- Departure procedure
- Engine Out Procedure
- Arrival Procedure
- Waypoints
- Airways

An Airway is a published route.



2 What is a Flight plan?

A flight plan is a combination of elementary elements:



Holding pattern

There are 3 types of holding patterns. The main difference between them is how they are terminated:

- Holding pattern to a Fixed Waypoint (HF)

The aircraft makes one circuit in the hold or of the entry procedure and then exits automatically when the fixed waypoint is sequenced.

- Holding pattern with an Altitude Termination (HA)

If the specified altitude is reached while in the hold, the hold is terminated when the aircraft next crosses the fixed waypoint.

-Holding pattern with a Manual Termination (HM)

This hold is terminated manually when the aircraft next crosses the fixed waypoint and an immediate exit action is requested by the pilot.

HF and HA holds are normally specified in Departure or Arrival procedures and pilot cannot enter them directly into the flight plan.

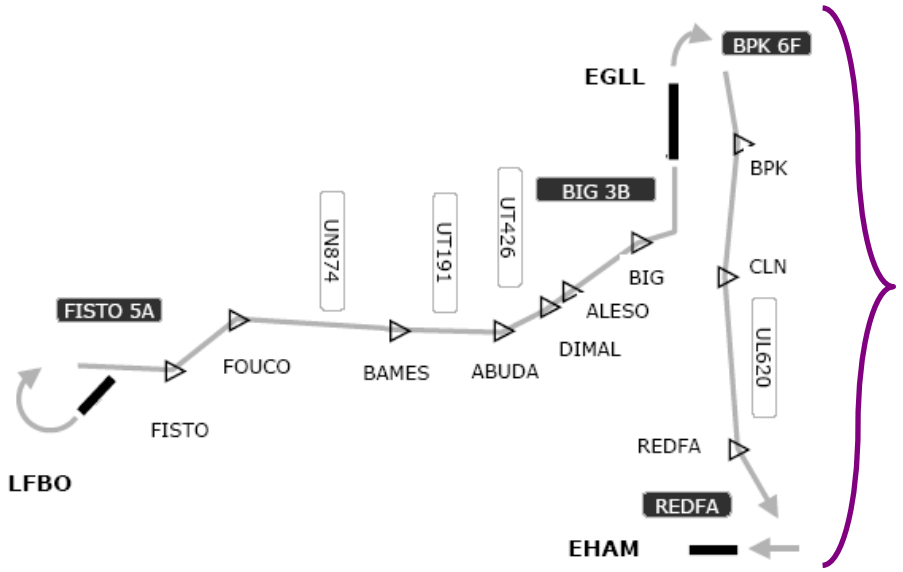
HM holds are pilot-entered or defined holding patterns and are the type most often used.

2 What is a Flight plan?

A flight plan is a combination of elementary elements:

- Departure airport
- Arrival airport
- Departure procedure
- Engine Out Procedure
- Arrival Procedure
- Waypoints
- Airways
- Holding Patterns
- Alternate Airport

An alternate airport is a stand-by destination used in case of non-landing on primary destination.
Once an alternate airport is inserted on F-PLN, an ALTN F-PLN portion is created between Primary and Alternate destination.
During the flight the alternate F-PLN potion can be activated by the pilot



2 What is a Flight plan?

A flight plan: combination of elementary elements + Tailored data:

- Departure airport
- Arrival airport
- Departure procedure
- Engine Out Procedure
- Arrival Procedure
- Waypoints
- Airways
- Holding Patterns
- Alternate Airport

+

Tailored data predefined by the Airlines such as CompanyRoutes (CoRoutes).

Company Routes Elements:

Departure airport
Departure procedure
Airways
Waypoints
Arrival procedure
Arrival airport

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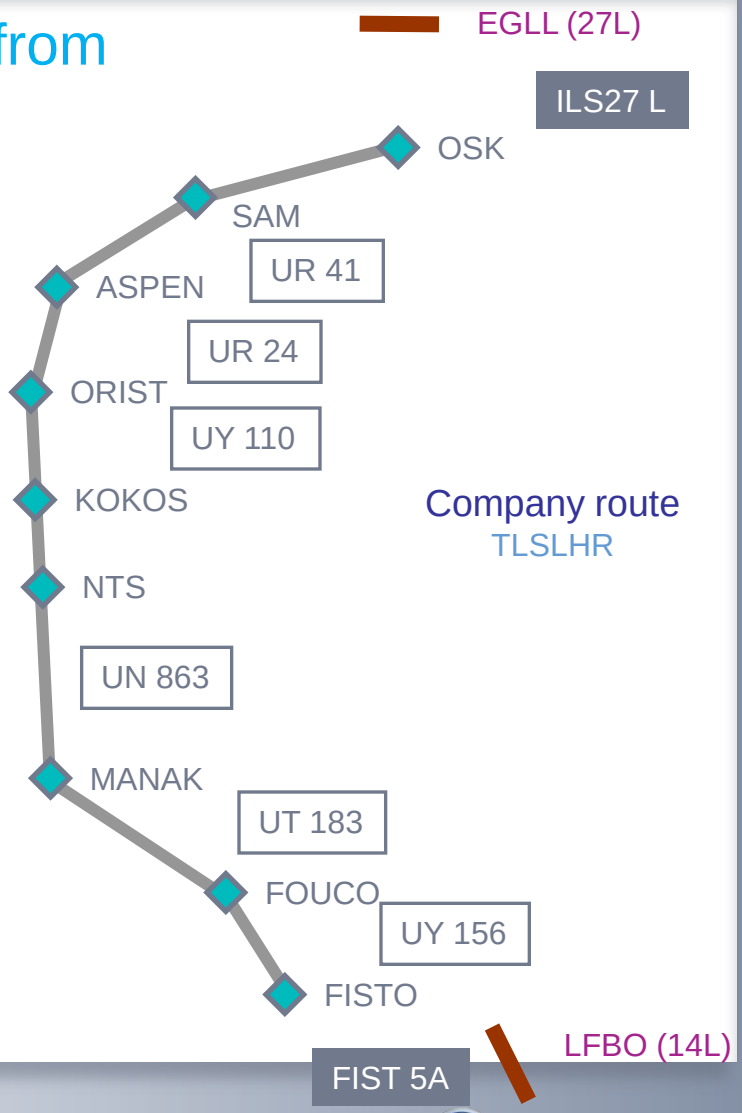
3 Flight Plan initialization

The primary mission of the crew is to fly from an airport A to an airport B.

- Example:

  How to fly from Toulouse (LFBO/TLS) to London Heathrow (EGLL/LHR)...

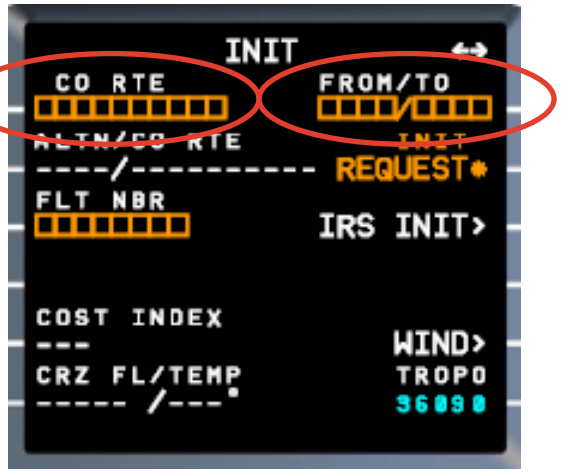
The FMS allows to define the Initialisation parameters of the Lateral flight plan.



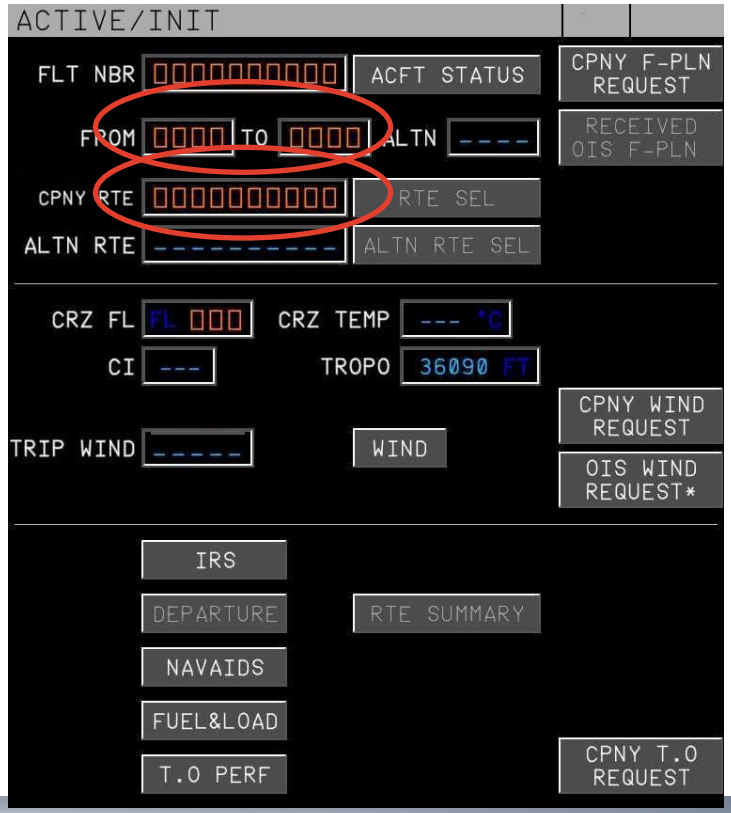
3 Flight Plan initialization

F-PLN initialisation starts with insertion of a primary origin and destination airport on INIT page

MCDU (SA/LR) OR MFD (A380/A350)



INIT page



Pilot can enter :

The primary origin / destination airport on FROM / TO field (LFBO/EGKK)

OR

The company route on CO RTE / CPNY RTE field (TLSLHR)

3 Flight Plan initialization

If the FROM / TO is entered (LFBO/EGKK) and several CO RTE exist the Route selection page is automatically displayed

MCDU (SA/LR) OR MFD (A380/A350)

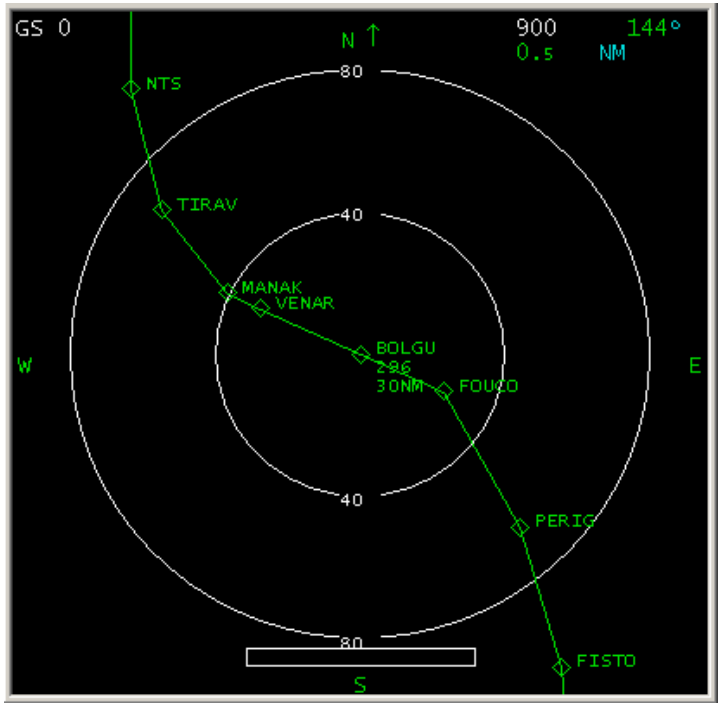
Route selection page

If no CO RTE is defined for the FROM / TO, all F-PLN elements are entered by the pilot
(refer F-PLN revisions chapter)

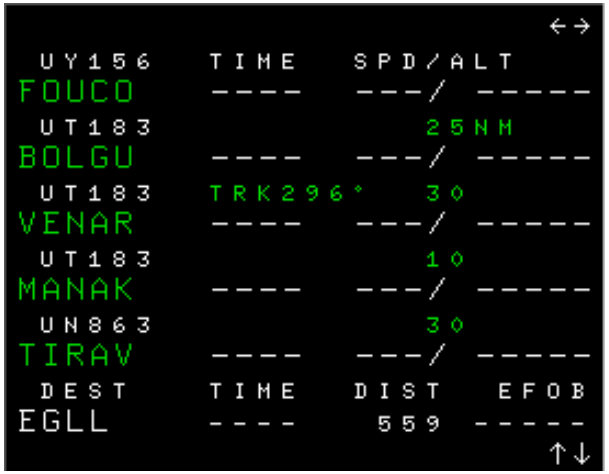
3 Flight Plan initialization

After this initialisation a skeleton of the complete F-PLN is available

Navigation Display (SA/LR)



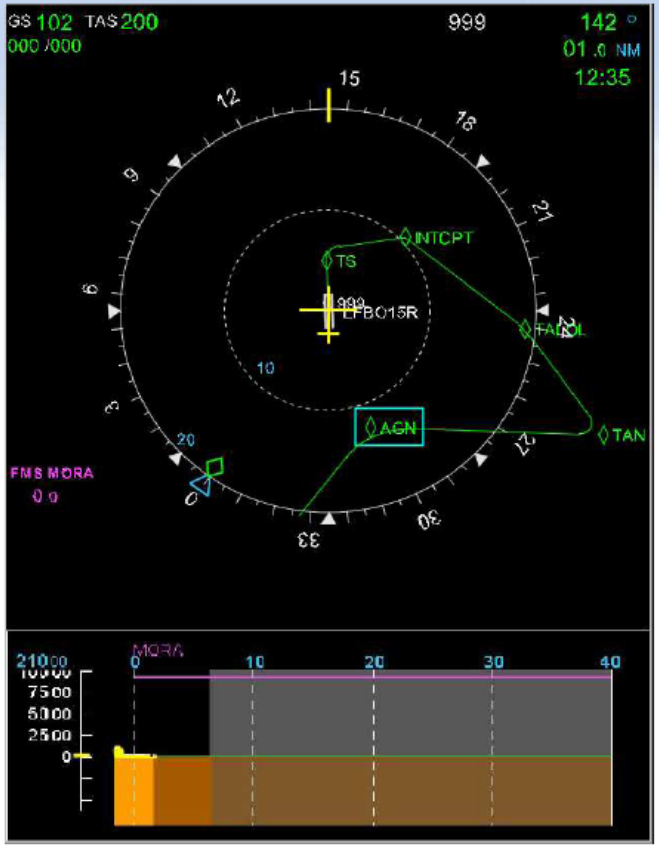
F-PLN page on MCDU (SA/LR)



3 Flight Plan initialization

After this initialisation a skeleton of the complete F-PLN is available

Navigation and Vertical displays (A380) **F-PLN page on MFD (A380)**



3 Flight Plan initialization

Remark

Other parameters are entered via the FMS to complete the flight plan initialisation such as:

- Choice of departure and arrival procedures and departure and arrival runways
- ZFW, ZFCG, Block FUEL
- Departure speeds (V1, V2, VR)
- Take off configuration(flaps, TOGA, FLEX, …)
- …

But the lateral flight plan only needs the Departure and Arrival or Co route informations to get initialized.

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4 Construction of the Flyable lateral path

•After initialization of the flight plan, it looks like a « skeleton » (succession of straight segments).

•The next step after the « skeleton » construction is to have a flyable lateral path : the geometric path.

•The geometric path is a succession of legs where a transition is defined between each pair of legs.

• A leg is a specific type of flight path with a specific type of termination of that flight path

4 Construction of the Flyable lateral path

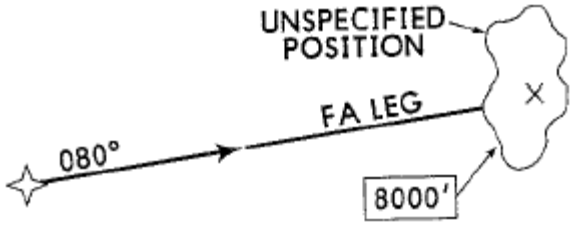
3 classes of legs are used :

Fixed path legs (1/2)

These are characterized by the fact that their geographic location is perfectly fixed.

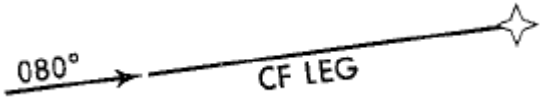
IF : Initial Fix

FA : Fix to an Altitude

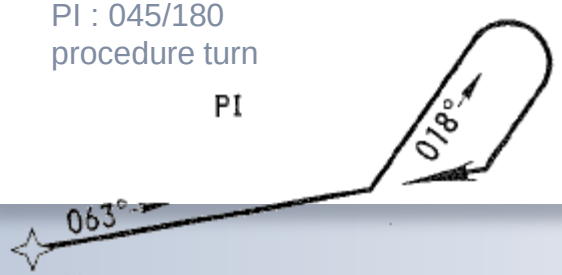


TF : Track to a Fix

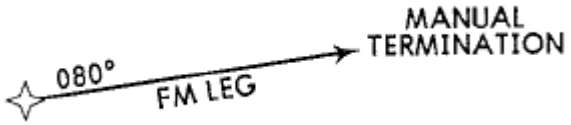
CF : Course to a Fix



PI : 045/180 procedure turn



FM : From a fix to a Manual termination



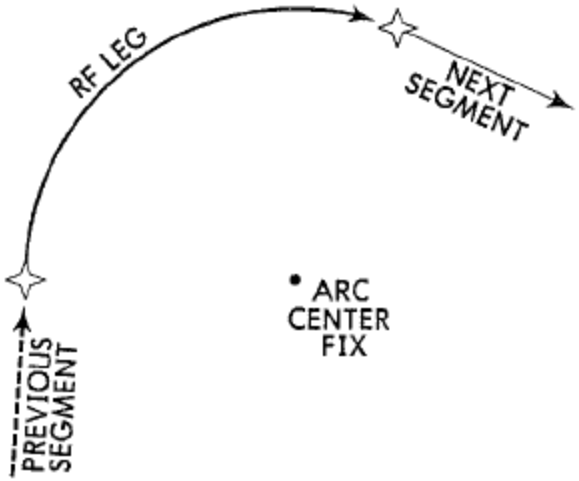
4 Construction of the Flyable lateral path

3 classes of legs are used :

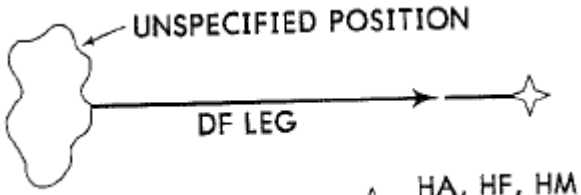
Fixed path legs (2/2)

These are characterized by the fact that their geographic location is perfectly fixed.

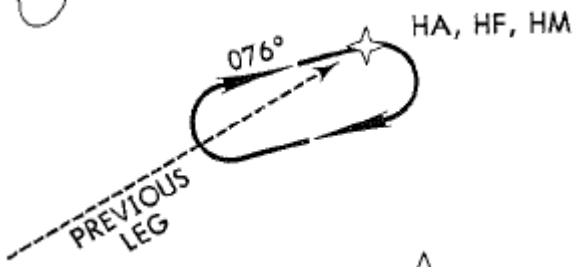
RF : Constant radius Arc



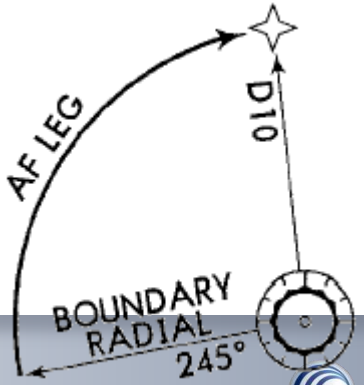
DF : Direct to a Fix



HA/HF/HM : Holding pattern



AF : Arc a Fix



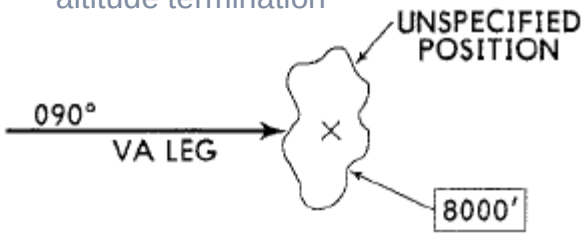
4 Construction of the Flyable lateral path

3 classes of legs are used :

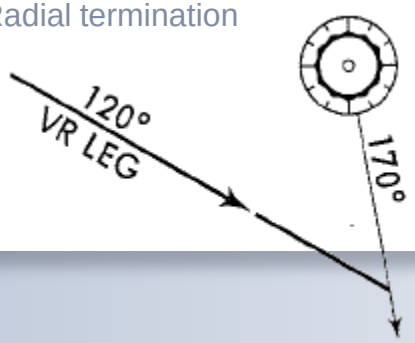
- Fixed path legs
- Heading legs

These are characterized by a heading to follow from the preceding leg.
They end when given conditions are met.

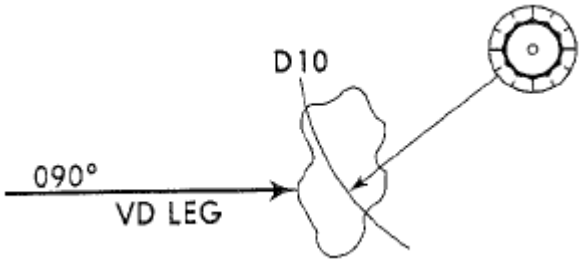
VA : Heading to an altitude termination



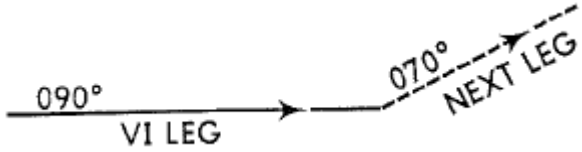
VR : Heading to a Radial termination



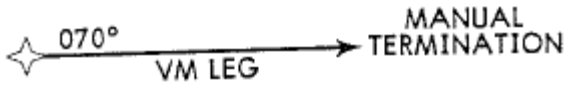
VD : Heading to a DME distance termination



VI : Heading to an Intercept



VM : Heading to a Manual termination



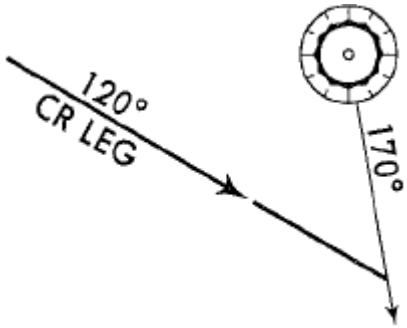
4 Construction of the Flyable lateral path

3 classes of legs are used :

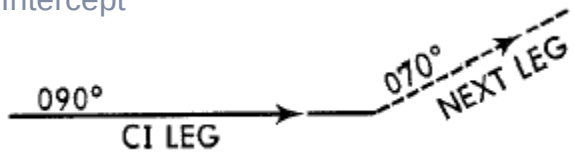
- Fixed path legs
- Heading legs
- Course legs

These are characterized by a Course to follow from the preceding leg.
They end when given conditions are met.

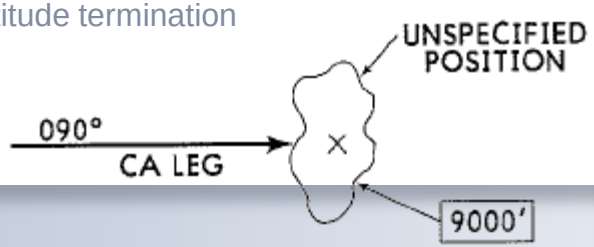
CR : Course to a Radial termination



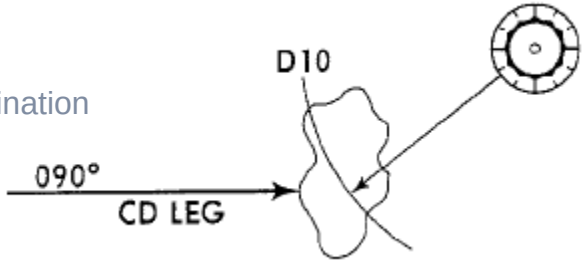
CI : Course to an Intercept



CA : Course to an altitude termination



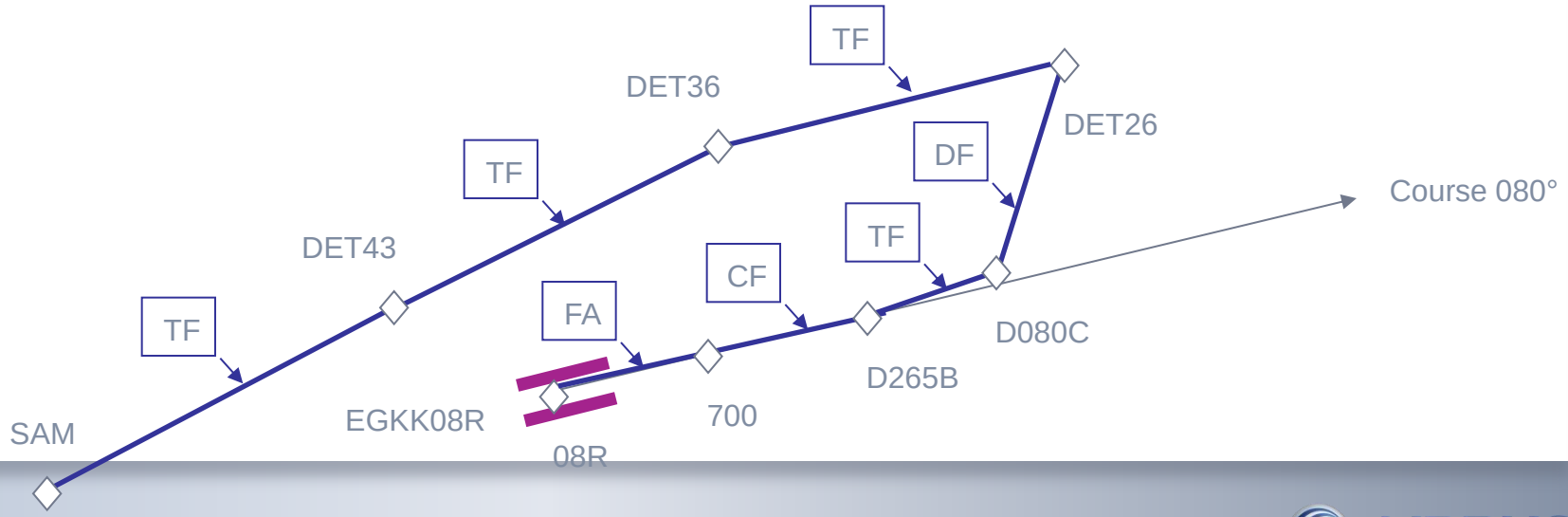
CD : Course to a DME distance termination



4 Construction of the Flyable lateral path

Example – SID SAM3P on EGKK airport with 08R runway :

Leg type	Fix	Couse/Heading	Altitude	Turn Direction
FA : From fix to an altitude	08R	80°	700A	
CF : Course to a fix	D265B	80°	1200A	
TF : Track to a Fix	D080C			
DF : Direct to a fix	DET26		2500A	Left
TF : Track to a Fix	DET36		3000	
TF : Track to a Fix	DET43		4000	
TF : Track to a Fix	SAM			



4 Construction of the Flyable lateral path

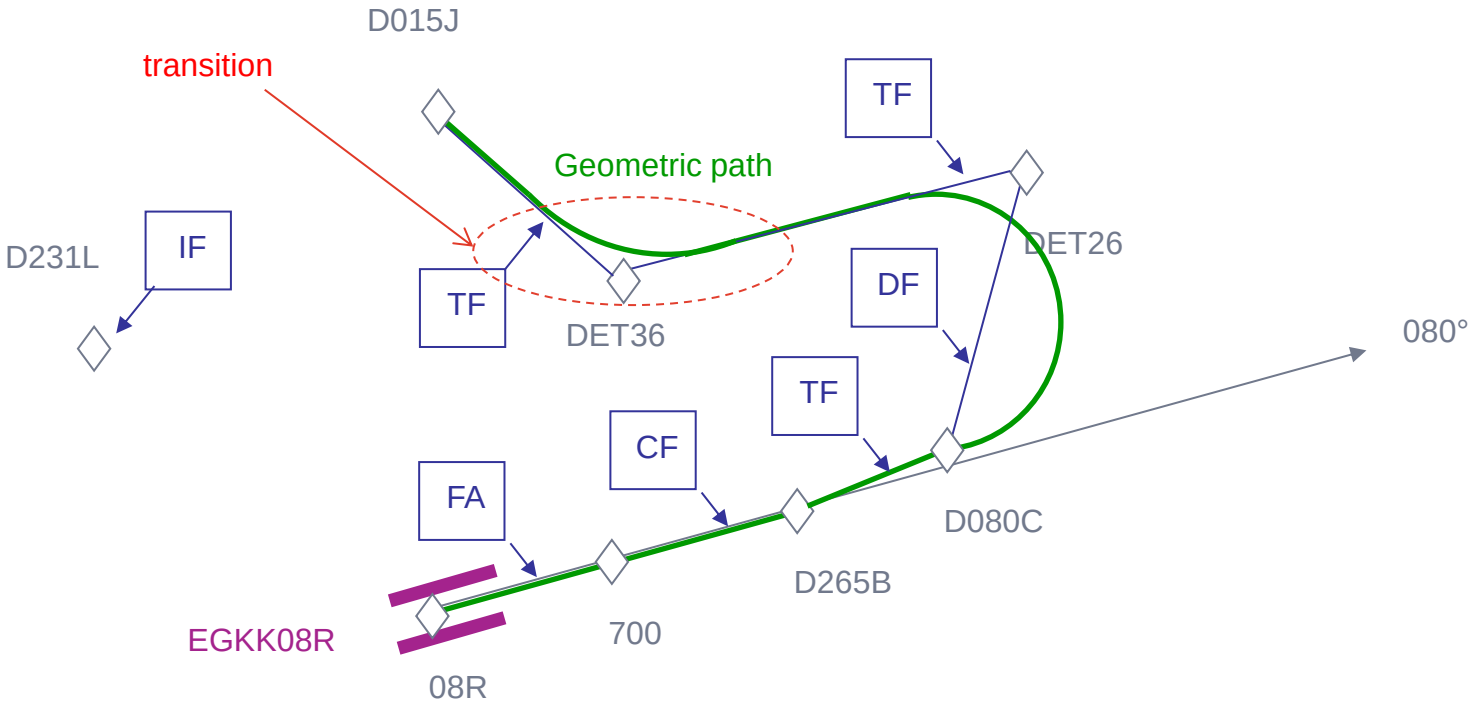
Transitions between legs:

Transitions are always combinations of straight segments and turns.

Transitions between two legs are dependent of:
- Type of both legs
- Aircraft parameters (Ground speed and Bank angle)
- The course change between both legs

4 Construction of the Flyable lateral path

Example in London :



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5 Predictions and operational constraints

At any time, the crew wants to know what will happen in the future along its lateral flight plan.

For this, predictions are computed by the FMS, taking into account :

-Aircraft performances (contained in the Performance Database) : Engine model, Aerodynamic and Performances

-Operational constraints (speed, altitude, time and airline's constraints reflected in the Cost Index parameter for instance)

5 Predictions and operational constraints

The FMS computes flight formula with the performance model loaded into the FMS.

At each waypoint, the FMS provides predictions of:

- Time
- Speed
- Altitude
- Distance
- Fuel

+ **Cost Index (CI)** to optimize the profile

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6 Different types of Flight plan to manage the flight

- The crew is aware of its situation at each instant and it has indications on what will happen in the next future (thanks to predictions).

  ⇨ The Active Flight plan is the one that is currently being flown by the aircraft.

- The crew has also the means to manage the Flight plan and the « mission » using two types of Flight plans managed by the FMS:

  ⇨The Temporary Flight Plan – used for tactical revisions to active F-PLN.

  ⇨The Secondary Flight Plan(s) – used for the strategical revisions to active F-PLN and ATC or AOC F-PLN or route modification uplinks.

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7 Flight plan management – Lateral revisions

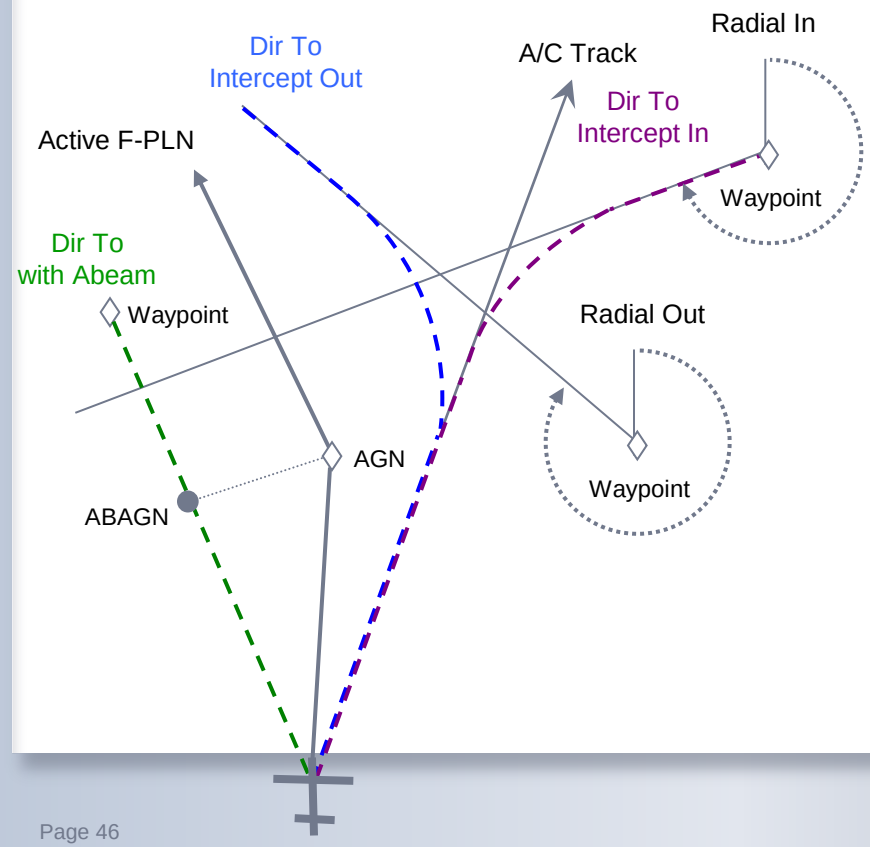
- The crew can modify the current flight plan thanks to Lateral Revisions.

- Based on the existing F-PLN the pilot can perform the following basic lateral revisions :
  - Insert or modify one element of the departure procedure
  - Insert or modify one element of the arrival procedure
  - Insert or clear a waypoint
  - Insert a new destination
  - Insert, modify or clear an holding pattern
  - Select or activate an alternate F-PLN
  - Insert an airway

7 Flight plan management – Lateral revisions

More complex lateral revisions are also available :

Dir To function



The Dir To function provides a mean of flying directly from the current A/C position to a selected waypoint.

3 options are available :

- Dir To Abeam : active F-PLN waypoints are projected along the Direct To route
- Dir To Intercept/Radial In : a Radial to reach the specified WPT is defined and intercepted from the current A/C position
- Dir To intercept/Radial Out : a Radial from the specified WPT is defined and intercepted from the current A/C position

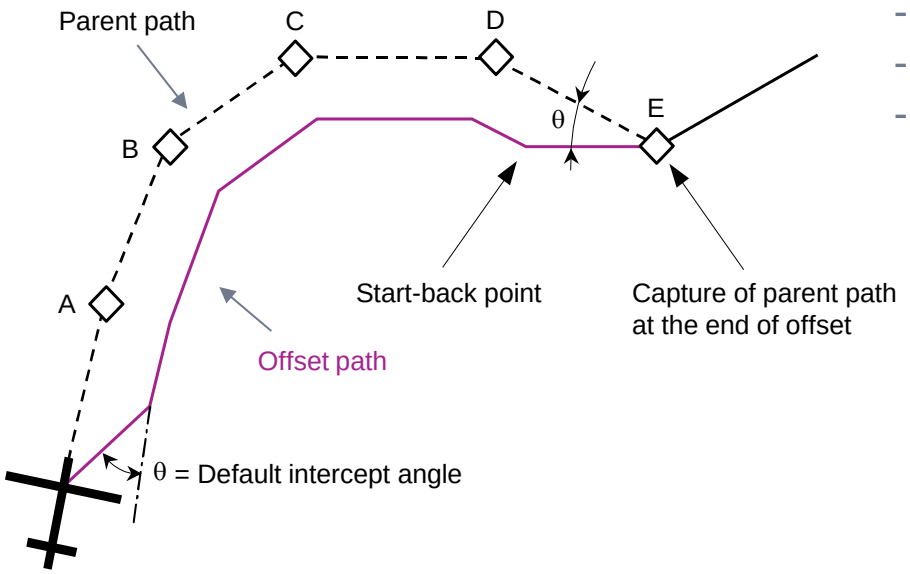
7 Flight plan management – Lateral revisions

More complex lateral revisions are also available :

- Dir To function
- Offset function

The Offset function is used to enable the A/C to fly parallel to the original active F-PLN.

Offset parameters :
- Distance (in NM)
- Direction (Left or Right)
- A Start Waypoint (or PPOS – current position)
- An End Waypoint
- An Intercept angle (in Degree)

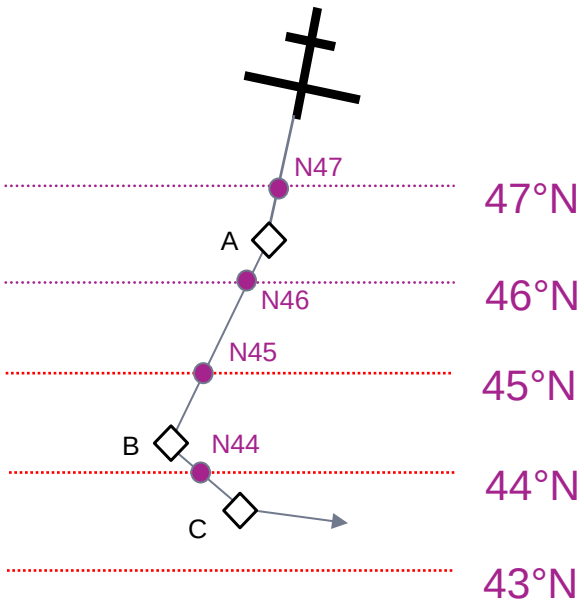


Rationale:
-To avoid a weather phenomena (storm …)
- Aircraft separation purposes

7 Flight plan management – Lateral revisions

More complex lateral revisions are also available :

Dir To function
Offset function
Lat/Long crossing function



This function allows the creation of a specific LAT or LONG crossing point along the flight plan or a series of crossing points at specified intervals following a specific latitude or longitude.
Parameters :

- A latitude or a longitude
- An increment in degree
- The number of expected crossing point

Ex :
43N/1/5 to create 5 Lat/long crossing point from latitude 43 ° North, separated by 1° latitude increment.

Rationale:
Informative waypoints for the pilots

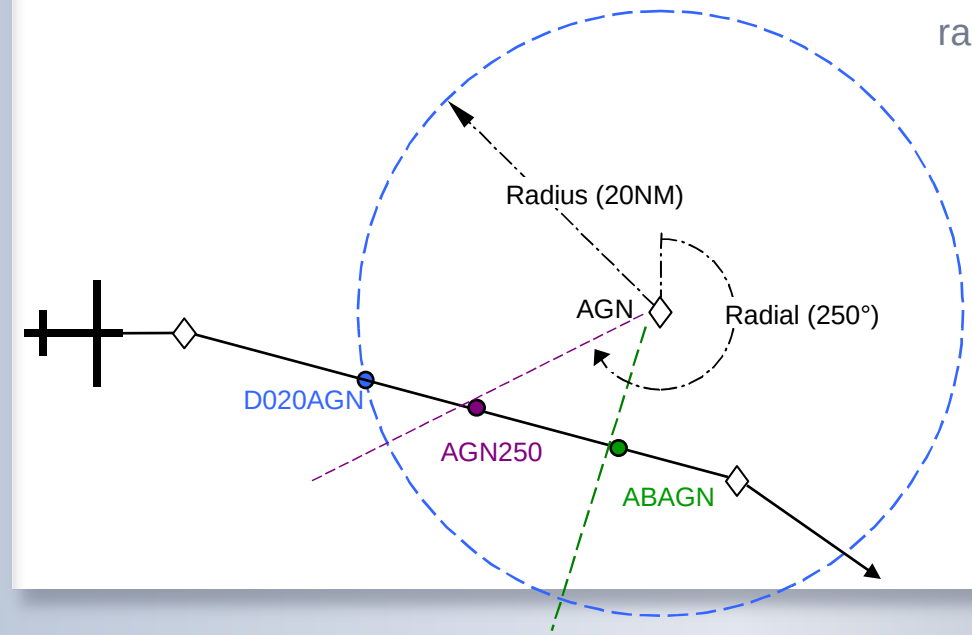
7 Flight plan management – Lateral revisions

More complex lateral revisions are also available :

Dir To function
Offset function
Lat/Long crossing function
Fix Info function

From a waypoint, the Fix Info function is used to insert into the flight plan :

- An Abeam point
- A Radial intercept point according to a given radial value
- A Circle intercept point according to a given radius value



Rationale:
Informative waypoints for the pilots

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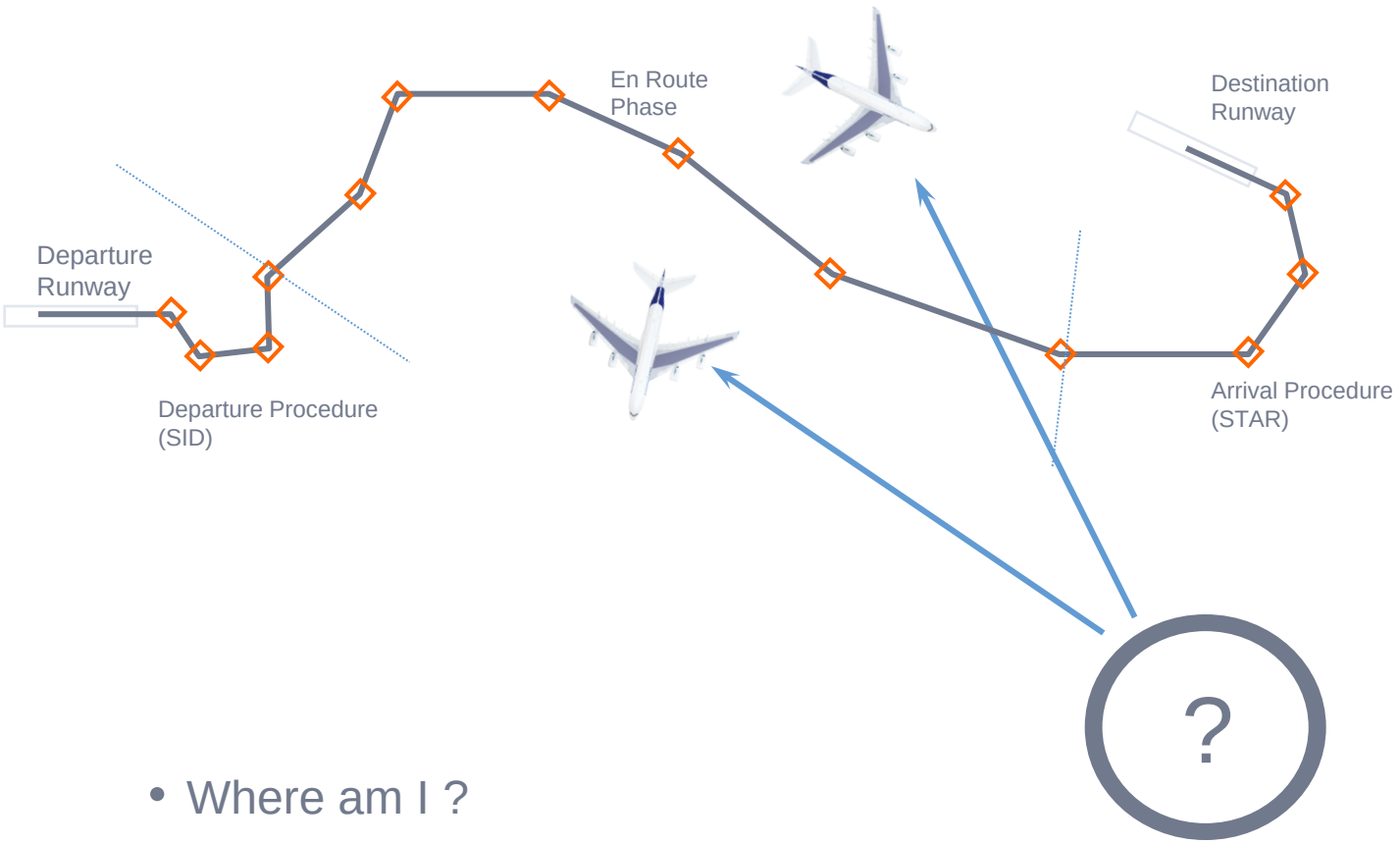
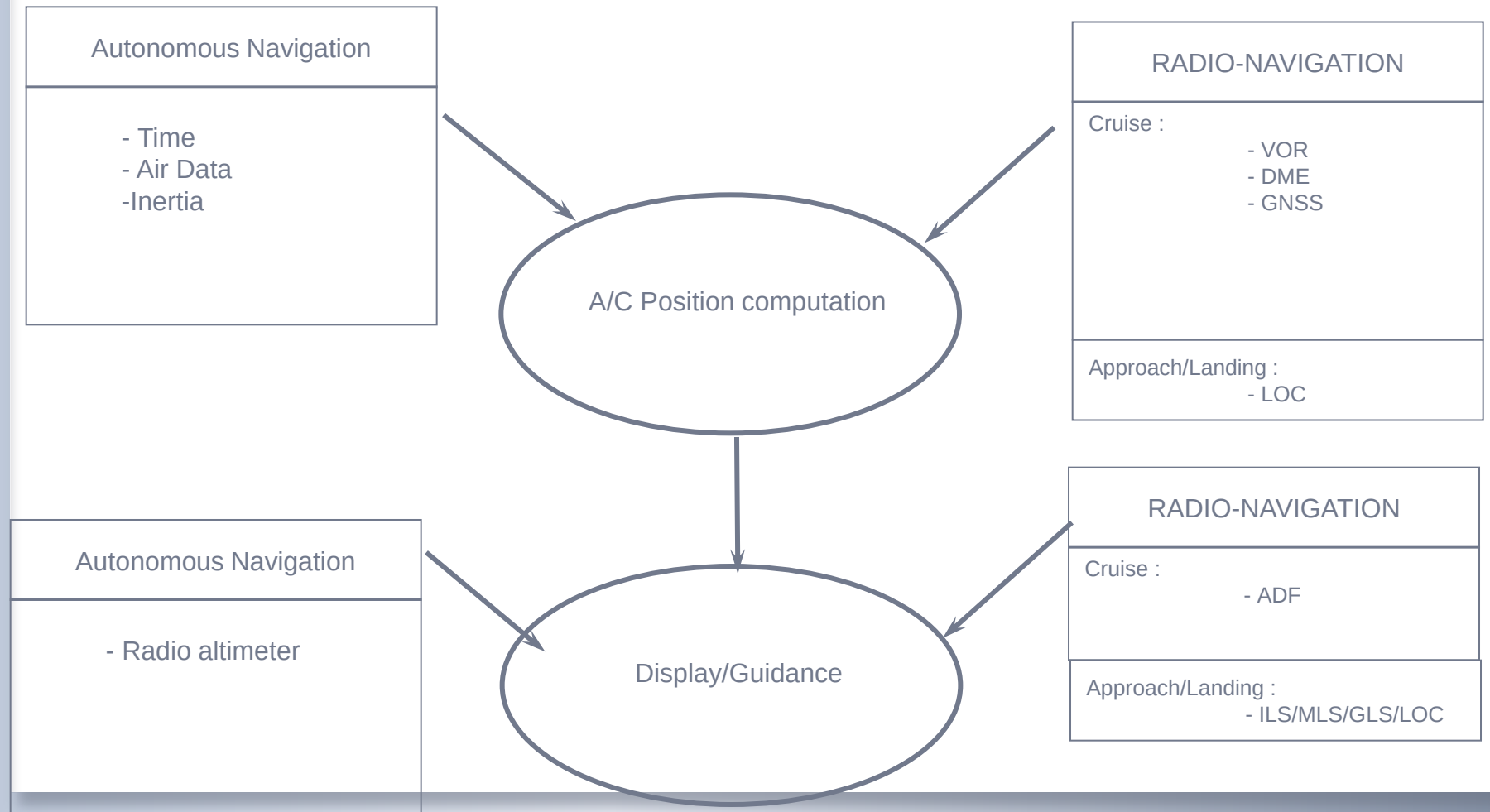
8 Position Computation



- Where am I ?

Position Computation

Conventional sensors/means onboard AIRBUS aircraft



Autonomous Navigation means (1/4)

- Inertial units:
  - Outputs:
    - Attitude
    - Position : Latitude / Longitude
    - Velocity
  - Advantages:
    - Integrity of delivered outputs
    - Embedded navigation means
  - Drawbacks:
    - Initialization need
    - Accuracy degrades versus time (drifts)

⇒ Inertial data are short term data to be used for position computation

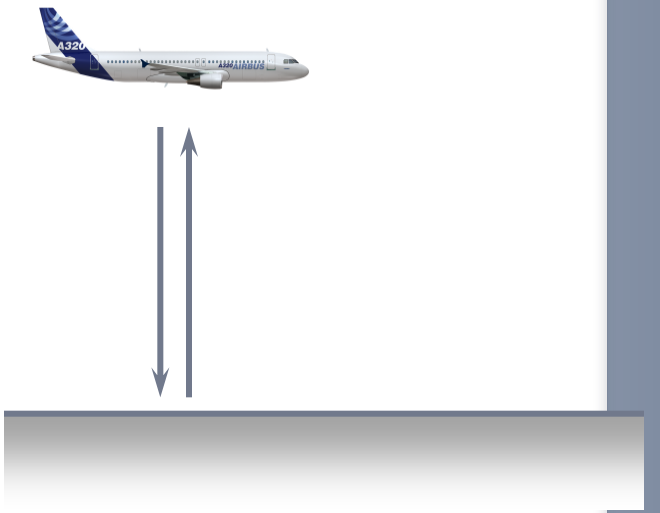
Autonomous Navigation means (3/4)

- Air Data Reference (ADR) :
  - Outputs:
    - Altitude with respect to Mean sea level
  - Advantages :
    - Accuracy sufficient for conventional operations
  - Drawbacks :
    - Data are noisy

⇒ Air Data are blended with inertial data to give Baro-inertial aircraft altitude

Autonomous Navigation means (4/4)

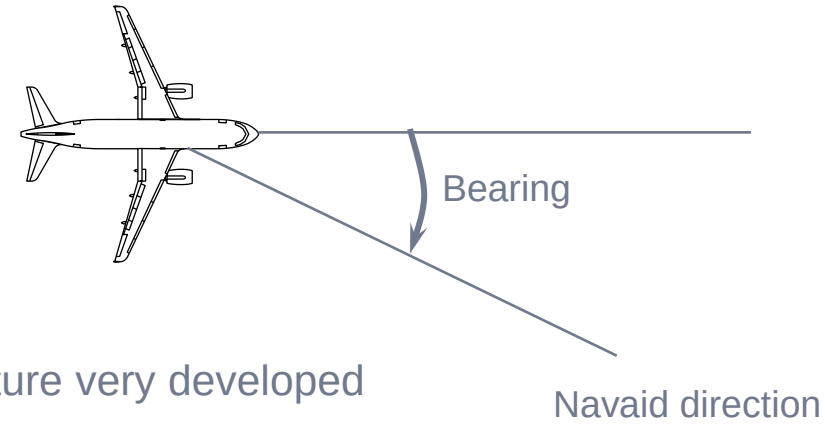
- Radio-altimeter:
  - Outputs
    - Altitude with respect to ground
  - Advantages :
    - Very accurate (+/- 1 ft ou +/- 2%)
  - Drawbacks :
    - Performance depends roll/pitch angles
    - Altitude range is limited (2500 ft max)



⇒ Only used during approach/landing operations. Not used for position computation.

Cruise Radio-Navigation (1/4)

- ADF (Automatic Direction Finder):
  - Outputs:
    - Azimuth of ADF Navaid wrt aircraft axis.

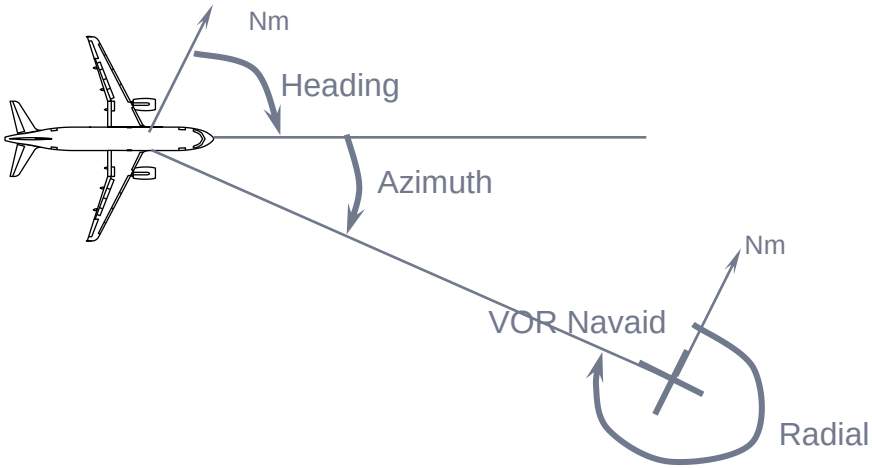


  - Advantages:
    - Simple means, ADF infrastructure very developed
  - Drawbacks:
    - Limited accuracy (3-5°)
    - Poor reliability (signal degraded in degraded meteorological conditions)

⇒ ADF are not used for position computation : only used as visual guidance aid

Cruise Radio-Navigation (2/4)

- VOR (VHF Omni Range):
  - Outputs:
    - Magnetic radial of the navaid

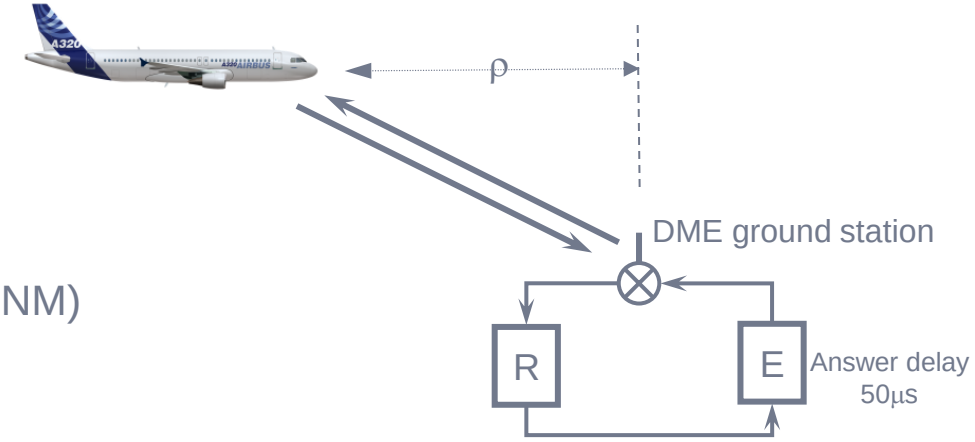


  - Advantages :
    - Simple means
  - Drawbacks :
    - Limited accuracy (3-5°) and function of the relative distance between the A/C and thee navaid
    - Poor Signal stability

=> VOR are used for radio position computation

Cruise Radio-Navigation (3/4)

- DME (Distance Measuring Equipment):
  - Outputs:
    - Direct distance between A/C and the DME navaid



  - Advantages:
    - Good accuracy (0.2-0.5 NM)
    - Simple means
  - Drawbacks:
    - Navaids have an active role to give distance info to each aircraft interrogating : risk of saturation

⇒The horizontal distance ρ is used for position computation

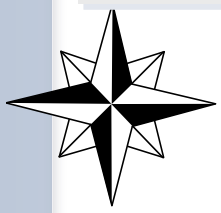
Cruise Radio-Navigation (4/4)

- GPS (Global Positioning System) :
  - Advantages:
    - Good accuracy (30 m)
    - Good availability of satellite constellation
    - Signal in space Integrity level is known in real time
  - Drawbacks:
    - Multipath (on ground or near the ground)

⇒ GPS is the preferred navigation sensor nowadays

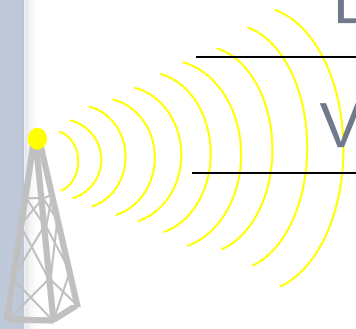
Position Computation

General principle of position computation in FMS



IRS 1, 2, 3

Inertial



DME

VOR

Radio

ρ/ρ position

ρ/θ position

MMR

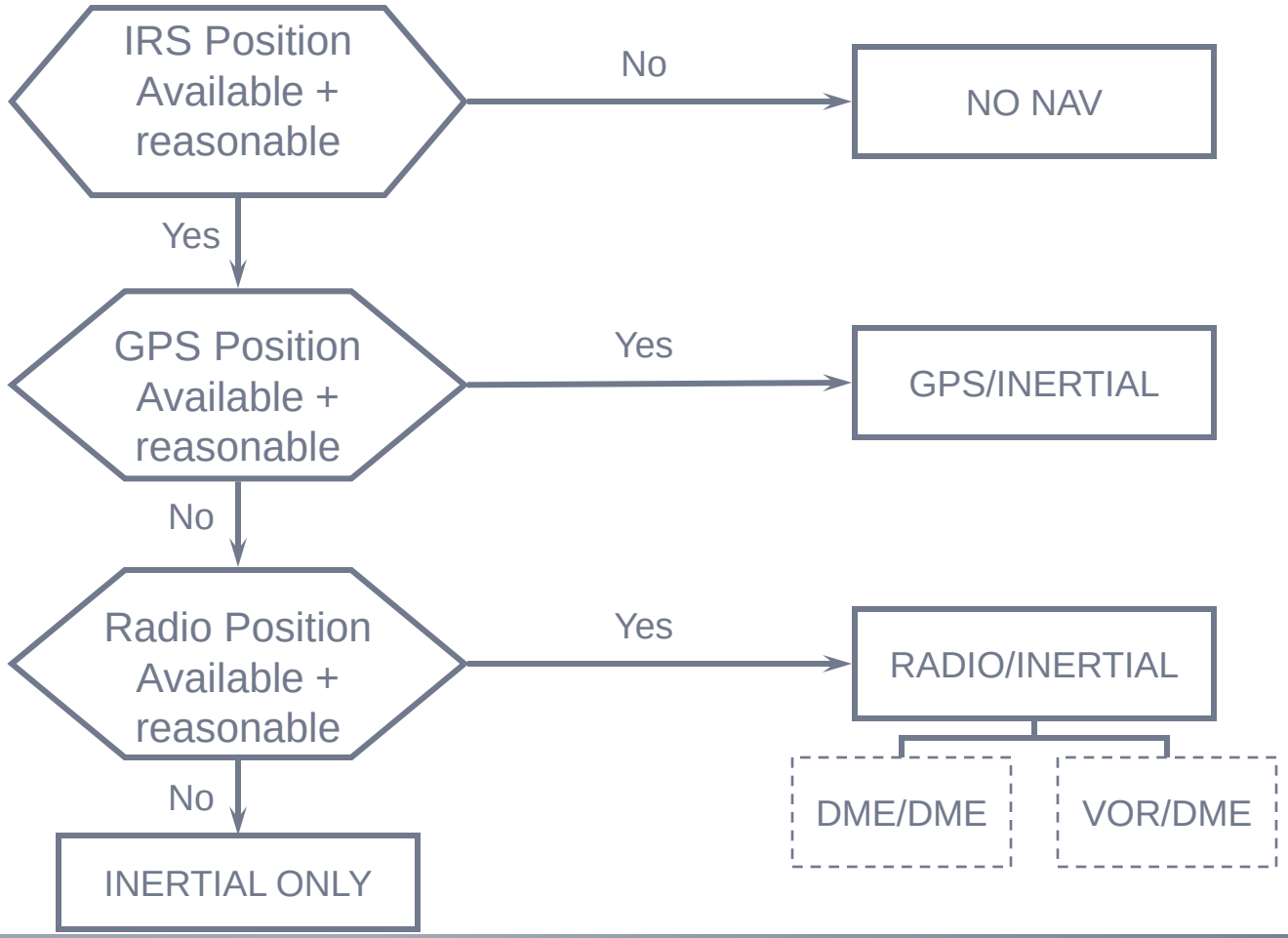
GP(IR)S

Navigation Function

FMS position

Position Computation

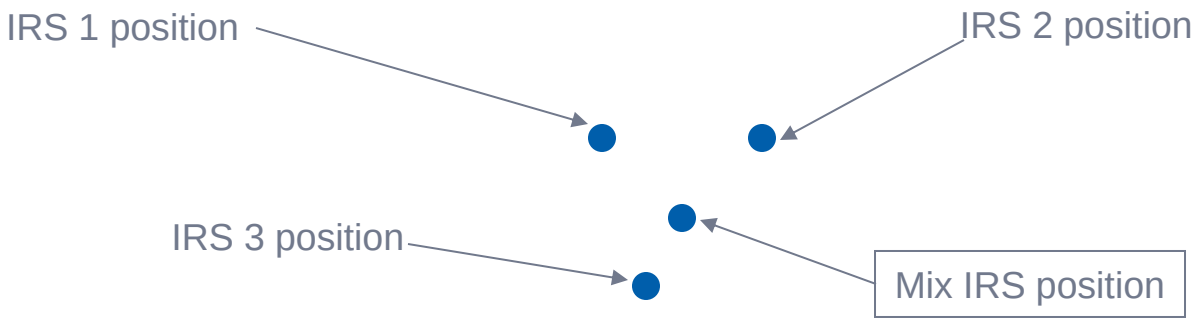
Navigation modes automatic/optimum selection



Position Computation

INERTIAL ONLY Navigation mode

- On AIRBUS aircraft, 3 IRU are available
- The 3 IRU positions are mixed to compute a MIX IRS position in order to eliminate an IRS position that would have drifted abnormally.
- Inertial position is then valid as long as at least one IRS position is valid



$$\text{Mixed IRS position} = \frac{P1((P3-P2)^2 + w) + P2((P3-P1)^2 + w) + P3((P2-P1)^2 + w)}{(P3-P2)^2 + (P3-P1)^2 + (P2-P1)^2 + 3w}$$

w = positive small weighting factor = $0.03125\ \text{degree}^2$

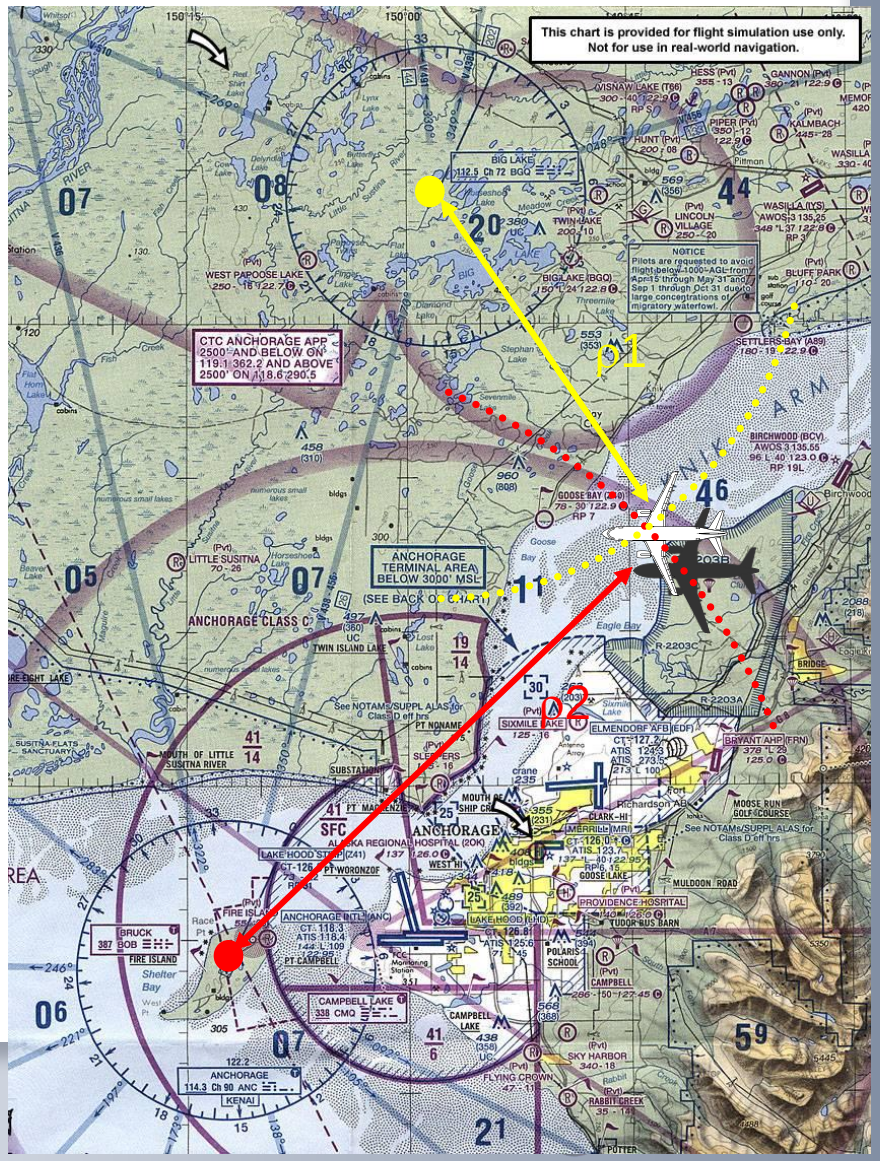
GPS/INERTIAL Navigation mode

- For hybrid configuration (= GPIRS) GPS data are transmitted to FMCs through the ADIRS (for navigation computation and data display).
- Nominally FMS1 (resp2) will choose GPIRS1 (resp2) source (On/3/Op logics).

- Monitoring is performed by the FMS in order to detect potential loss of GPS signal integrity.
  - Through Kalman filters within Thales FMS
  - Through stability checks within Honeywell FMS
    - 1st check: stability of the GPS bias
    - 2nd check: stability of GPIRS position compared to mixed IRS position (considering IRS draft model)

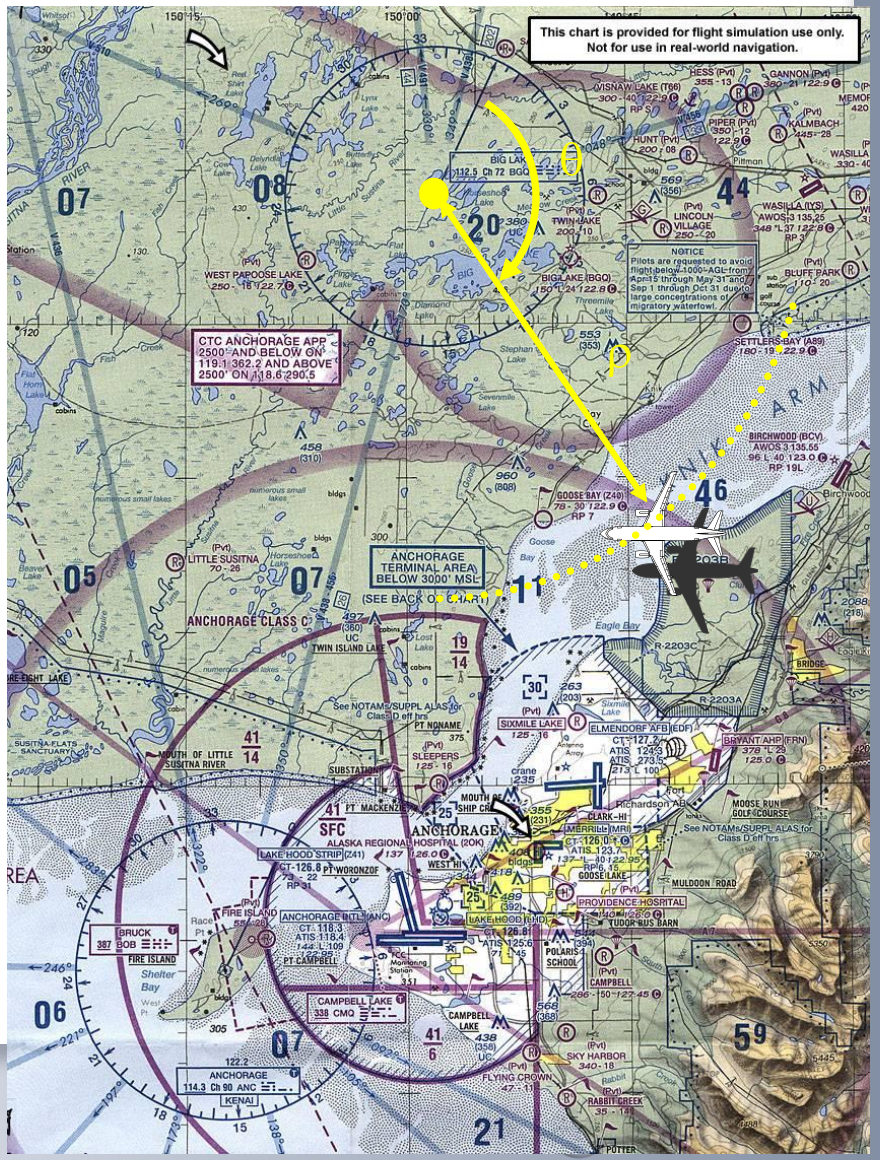
Position Computation

Radio-Navigation : DME/DME Navigation mode



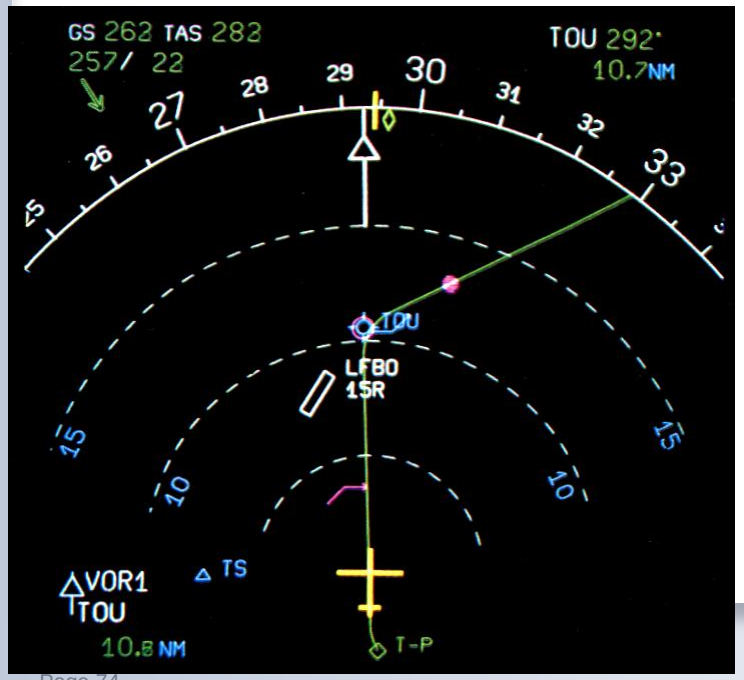
Position Computation

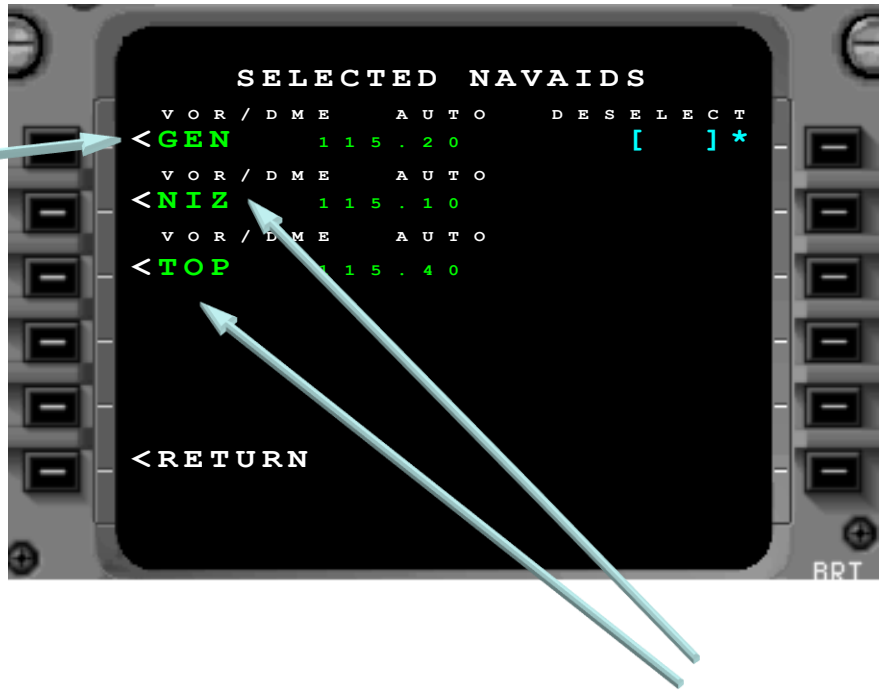
Radio-Navigation VOR/DME Navigation mode



HMI – Tuned Navaids

For display on ND

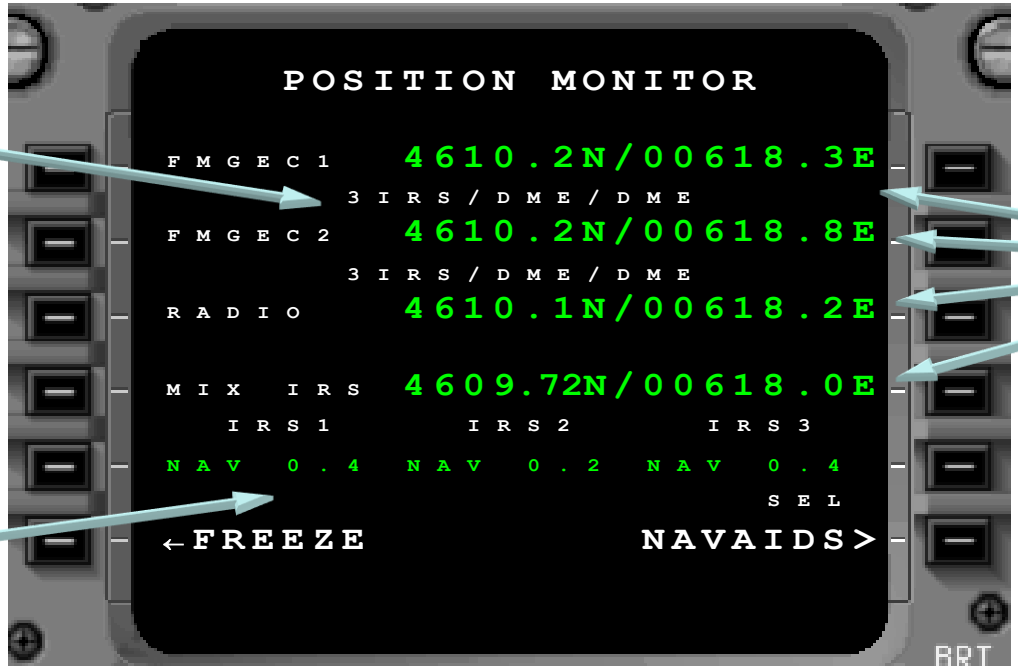




For position computation

HMI – Synthesis of Position computation function

NAV mode

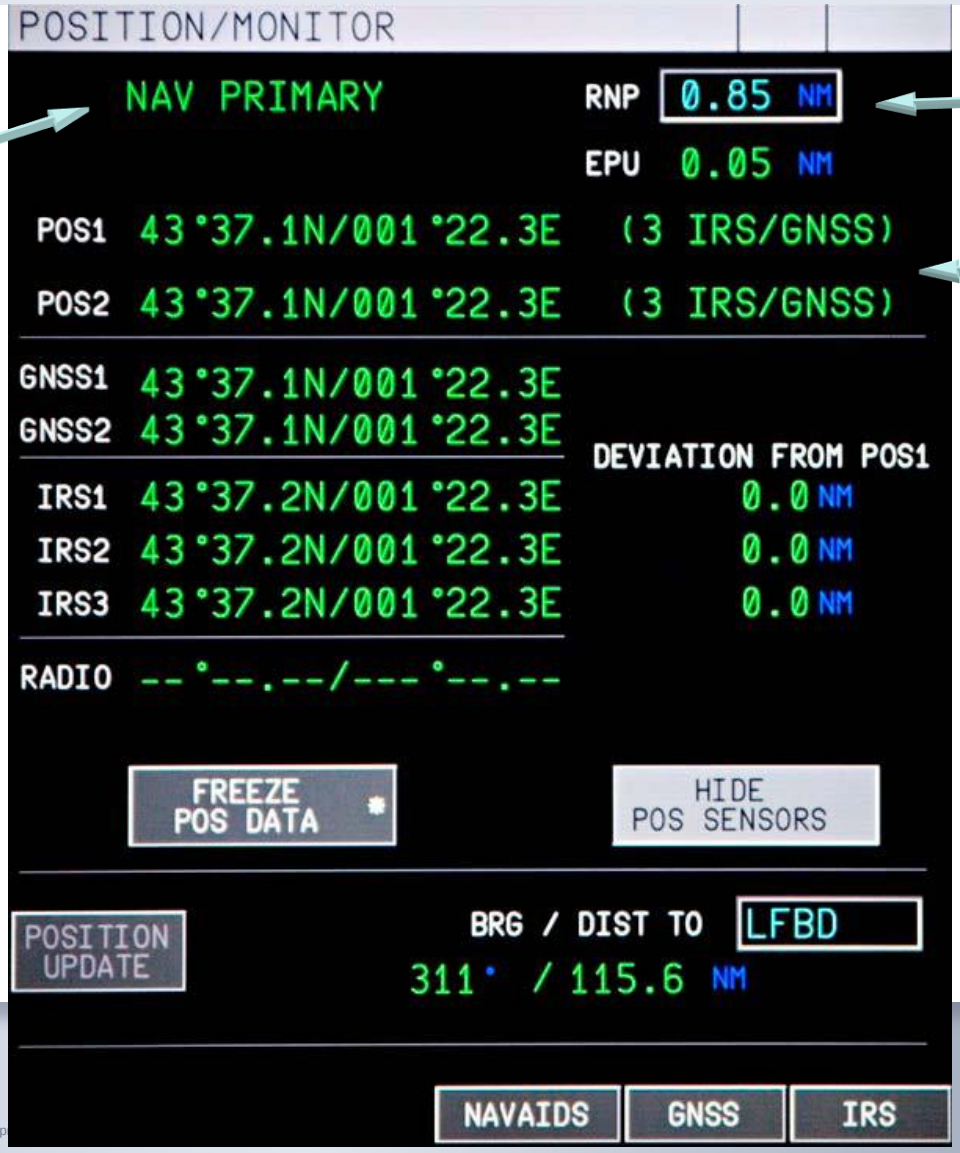


Available positions

IRS drift

Position Computation

A350 HMI – Synthesis of Position computation function



NAV status

POS sensors status

RNP

Available positions and Navigation mode

AIRBUS

Position Computation

A350 HMI – Synthesis of Position computation function

NAV status

PSO sensors status

RNP

Available positions and Navigation mode

AIRBUS

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9 Guidance along the lateral path

- Lateral guidance :
  - Is controlled by pilot or by FMS depending on lateral guidance mode.
  - Is based on the Active leg *(leg A/C is supposed to fly)* of the Primary F-PLN.
  - Takes into account a notion of F-PLN sequencing in order to update the active FPLN when necessary (leg switching when specific condition between two legs is reached).

9 Guidance along the lateral path

Two lateral guidance modes are available

Managed mode

Managed mode is engaged by pushing the HDG/TRK selector knob on FCU
Lateral guidance is controlled by the FMS to follow the trajectory as defined on MCDU (MFD).

Selected mode

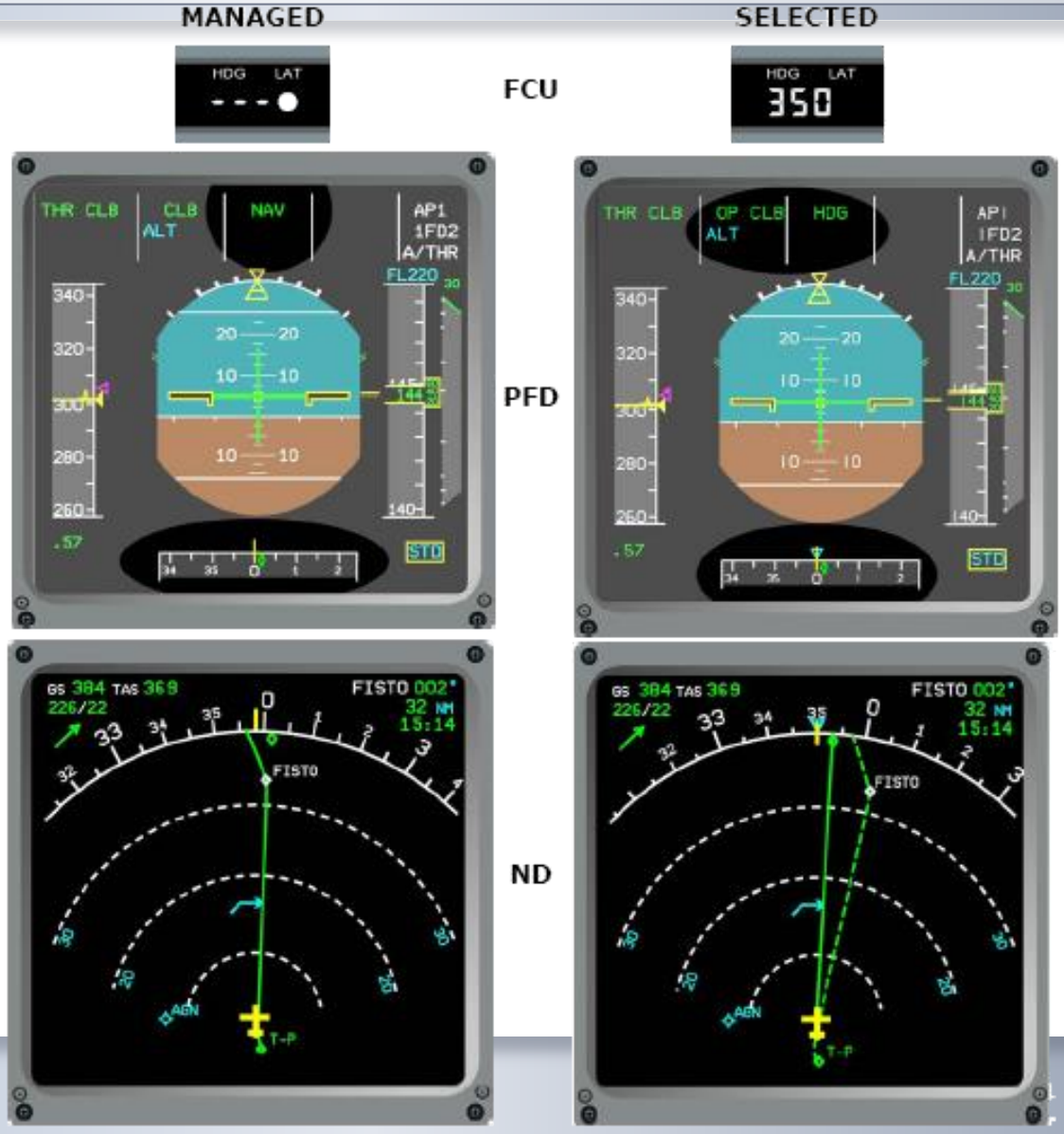
Selected mode is engaged by pulling the HDG/TRK selector knob on FCU
Lateral guidance is controlled by pilot selection on the FCU.

FCU on SA/LR

FCU on A380/350

9 Guidance along the lateral path

Lateral Guidance mode



SA/LR

9 Guidance along the lateral path

In both modes (managed or selected) the FMS compares the A/C actual situation with the desired situation on active leg

In Managed mode (NAV)

The FMS generates steering commands to the Autopilot and Flight director.

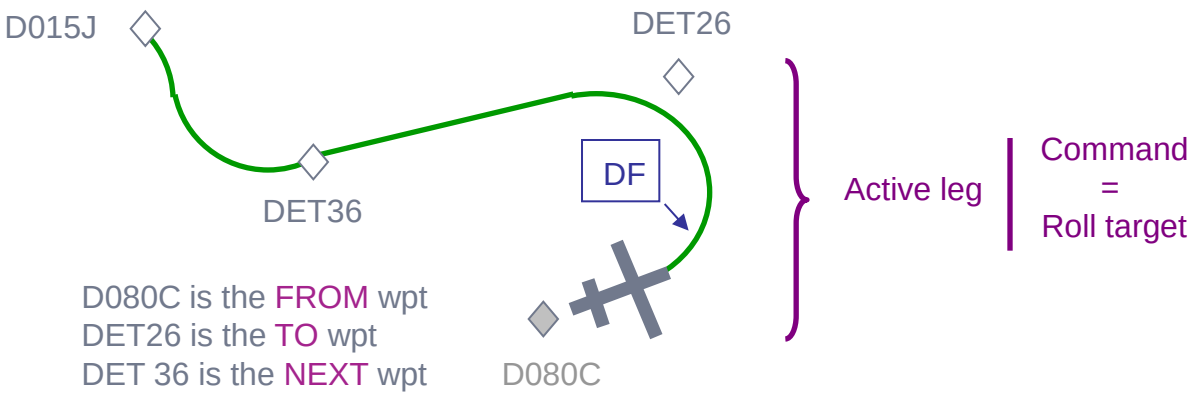
In Selected mode (HDG or TRK)

The FMS computes a Navigation Capture zone where the Managed mode can be engaged and displays a Pre-Nav engagement path (predicted lateral path from A/C to active leg) if Managed mode is armed and A/C is not on this capture zone

9 Guidance along the lateral path

In **Managed** mode, depending on active leg type the FMS steering commands are :

- **Roll targets** for fixed path legs (TF, CF, DF, …)
- **Heading targets** for heading legs (VD, VI, VM, …)
- **Track targets** for course legs (CD, CI, CA, …)



-Cross Trak Error (XTKE) = distance between the A/C and the nearest point of the active leg (right or left)

-Track Angle Error (TKAE) = desired course – A/C true track

9 Guidance along the lateral path

F-PLN Sequencing :

An automatic sequencing occurs when :
- A/C overflies TO waypoint or crosses with specific condition for fixed path legs.
- conditions linked to the leg are met for heading and Course legs.

XTKE error

In this example, A/C is in selected mode, ABADI has been passed with a Crosstrack error less than 5NM.
TO waypoint is now BOKNO

9 Guidance along the lateral path

F-PLN Sequencing :

When conditions for automatic sequencing are not met the F-PLN must be sequenced manually.

The FROM is cleared

9 Guidance along the lateral path

F-PLN Sequencing :

When conditions for automatic sequencing are not met the F-PLN must be sequenced manually.

ABADI becomes the FROM WPT

A HDG/TRK is selected on FCU to intercept the active leg before TMPY F-PLN insertion