GEA Tianjin / 中国民航大学中欧航空工程师学院

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Airbus

FLIGHT MANAGEMENT SYSTEM
Part 2

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Lateral Flight Management: F-PLN

Objective:

Help the crew in lateral operation for:

✓ **On ground**:

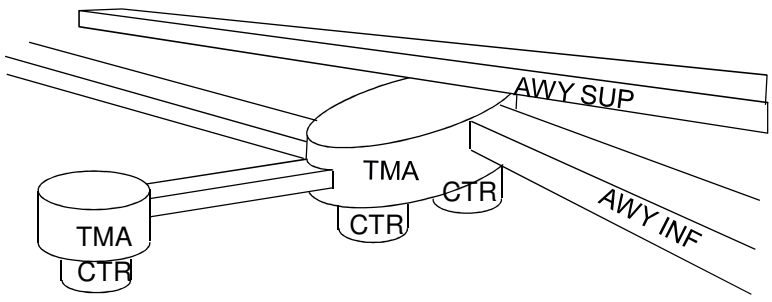
- flight plan construction → Initialization
  → Procedure insertion
  → Airways

✓ **In flight**:

- trajectory modification → Direct TO
  → OFFSET
  → Holding pattern
  → Lat/long xing pts

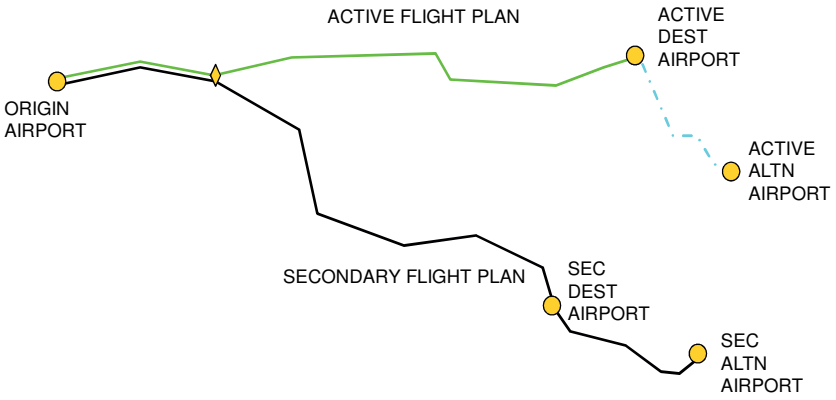
Lateral Flight Management: Air Space

- The commercial aircrafts are integrated in the general traffic.
- Air space is cut is several areas.



- CTR = Controlled area around airports, from the ground up to the TMA level
- TMA = terminal controlled area established above one or several big airports
- AWY = Airway = controlled air corridor (width around 10 Nm, max level FL195)

Flight Plan: active/secondary/alternate



- ACTIVE FPN: Alternate mandatory except if conditions MTO are valid on active DEST
- SECONDARY FPLN: usually used for
  - flight back or next flight
  - for alternative route on long range flights

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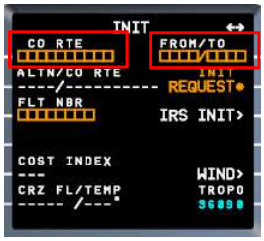
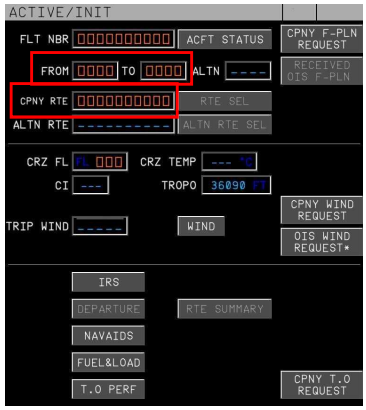
Lateral Flight Management: F-PLN

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



INIT page



The crew can select:
- an airport pair
- a company route (the FMS builds the route)

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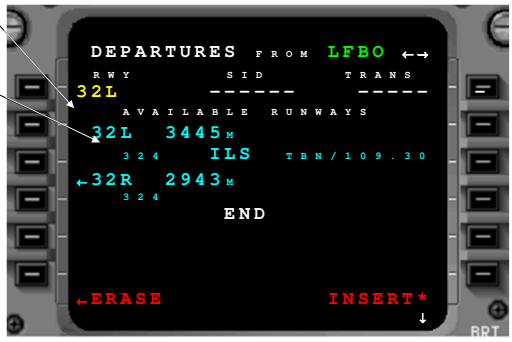
Lateral Flight Management: F-PLN

The crew can select:

- a departure runway in the list of available runways at the departure airport

The pilot has info about:

- the runway bearing
- the runway length
- the runway ILS



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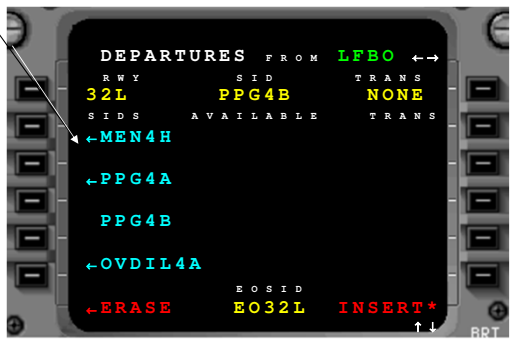
Lateral Flight Management: F-PLN

The crew can select:

- a Standard Departure Procedure (SID) among the list of available ones

Same behavior for:

- arrival procedures (STAR)
- approaches



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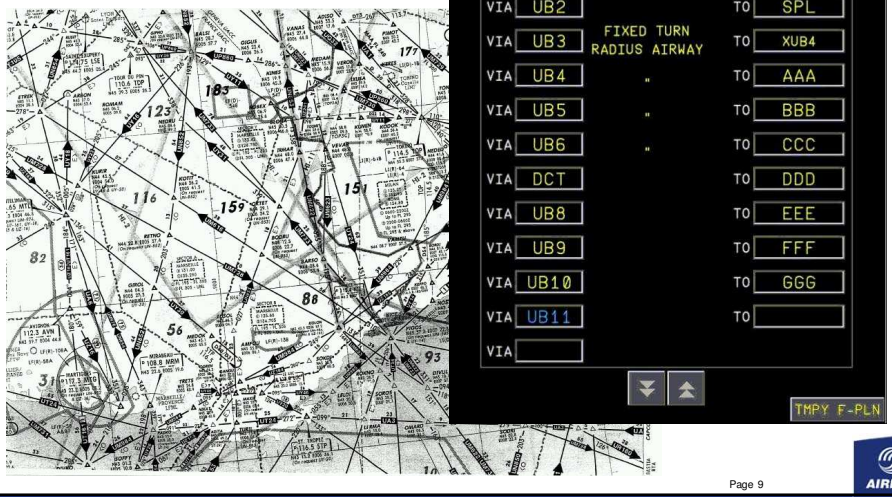
Lateral Flight Management: F-PLN

The crew can select a succession of airways => FMS computes intersections



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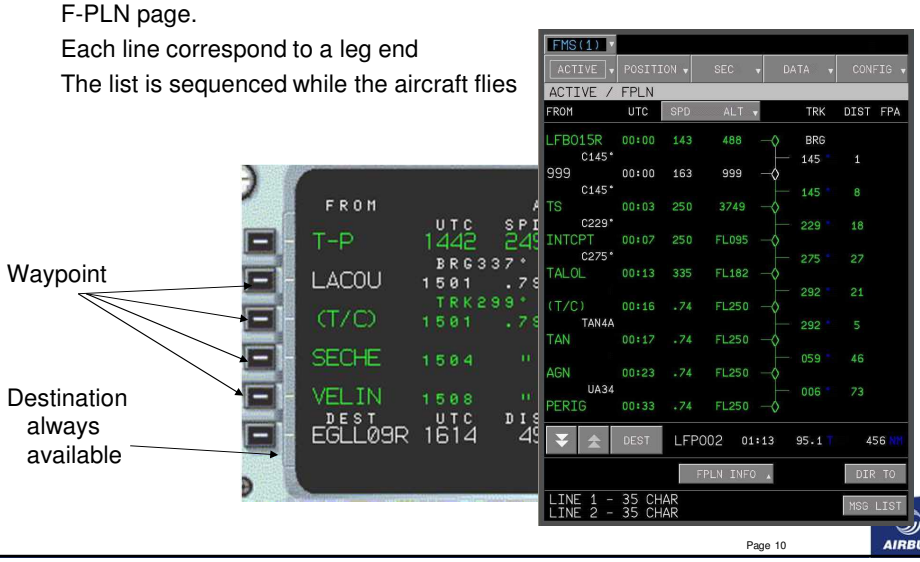
Lateral Flight Management: F-PLN

Once all is initialized and selected, the pilot can see the flight plan list on the F-PLN page.

Each line correspond to a leg end

The list is sequenced while the aircraft flies



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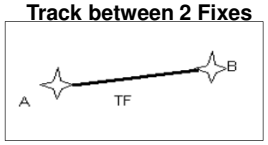
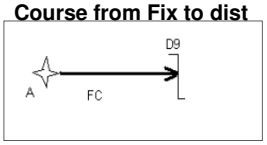
Lateral Flight Management: F-PLN

- **Fix Legs**

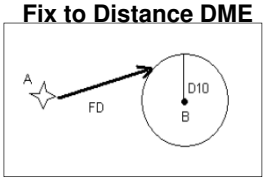
Track between 2 Fixes



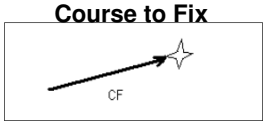
Course from Fix to dist



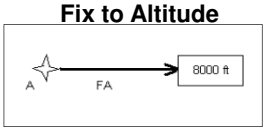
Fix to Distance DME



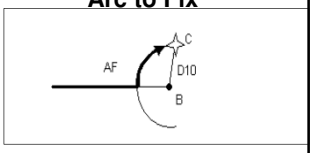
Course to Fix



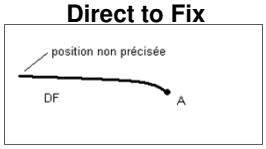
Fix to Altitude



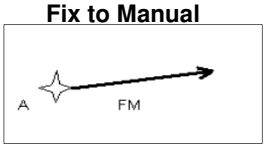
Arc to Fix



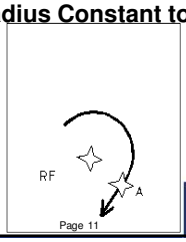
Direct to Fix



Fix to Manual



Radius Constant to Fix



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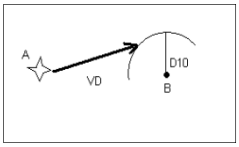
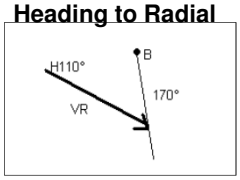
Lateral Flight Management: F-PLN

- **Heading Legs**

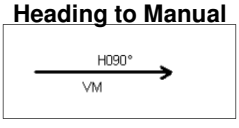
Heading to Distance DME



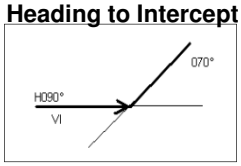
Heading to Radial



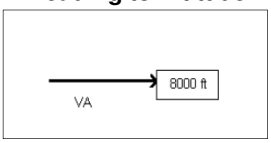
Heading to Manual



Heading to Intercept



Heading to Altitude



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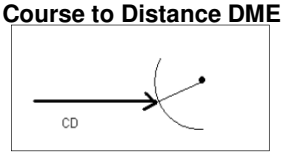
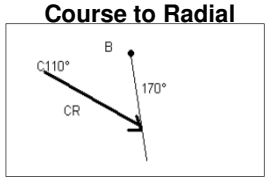
Lateral Flight Management: F-PLN

- **Course Legs**

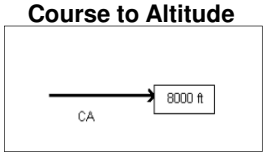
Course to Distance DME



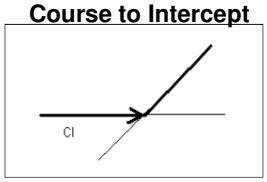
Course to Radial



Course to Altitude



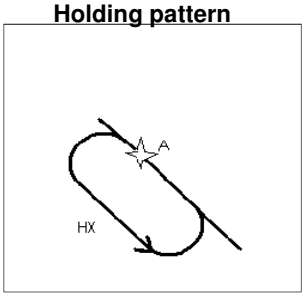
Course to Intercept



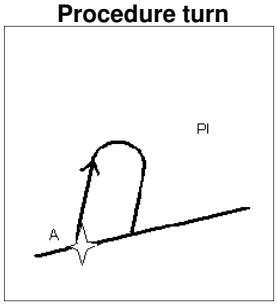
Lateral Flight Management: F-PLN

- **Hold & PI Legs**

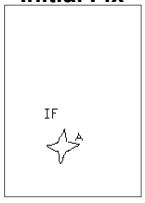
Holding pattern



Procedure turn

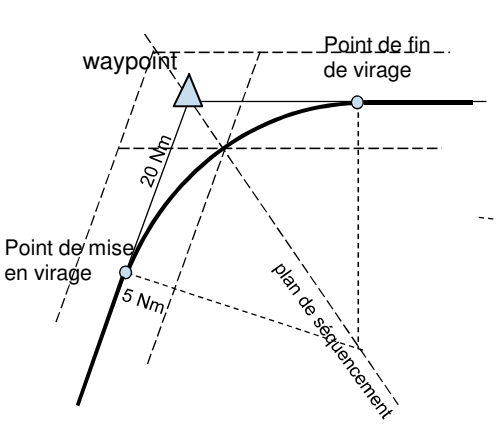


Initial Fix

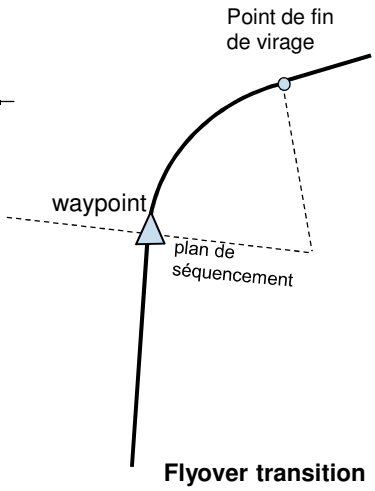


Lateral Flight Management: F-PLN

- **Transitions**



Non-Flyover transition



Flyover transition

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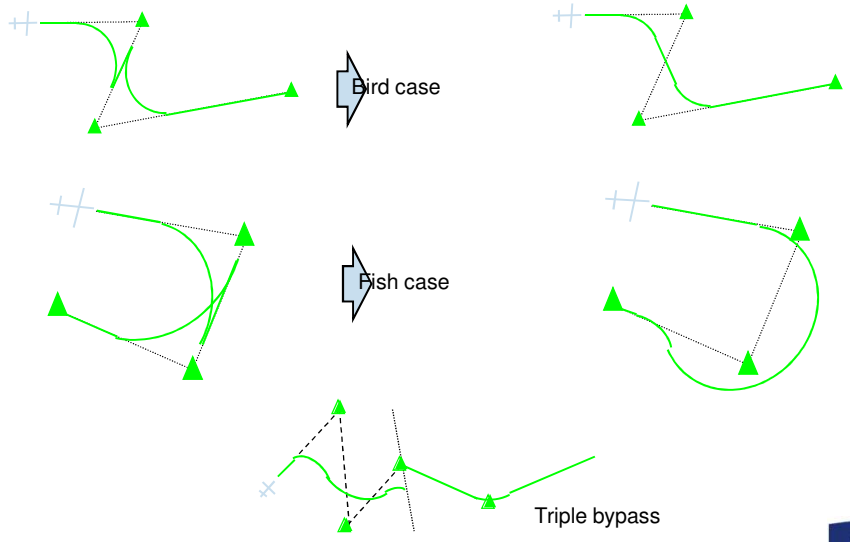
Lateral Flight Management: F-PLN

- **Bypass**



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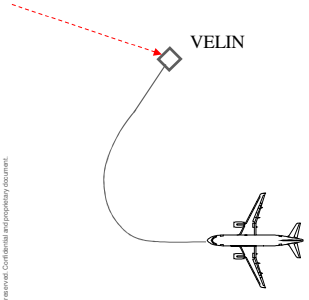
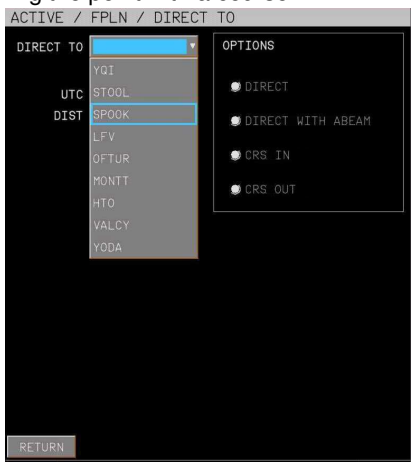
Lateral Flight Management: F-PLN

The pilot can order a **DIRECT TO** a waypoint with several strategies:

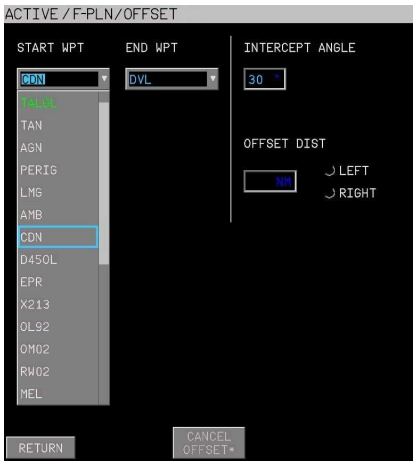
- direct to
- including abeam points
- reaching the point with a bearing
- leaving the point with a course





Lateral Flight Management: F-PLN

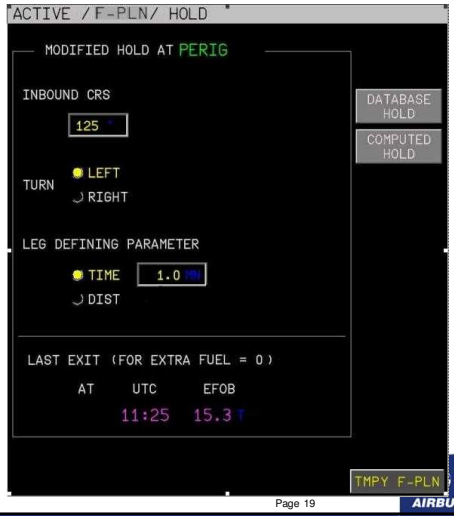
Due to bad weather or traffic avoidance, the pilot may define an offset route.
The FMS inserts the offset into the flight plan:



Lateral Flight Management: F-PLN

Due to traffic, the pilot may define holding pattern.

The FMS inserts the Holding pattern into the flight plan:



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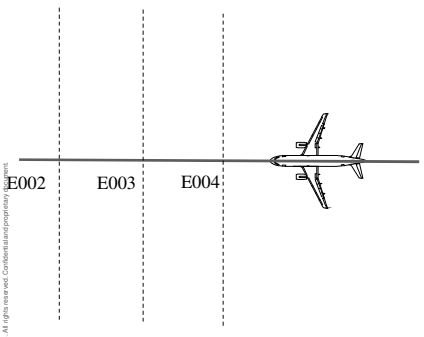
Lateral Flight Management: F-PLN

In order to report position, the pilot may define intersection when crossing latitude or longitude.

The FMS inserts the intersections into the flight plan:



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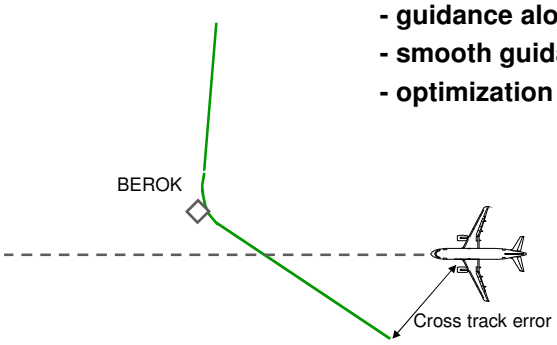
Lateral Flight Management: Guidance

Objective:

Help the crew in lateral operation for:

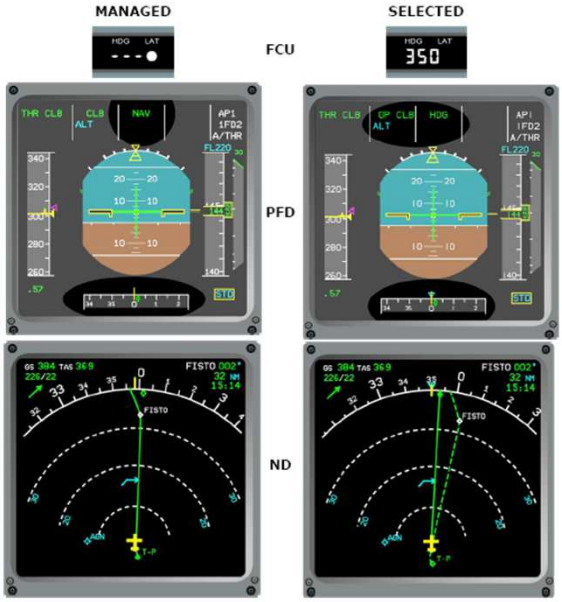
✓ **In flight**

- Guidance → **FMS guidance provide:**
  - **guidance along flight plan**
  - **smooth guidance between legs**
  - **optimization between legs**



Lateral Flight Management: Guidance

Lateral Guidance mode



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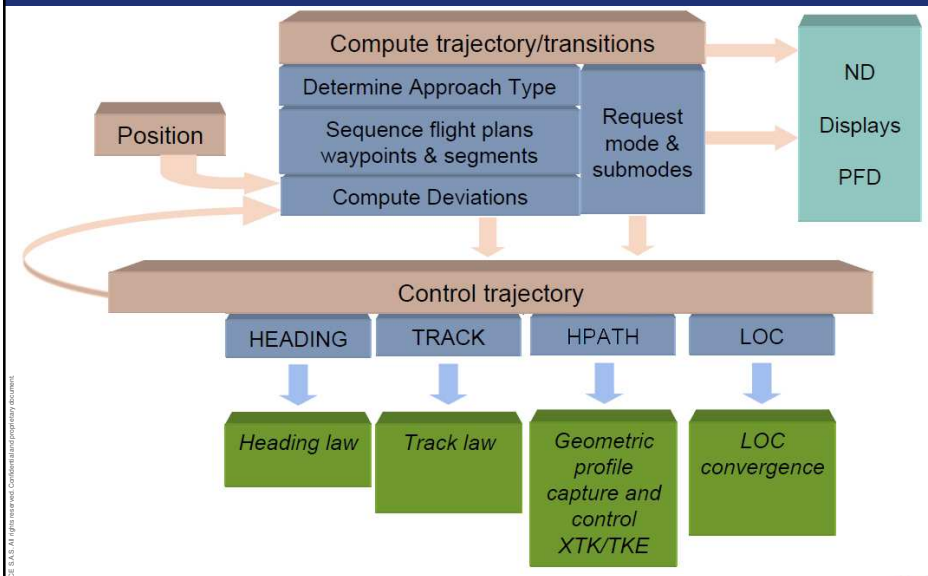
Lateral Flight Management: Guidance



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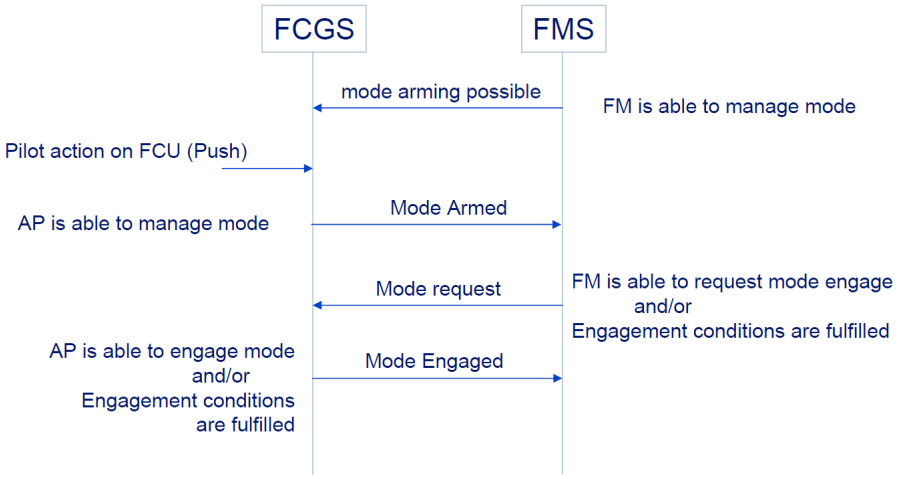
Lateral Flight Management: Guidance

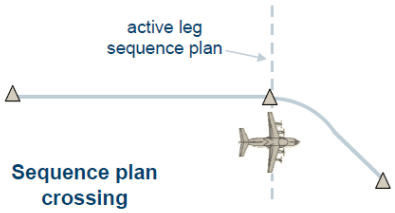
Sequence of actions for FM Managed mode engagement:



Lateral Flight Management: Guidance

Lateral Guidance is responsible for active leg identification along flight whatever the engaged mode → Need to sequence legs

- Condition for sequencing are periodically tested :
  - Cross sequencing plan for usual legs (either fly-by or overfly)
  - Less than 5 Nm from IF leg fix or all legs when NAV mode not engaged
  - Cross termination altitude of legs CA, VA or FA



Lateral Flight Management: Guidance

FM is responsible for sub-mode selection

- **TRACK: Allow to control a course (wind consideration)**
  - When aircraft need to follow a route with legs CA, CD, CR.
  - To allow better LOC beam capture in approach
- **HEADING: Allow to control leg heading (no wind consideration)**
  - When aircraft need to follow a heading on legs VA, VD, VR, VM.
- **HPATH: Allow to control FMS computed trajectory**
  - All other situations

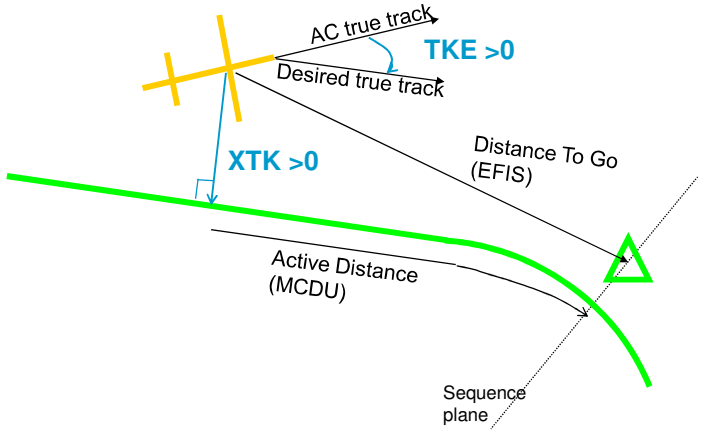
Lateral Flight Management: Guidance

Command sent as Heading (Hdg) or Track (Trk)

- Heading or Track
- Max Roll Angle (based on speed, …)
- Consideration of Mag/True switch on the cockpit control panel
- Aircraft is not controlling the computed trajectory. FM is responsible for sub-mode selection

Lateral Flight Management: Guidance

HPATH case



XTK TKE

HPATH Law + Comfort law

Roll angle ϕ

$\Phi_c = \Phi_{nom}$ (trajectory)
+ K_1.XTK + K_2.GS.TKE
+ roll limitations (fct speed)
+ comfort law (2nd order)

With $\Phi_{nom} = ATAN\ (GS^2/R.g)$

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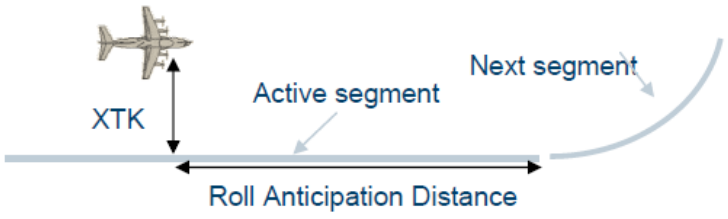
Lateral Flight Management: Guidance

Pre-command relative to next segment

- Roll Anticipation Distance Allow Auto-Pilot to anticipate roll
- Distance necessary to reach nominal bank angle at the start of next segment
- Use parameters of next segment (Curve, max bank angle, …)



$$RAD = GS * \left[\frac{ABS[\Delta\varphi_{nom}]}{R.oll\_rate} + inertia \right]$$

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Lateral Flight Management: Guidance

Maximum roll command depend upon:

- Aircraft type
- Airspeed/Altitude (increased comfort at high speed, high altitude)
- Flight area (Enroute, Terminal)
- Engines out

FM Path Max Roll < FM Max Roll Command < FG Max Roll

➔ allow accurate path control even with wind variation

Roll command variation

- Limited according to autopilot capabilities
- Passenger comfort limitation on roll rate

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The Vertical Flight Management

Objective:

Help the crew in lateral operation for:

On ground:

- Loading analysis → Fuel planning
- Meteo analysis → Predictions

In flight

- Performance monitoring → Predictions
  → What if functions
- Meteo analysis → Predictions
- Guidance → FMS guidance

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Vertical Flight Management: Predictions

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

The FMS provides predictions of:

- Distance
- Altitude
- Time
- Speeds
- Fuel

at each waypoint of the flight plan

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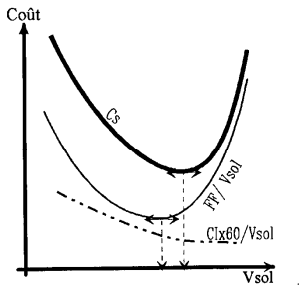
Vertical Flight Management: Predictions

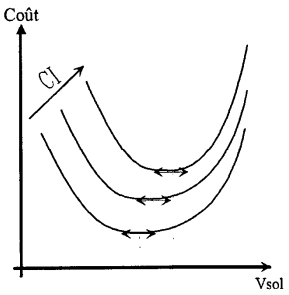
The FMS optimize speeds (CLB, CRZ, DES) in order to minimize a criteria fixed by the Ariline: the cost index:

$CI = C_{T\ (\$/kg)} / C_{C(Kg/min)}$

CI=0: minimum fuel

CI=999: minimum time





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Vertical Flight Management: Predictions

The FMS also takes into account a real meteorological model for computation with:

- tropopause value
- wind model
- temperature model

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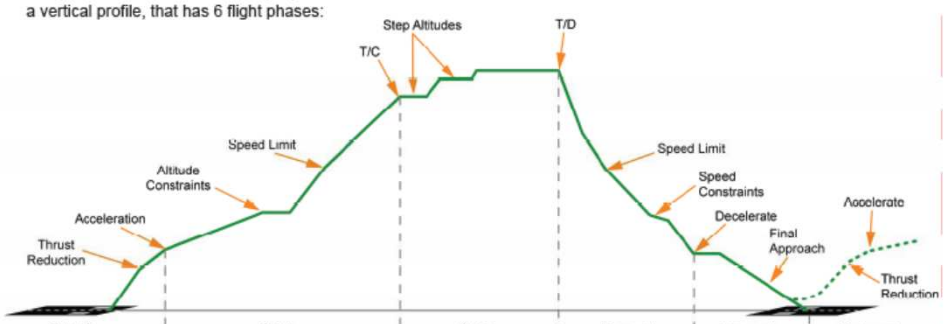
Vertical Flight Management: Flight Phases

The predictions and the lateral flight plan combine to form a vertical profile, that has 6 flight phases:

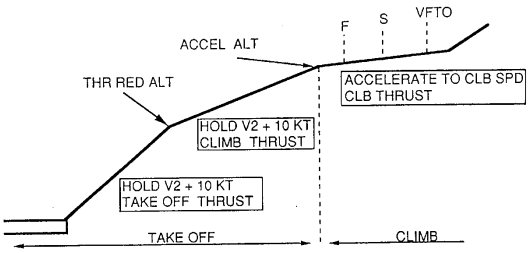


Takeoff	Climb	Cruise	Descent	Approach	Go Around
- V2+10kt (SRS) - TO GA thrust up to thrust reduction altitude, then CLB thrust	- 30% of thrust for altitude gain - 70% of thrust for acceleration up to first climb speed - Altitude/speed constraints taken into account	- Altitude steps may exist - ECON cruise speed varies as weight decreases	- ECON descent speed - IDLE thrust - Altitude/speed constraints taken into account	- Deceleration for configuration changes - Approach speed reached at 1000 ft AGL	- Same as takeoff

Note: A Noise Abatment Departure Procedure (NADP) has different thrust parameters for takeoff and acceleration

Vertical Flight Management: Flight Phases

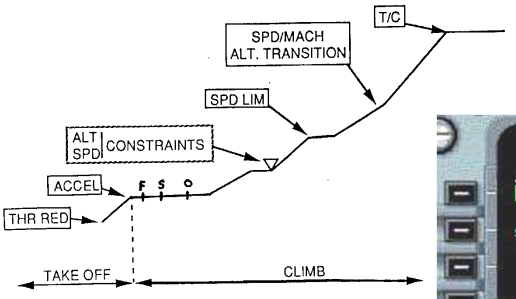
Take off



The FMS helps the pilot to monitor the take off phase
No guidance during take off

Vertical Flight Management: Flight Phases

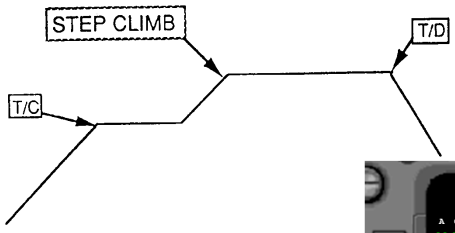
Climb

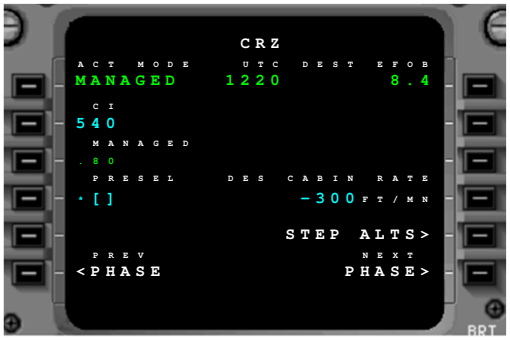


Speed and altitude guidance available

Vertical Flight Management: Flight Phases

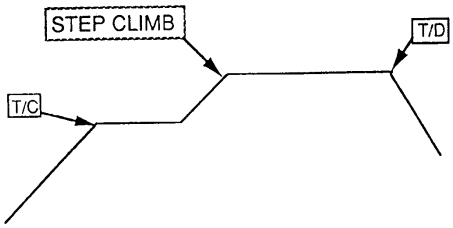
Cruise





Speed guidance available:
the speed is optimized
all along cruise

3.2.2 The Vertical Flight Management: Phases



Time guidance also available (called 4th D)

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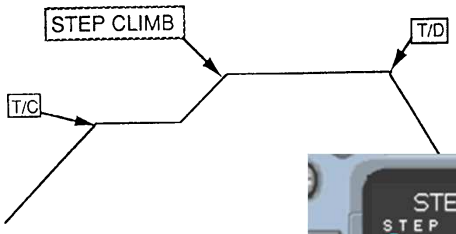
Vertical Flight Management: Flight Phases



The FMS helps the pilot in choosing the best cruise altitude

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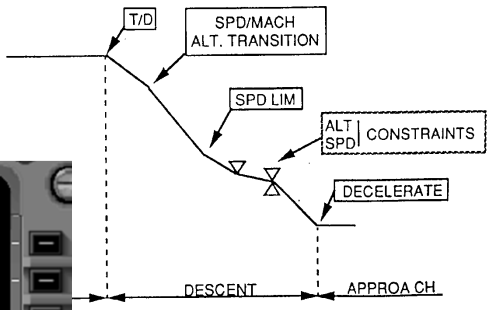
Vertical Flight Management: Flight Phases

Descent

The FMS helps the pilot to monitor the Descent phase

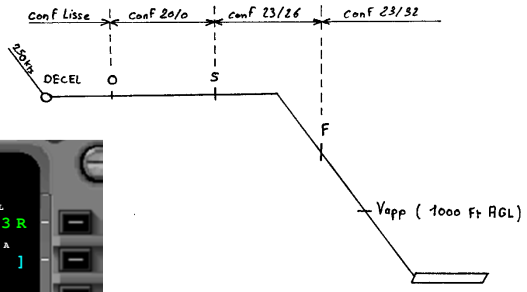


The FMS computes a descent path based on idle thrust
Speed, altitude and time guidance available

Vertical Flight Management: Flight Phases

Approach

The FMS helps the pilot to monitor the Approach phase



The approach path is built.
Speed, altitude guidance is available

Vertical Flight Management: Flight Phases

Optimum altitude

Based on current aircraft gross weight, the FM computes the best altitude the aircraft can reach with a minimum rate of climb

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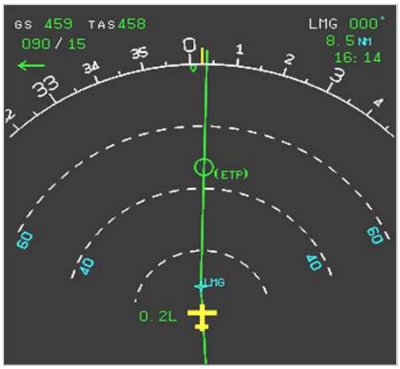
Vertical Flight Management: Flight Phases

Equitime point

The FM computes the position on the flight plan at the same flight time of two given airports



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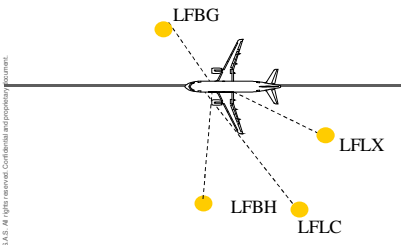
Vertical Flight Management: Flight Phases

Closest airports

The FM computes for the five closest airports:

- arrival time
- arrival fuel
- bearing to go



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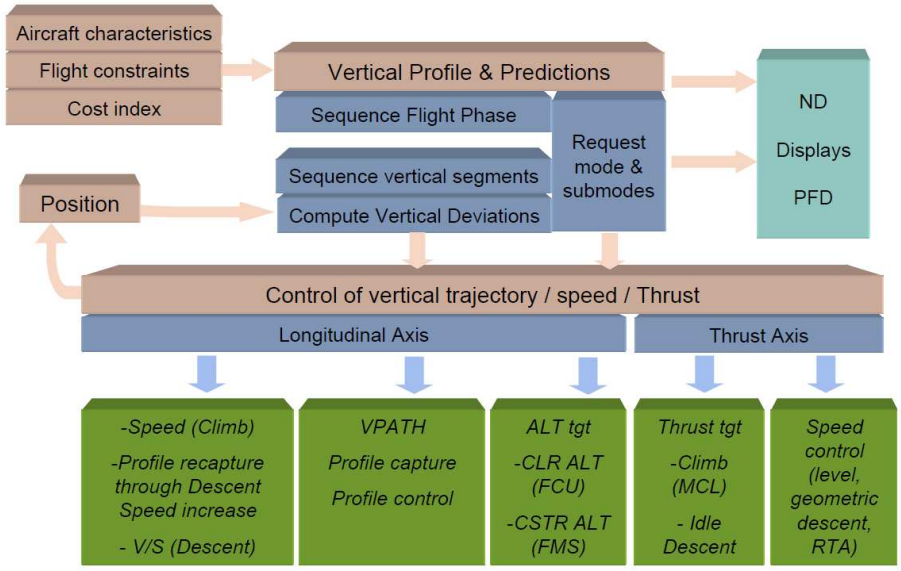
Vertical Flight Management: Guidance



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Vertical Flight Management: Guidance

FMS is responsible of **CLB mode**

- Managed Mode used in Climb phase (or Step climb during cruise phase)
- Use of Speed/Thrust submode
  - ✓Request of MCL thrust in climb to the AP/ATHR
  - ✓Control of FCU selected speed or FM managed speed
- Considering FM altitude constraints and Speed constraints

FMS is responsible of **DES mode**

- Managed Mode used in Descent or Approach phase or Step Descent in Cruise
- Use of 4 sub-modes Spd/Thr, Vpath/Thr, Vpath/Spd, Vs/Spd
  - ✓Control of Altitude profile in Idle Thrust in upper part of descent (Vpath/Thr submode)
  - ✓Control of Altitude profile in Speed in lower part of descent and approach (Vpath/Spd submode)
  - ✓Control of FCU selected speed or FM managed speed
- Considering FM altitude constraints and Speed constraints

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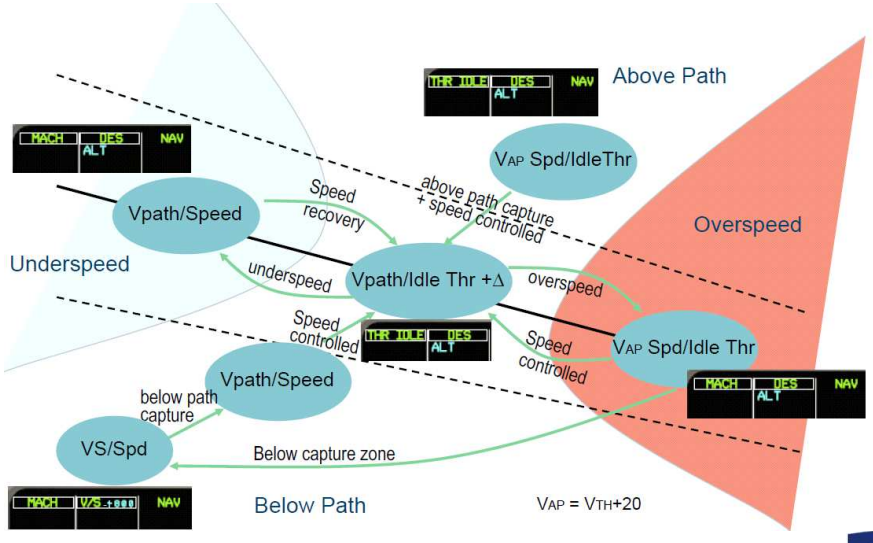
Vertical Flight Management: Guidance

DES Submodes

Submodes	Pitch axis	Thrust Axis	Flight phase
SPEED/THRUST	Speed	Thrust	CLB (+Step CLB in CRZ)
VPATH/THRUST	Pitch	Thrust	DES
VPATH/SPEED	Pitch	Speed	DES
VS/SPEED	VS	Speed	DES (+Step DES in CRZ)

Vertical Flight Management: Guidance

Submode reversions



Vertical Flight Management: Guidance

ALTITUDE Targets

The FMC computes and sends altitude target to autopilot:

- Altitude constraints (at, at or below, at or after, below) sent as FM alt constraint (magenta when made or amber when missed) to be captured and levelled by the autopilot
- Clearance altitude/ selected FCU altitude (cyan)
- Sent along with the current baro setting selected by the pilot on the FCU (STD, Baro QNH or baro QFE)
- End or start of level-off are displayed on ND and MCDU as pseudowaypoint which are:
  - ➢For MCDU Fpln page: top of climb (T/C), top of descent (T/D), top of step climb (S/C), top of step descent (S/D)
  - ➢For ND: top of climb (T/C), top of descent (T/D), top of step climb (S/C), top of step descent (S/D)

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Vertical Flight Management: Guidance

VDEV Display

- VDEV is the height between the aircraft and the vertical profile
- It is displayed:

Actual a/c altitude

Reference profile altitude

On the progress page of the FMD

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Vertical Flight Management: Guidance

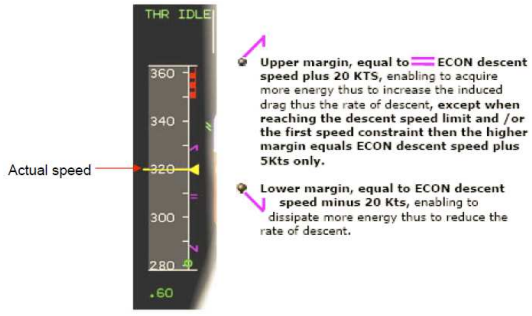
SPEED Targets
The FMC sends managed speed target to autopilot

- **In CAS/MACH reference with associated cross-over altitude**
- **Allows to control computed speed profile**
  - **Optimal speed (computed by performance server according to entered Cost Index or Flight Criteria)**
  - **With the following constraints and limitations:**
    - ✓Speed constraints (at or below) on waypoints
    - ✓Speed limit (250 kts below FL100)
    - ✓ICAO speed limit on Holding pattern and procedure intercept
    - ✓Time constraints (RTA/CTA), (at, at or before, at or after, between)
    - ✓Flight envelope: maximum (MMO/VMO, Vbuffeting, VFE) and minimum (VLS,VS)
    - ✓Green dot in Engine out, Endurance speed in holding pattern or max range
- **Speed change are displayed as pseudo-waypoint**
  - on MCDU Fpln page: speed limit (SPD LIM), Approach Deceleration (DECEL)
  - on ND: idem + all speed change

Vertical Flight Management: Guidance

SPEED Targets
The FMC computes speed deviations and margins to allow:

- Speed status display to the crew on the PFD (actual speed, theoretical Econ speed, Upper Margin, Lower margin)

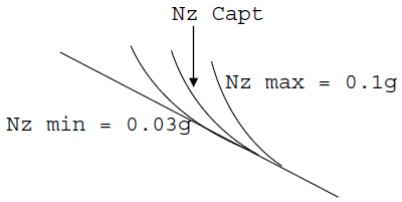


- Deviation status (overspeed, underspeed, speed recovery, speed controlled,…) triggering a submode change to recover a normal speed status

Vertical Flight Management: Guidance

VPATH Control law
The FMC sends Commanded Load Factor to autopilot

- Determination of constant capture load factor



- Vpath Law: load factor or pitch command

$$Nz_c = K\left[K_V(Vz - Vz_c) + K_Z(Z - Z_c)\right]$$

$$\Delta\theta_c = \frac{Nz_c(g)}{Vs(kt)} \cdot \frac{1}{k}$$

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Datalink Flight Management

Objective:

Help the crew in all operation for:

On ground:

- Loading information → AOC flight plan
  → AOC performance
- Meteo analysis → AOC winds

In flight:

- Meteo analysis → AOC winds
- Trajectory modification → AOC flight plan
- ATC clearance → ATC flight plan
- ATC surveillance → ADS

ATC: Air Traffic control AOC: Airline Operations Control

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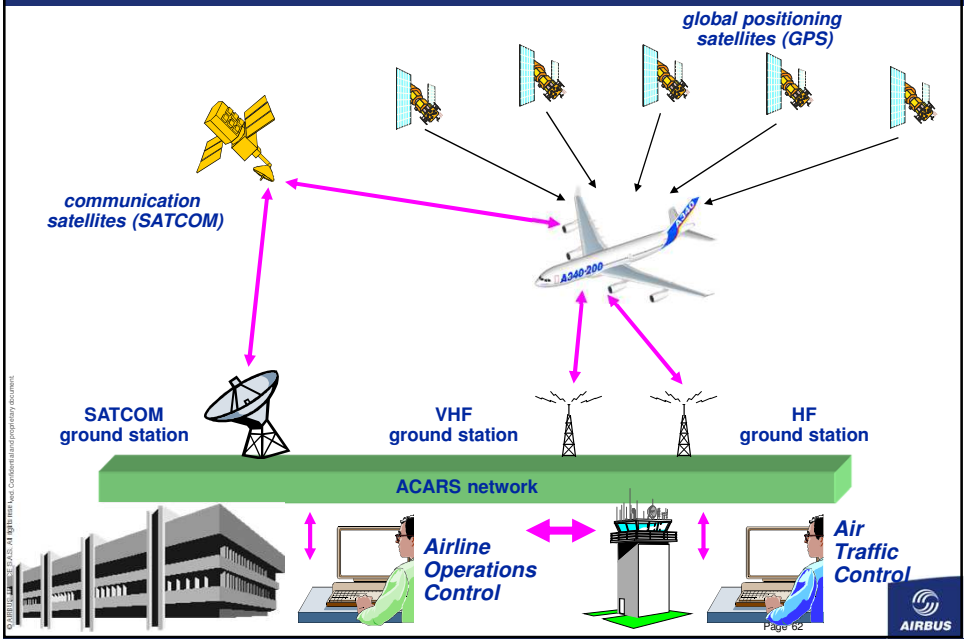
Datalink Flight Management



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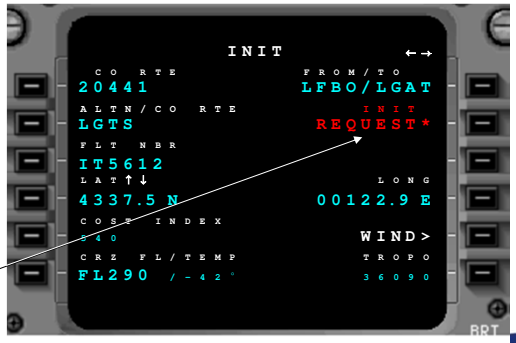
Datalink Flight Management: AOC

The crew may exchange data with Airline through:

- flight plan initialization
- flight plan update
- wind update
- take off performance computation
- free text



Specific prompts

Datalink Flight Management: ATC

The crew may exchange date with ATC trough datalink:

- clearances from ATC: flight plan, flight level, speed, ...
- request to ATC
- request for information from ATC

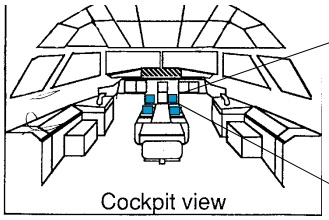
The FMS acts as a data provider for :

ADS : automatic dependent surveillance

CPDLC : controller pilot data link communication

- Confirmations requests
- Report requests
- Deferred clearances
- Route initializations / modifications with time constraints

Datalink Flight Management



The crew may exchange flight plans with the ATC .

The ATC flight plan is prepared/received in the secondary flight plan (FANS A) through out the DCDU

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The future of the Flight Management System

The evolutions of FMS in the future:

- **Improve man-machine interface** :
  - Most efficient use of large displays
  - Improvement of vertical situational awareness
- **Increase exchanges with ATC**
  - Include more messages
  - ATIS and wind information
  - (Pre)negociate 4D trajectories
- **Improve flight accuracy monitoring**
  - Lateral (RNP)
  - Vertical
- **Provide fully integrated Mission Management tools**

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Recent FMS evolutions

On A380, MCDU replaced by Multi-Function Display (MFD) and Keyboard & Cursor Control Unit (KCCU)

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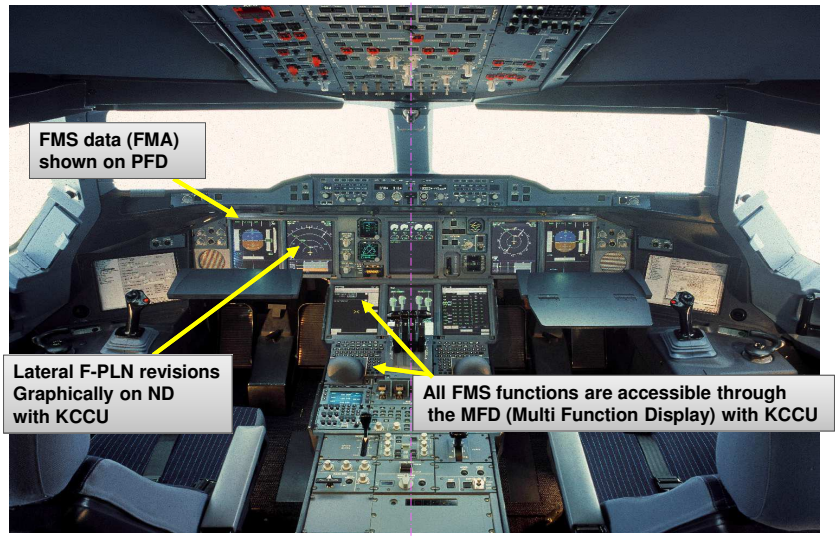
Recent FMS evolutions



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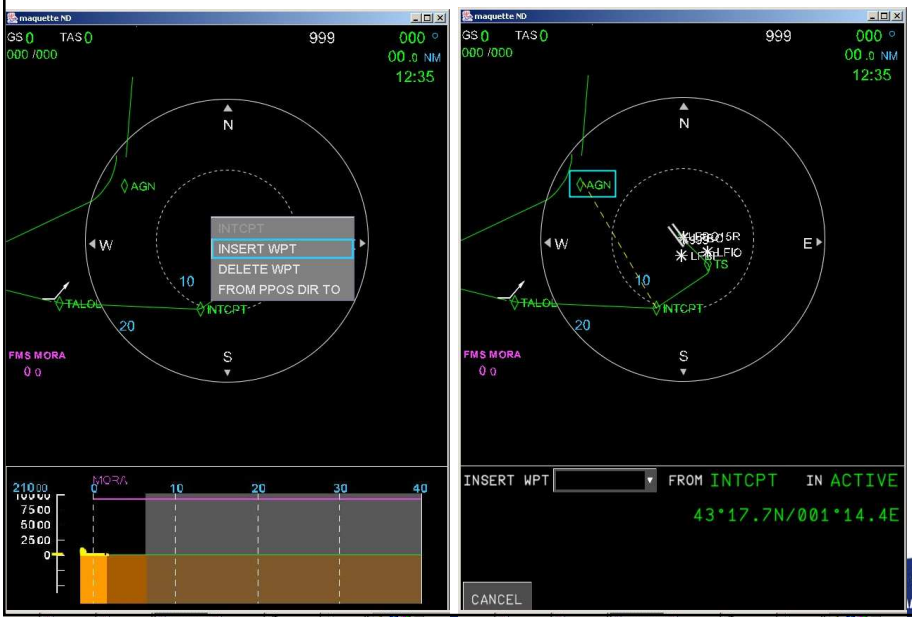
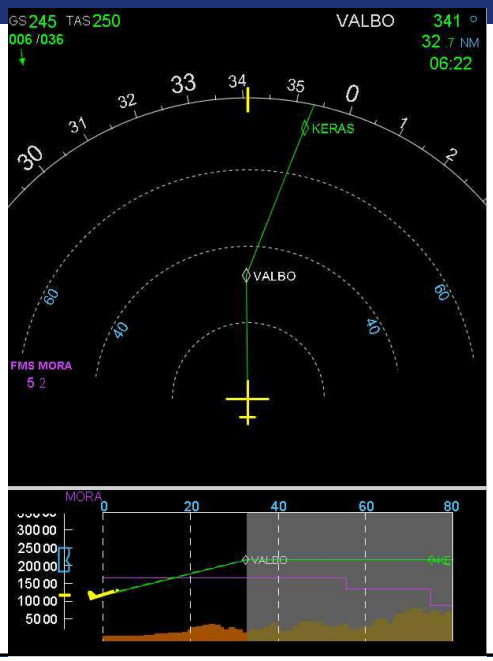
Recent FMS evolutions: ND interactivity



Recent FMS evolutions: Vertical Display



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The future of the FMS: A350, the next step

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The future of the: A350, the next step

Functional improvements:

Designing FMS: difficulties & dimensioning aspects

Drivers:

1. Safety of operations
2. Operational reliability
3. Ease of use, intuitivity

Difficulties:

1. System complexity
2. Interfaces
3. Supplier management

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