Priteche VENILAL
Flight Control Laws
AIRBUS OPERATIONS SAS

# AUTOFLIGHT

*From systems to flight control laws*

# Outlines

## 1 – « Guidance & Control » functions of autoflight system

- Autopilot (AP), flight director (FD) and autothrust (ATHR) principles
- AP flight envelope
- Onboard integration and architectures history

## 2 – Modes and interfaces of autoflight system

- Classification of AP / FD and ATHR modes
- Interfaces with the crew and with the other systems
- Modes and transitions principles

## 3 – Introduction to autoflight control laws

- Autoflight control laws principles
- Principles and functional breakdown

# 1 – « Guidance & Control » functions of autoflight system

# Guidance and control are not the only tasks of a flight crew

Important

- **Control:** act on surfaces to control the aircraft attitude
  - Short-term objectives: pitch, roll, sideslip
  - Short time response

- **Guide:** act on aircraft attitude to control the trajectory
  - Mid-term objectives: heading, vertical speed, speed, …
  - Time response longer than for control

- **Navigate:** locate the aircraft, optimize and follow the flight plan
  - Long-term objectives: intermediate waypoints before destination
  - Constraints management: climb, descent or speed profiles

- **Communicate:** announce the aircraft intentions, follow ATC instructions
  - Communication means: voice, datalink

*ATC: Air Traffic Control*

# Integration of navigation, guidance & control functions

Navigation targets

Guidance targets

3

Sensors outputs


Aircraft

4

NAVIGATION FUNCTION

4

GUIDANCE FUNCTION

2

3

Commanded surfaces positions

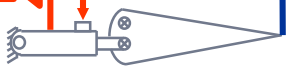
Surfaces actual positions

2

Control targets

CONTROL FUNCTION

1



Actuators


Pilot Controls

1 = Actuators position control loop

2 = Control loop: short term management (attitudes & accelerations control)

3 = Guidance loop: mid term management (trajectories, speed...)

4 = Navigation loop : long term management (flight plan tracking)

# What are the missions of assistance means ?

- Improve the A/C handling qualities
- Assist the crew in demanding tasks
- Alleviate the crew workload
- Manage the flight

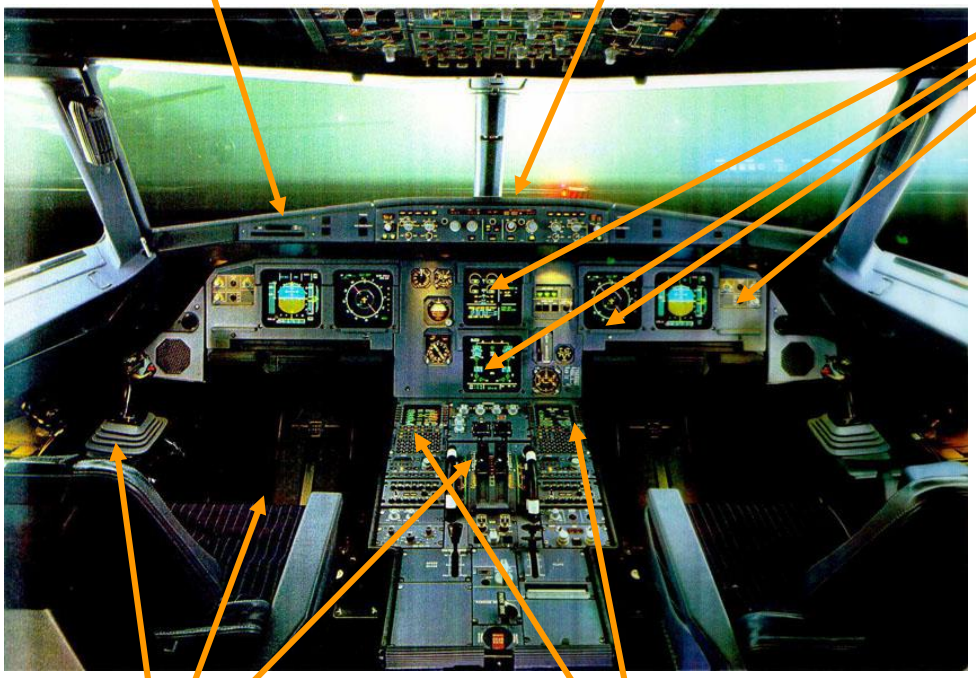
**With an appropriate level of safety**

# Stakeholders in « navigation, guidance & control » functions

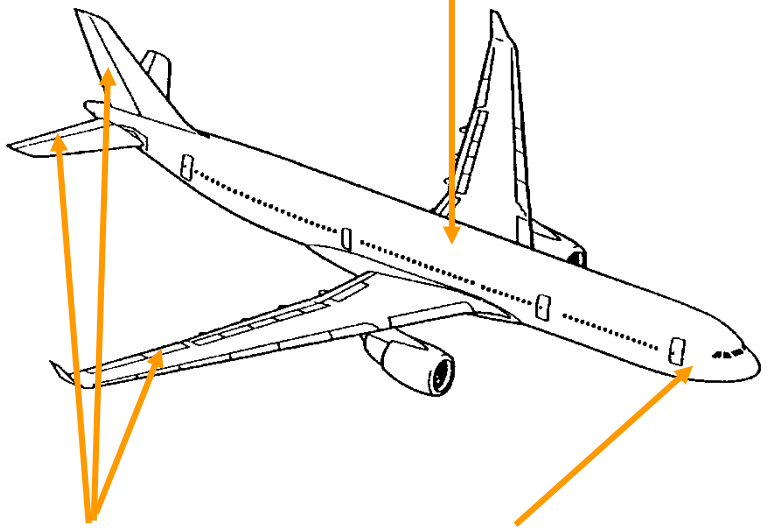
**Guidance cues**
HUD (Head Up Display)

**Control panels**
FCU, ECP

**EIS**
**(ELECTRONIC INSTRUMENT SYSTEM)**
System status, Alarms



**Power generation & distribution**
Hydraulic, Electrical



**Controls**
Sidestick, pedals, thrust levers

**FMS keyboard**
MCDU
MFD (A380, A400M, A350)

**Actuators**

**Computers**
Electronic bay, Bus

*MCDU: Multi Control Display Unit*
*FCU: Flight Control Unit*

*MFD: Multi Functionnal Display*
*ECP: Electronic Control Panel*

# Guidance functions: AP

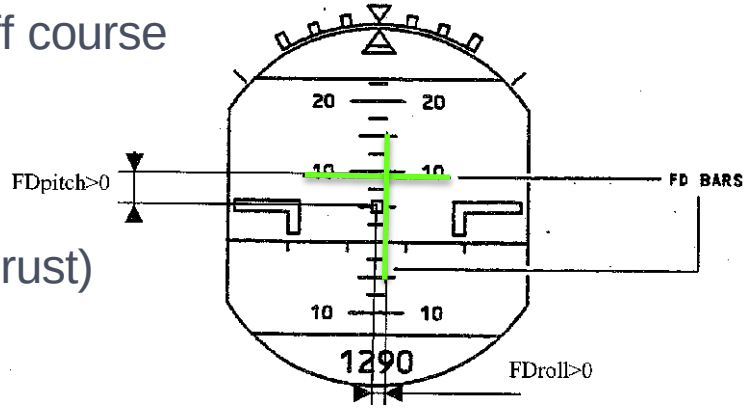
- Autopilot acts on control surfaces and nose wheel to:
  - Follow **targets** set by the crew: heading, slope, speed…
  - Follow a **flight plan** provided by the Flight Management System (FMS)
    - Climb, cruise, descent, approach… and tactical phases on A400M
  - Achieve an **automatic landing** (including an automatic rollout on ground)
  - Achieve an **automatic go-around**
  - Limit the excursions outside the nominal flight envelope: **protections**

- Autopilot can not be engaged on ground for take-off course
  - Engagement is possible a few seconds after take-off

*FMS: Flight Management System*

# Guidance functions: FD and ATHR

- Flight Director **displays** the orders to execute
  - To help, in manual flight, to follow the guidance targets
  - To monitor, in automatic flight, the autopilot behaviour
  - Engagement is possible on ground for take-off course

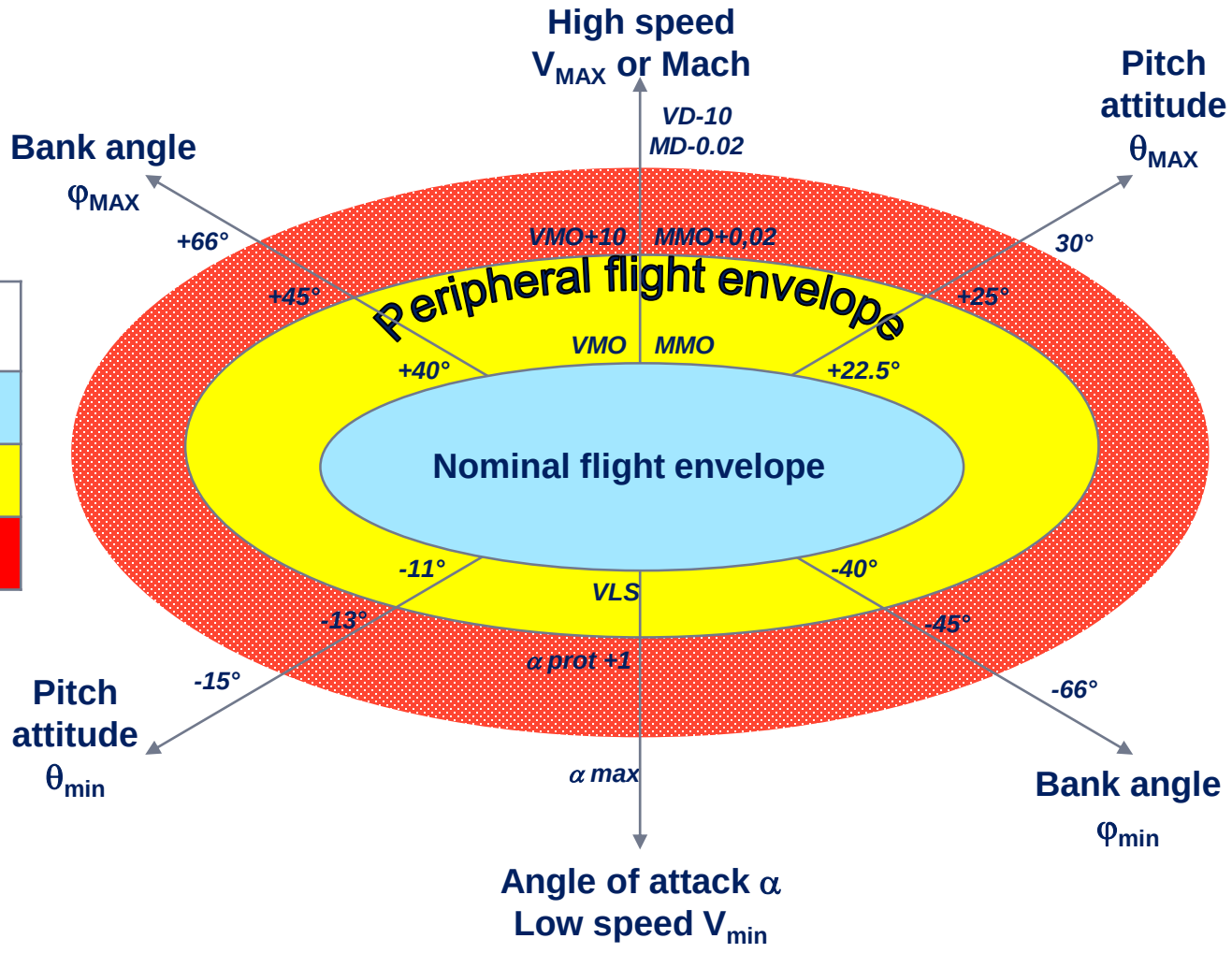



- Autothrust acts on engines to:
  - Hold a thrust or a power (e.g. TOGA or idle thrust)
  - Hold a speed or a Mach number

- Autopilot, flight director and autothrust are **independent**
  - They can be engaged alone or together

# AP flight domain

| | AP Engagement | AP Automatic Disconection |
|---|---|---|
| **D1** | Possible | NO |
| **D2** | NO | NO |
| **D3** | NO | YES |

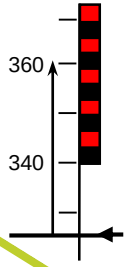


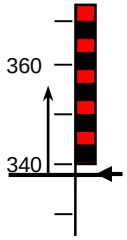

*VMO: vitesse maximum opérationnelle*
*VD: vitesse de dive*
*VLS: vitesse lowest selectable*

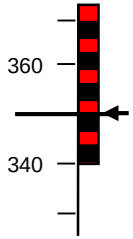
*MMO: Mach maximum opérationnel*
*MD: Mach de dive*

# Example of AP protection

- A/C initially stabilized in descent at $VS_{TGT}$ = -2000ft/min
- Headwind appears and makes the speed increase



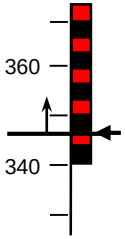




Stabilisation
at VMO+10
(stick neutral)

**AP max speed protection take-over**
**Target = VMO**

$\gamma = 0°$

$VS_{TGT}$ = -2000 ft/min




**No Flight Path Angle inversion**
**Target = FPA = 0°**

**AP disconnection**
**Manual max speed protection take-over**
**Target = speed f(stick)**

# AP engagement logic (“AND”)

**AP pushbutton pressed**

FLIGHT CONTROL UNIT


ON

**Enough primary control surfaces**

**Sensors available**

- ADIRU
- Aerodynamics angles: α, β
- Only for approach: RA, ILS

**Activity on pilot controls**

- Sidestick
- Pedal


**5 s after lift-off**

**Within nominal flight domain**

- VLS < Speed < VMO
- |φ| < 40°, -11° < θ < 22,5°
- Protections not active

AP ENGAGEMENT

Pilot controls are hardened upon AP engagement « CLONG »

*ADIRU: Air Data Inertial Reference Unit*
*ILS: Instrument Landing System*

*RA: Radio Altimeter*
*PRIM: PRIMary flight control computer*

# AP disengagement logic (“OR”)

X = connection lost

(*) = depending A/C

**AP pushbutton pressed**

FLIGHT CONTROL UNIT


OFF

**Loss of surfaces (*)**

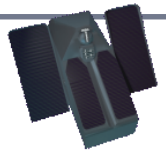
- THS, elevators
- Ailerons, rudder
- …

**Sensors failures (*)**

- ADIRU
- Aerodynamics angles: α, β
- Only for approach: RA, ILS

**Activity on pilot controls**

- Sidestick, pedal
- Takeover & priority switch
- Only on ground: throttle levers




**Computer failures (*)**

- PRIM
- SFCC, LGCIU
- FCU
- …

**Out of nominal flight domain (*)**

- Speed > VMO + 10
- $\theta > \theta_{MAX}$ or $< \theta_{min}$, $|\varphi| > \varphi_{MAX}$
- $\alpha > \alpha_{prot} + 1$

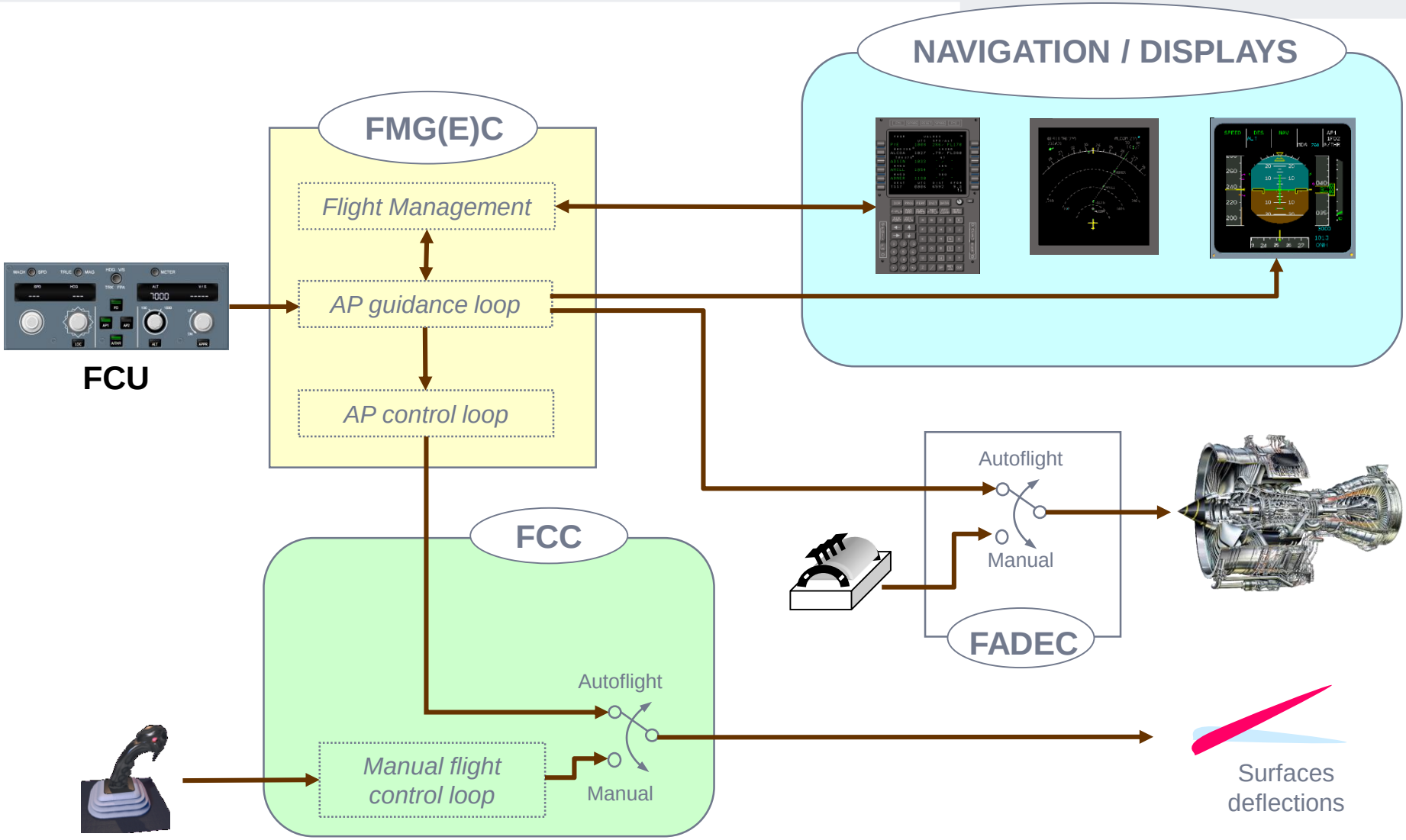
**AP DISENGAGEMENT**

« Cavalry charge »


*THS: Trimmable Horizontal Stabilizer*
*LGCIU: Landing Gear Control Interface Unit*

*SFCC: Slat Flap Control Computer*

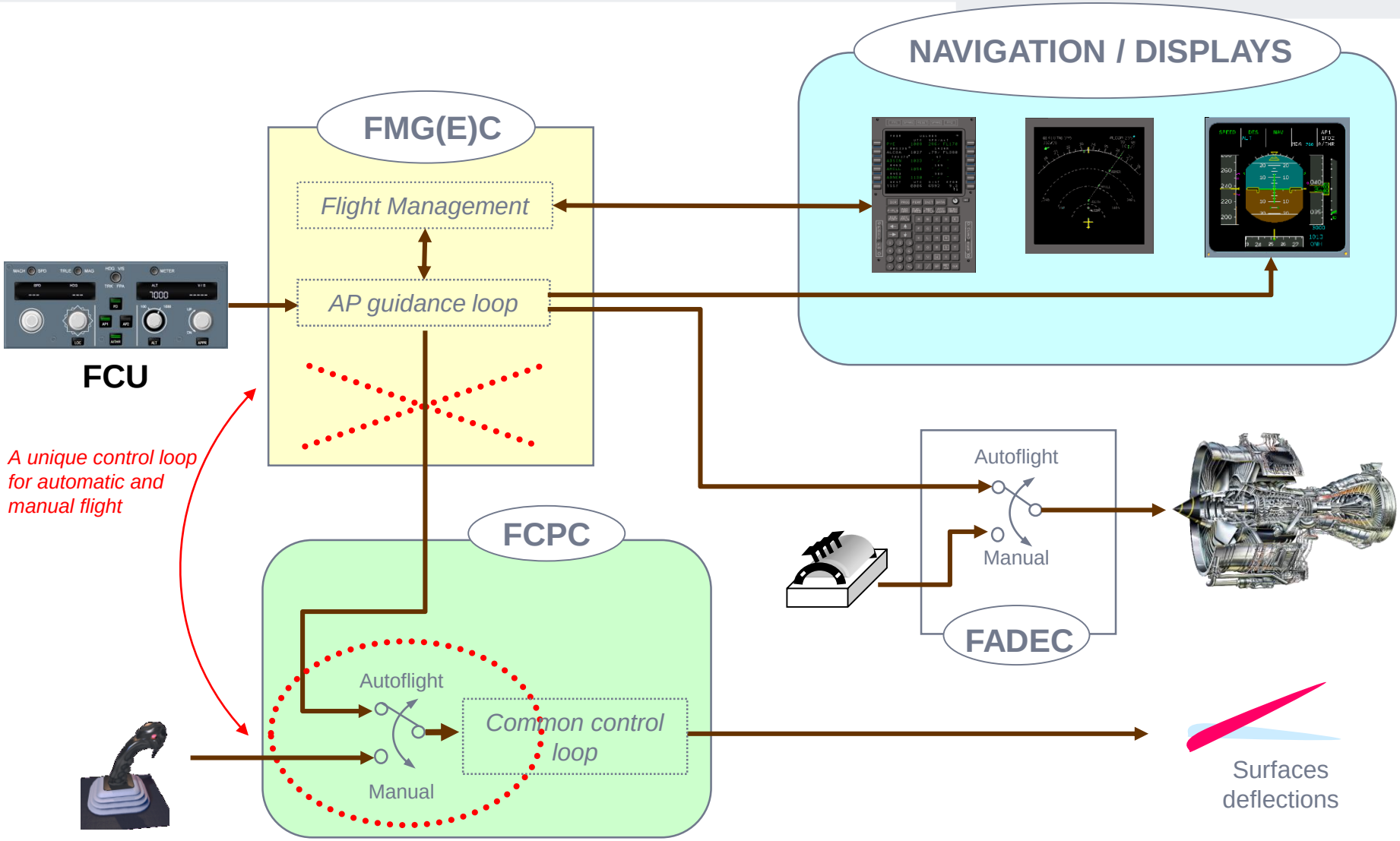
# Integration on A320, A330 & A340




FMGEC: Flight Management Guidance (and Envelope) Computer
FADEC: Full Authority Digital Engine Computer

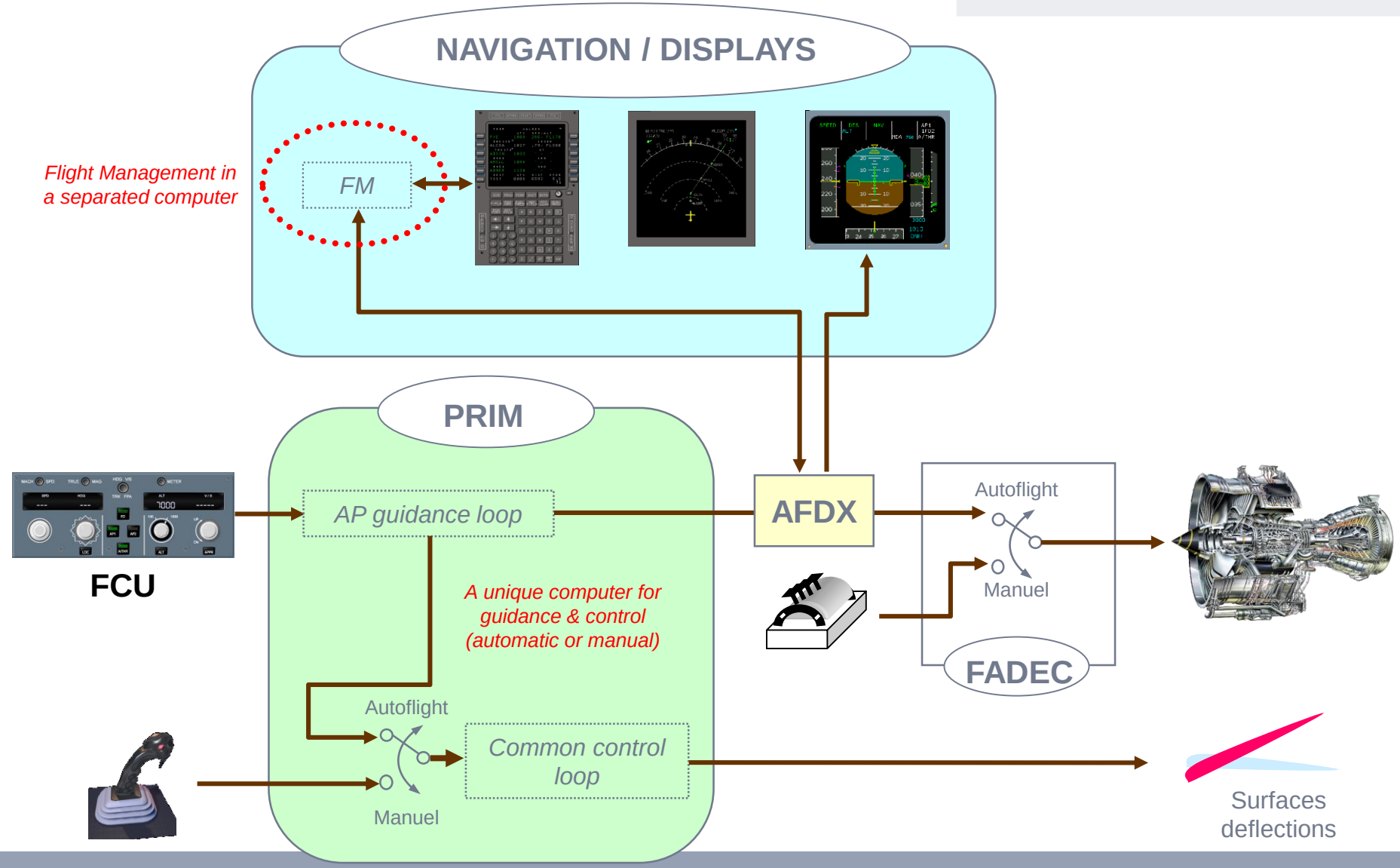
FCC: Flight Control Computer

# Integration on A340-500 & A340-600




FCPC: Flight Control Primary Computer

# Integration on A380, A400M & A350




AFDX: Avionics Full Duplex

# Autoflight systems evolution on AIRBUS aircraft

- From first generations to A330 family
  - Progressive transition to digital world
  - More and more integrated functions
    - A300B2-B4 (1974): 19 computers to support guidance and control functions
    - A330/A340 (1994): 2 computers only
  - Introduction of new functions
    - Autopilot coupling with Flight Management System (FMS)
    - Automation of autopilot modes management (operational logic)
    - Protections (speed & pitch) to limit excursions out of nominal flight domain

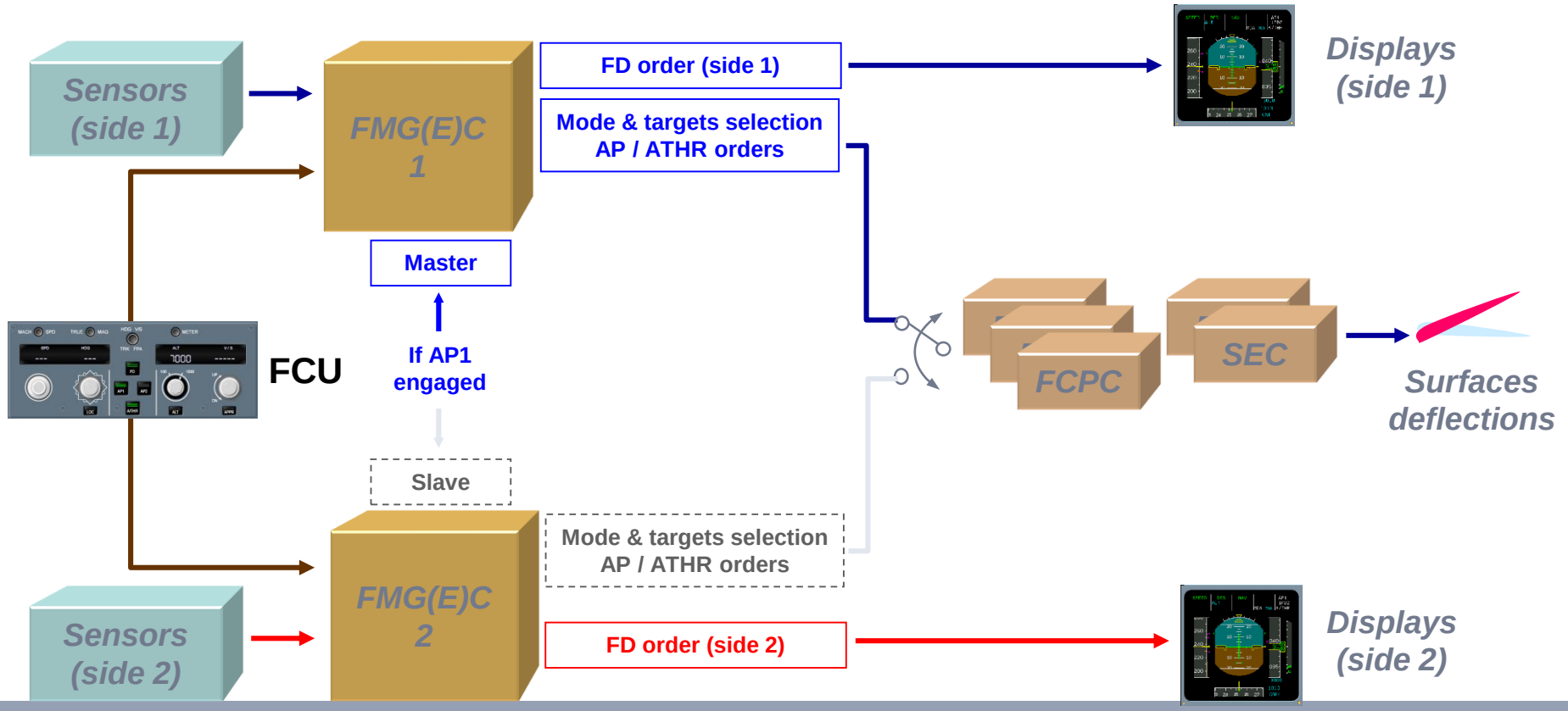
- Since A340-600 (2002), a stronger integration of autoflight and flight controls
  - Common interfaces with peripherals such as IRS and ADC
    - No need to duplicate acquisitions or processing of inertial and air data
  - A unique control loop common to both autoflight and manual flight
    - More efficient design, tuning and validation

*IRS: Inertial Reference System* *ADC: Air Data Computer*

# A320 / A330 / A340 autoflight system architecture (1)

***Redundancy level of the autoflight system shall meet the requirements set by:***

- ***The safety analysis***
- ***The operational objectives (system availability, cost …)***



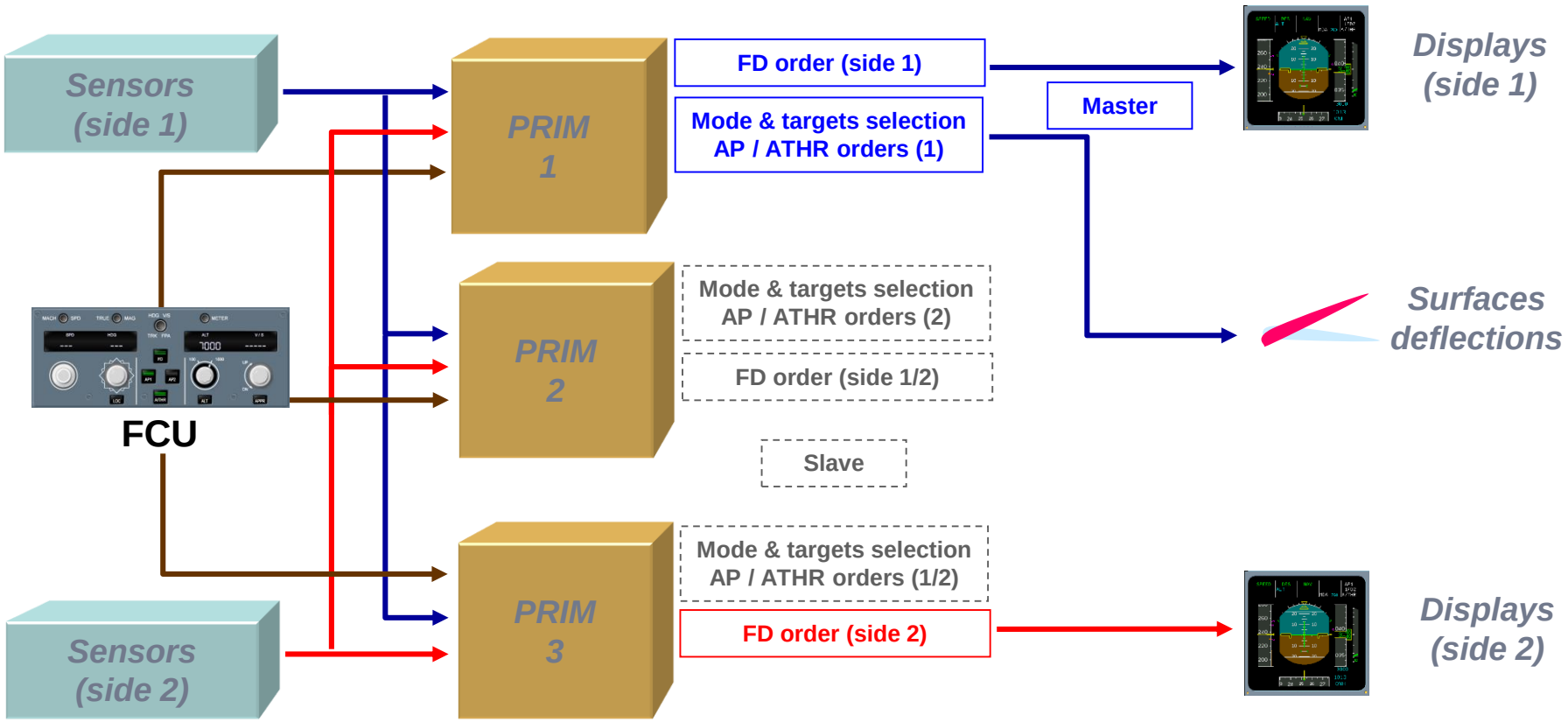
# A320 / A330 / A340 autoflight system architecture (2)

- « Split » cockpit principle retained for primary flight parameters
  - AP1 / FD1 orders computed from side 1 sensors (source 3 as a backup)
  - AP2 / FD2 orders computed from side 2 sensors (source 3 as a backup)
  - Crew is aware of discrepancies between sources through FD orders
    - In heading mode, AP1 maintains heading from IRS1 on the heading target
    - FD1 is centered (no roll demand) since heading 1 is on the target
    - FD2 will not be centered if heading from IRS2 is different from that of IRS1
    - The crew decides then to stay on AP1, to switch AP1 on IRS3 or to engage AP2
- Direct link between the AP engaged and the master FMG(E)C computer
  - AP1 / FD1 orders computed by FMG(E)C1 only
  - AP2 / FD2 orders computed by FMG(E)C2 only

# A380 autoflight system architecture

***Autoflight availability increased… but at the cost of system complexity***

- ***Any PRIM can compute APx / FDx (new logic dedicated to PRIM selection)***
- ***No direct link between the AP engaged and the master PRIM computer***



# 2 – Autoflight: interfaces & modes

# Main autoflight / pilot interface: the flight control unit (FCU)


HDG-V/S / TRK-FPA Commutation button

Managed vertical mode Selection indicator

HDG / TRK Selection indicator

Managed lateral mode Selection indicator

Altitude target

VS / FPA Selection indicator

Managed speed Selection indicator

Heading or track target

Vertical speed or flight path angle target

SPEED / MACH Commutation button

SPEED / MACH Selection indicator

Rotactor for vertical speed or flight path angle target selection

Speed or Mach target

Rotactor for speed or mach target selection

Rotactor for heading or track target selection

LOC mode arming (No GLIDE)

FD, AP1, AP2 and ATHR engagement

Level-off engagement

Rotactor for altitude target selection

APPROACH modes (LOC & GLIDE) arming

# AP guidance modes: selected & managed

- After AP/FD engagement, 2 guidance types are possible
  - The pilot wants to impose guidance targets through **FCU rotactors** (SPEED/MACH, HDG/TRACK, ALT, VS/FPA)

    ➔ use of **selected modes**
  - The pilot lets the **Flight Management System** do the navigation which provide the guidance targets (lateral and vertical flight plan, speed or Mach number)

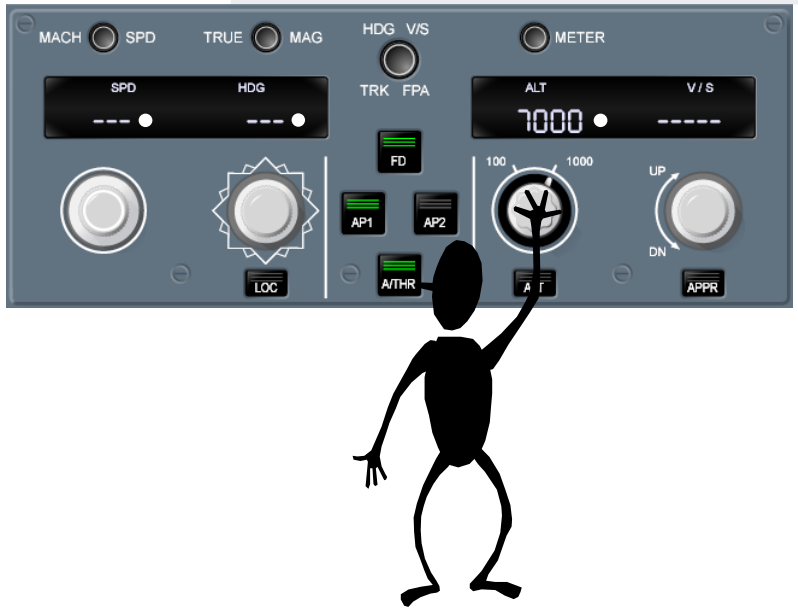
    ➔ use of **managed modes**

- How to transition from a selected mode to a managed mode and vice versa?
  - Thanks to the FCU rotactors
  - Through **push/pull actions**

# AP guidance modes: pull/push

- **Pull** = « the pilot takes over control »
  - ➔ selected mode and guidance done through FCU targets

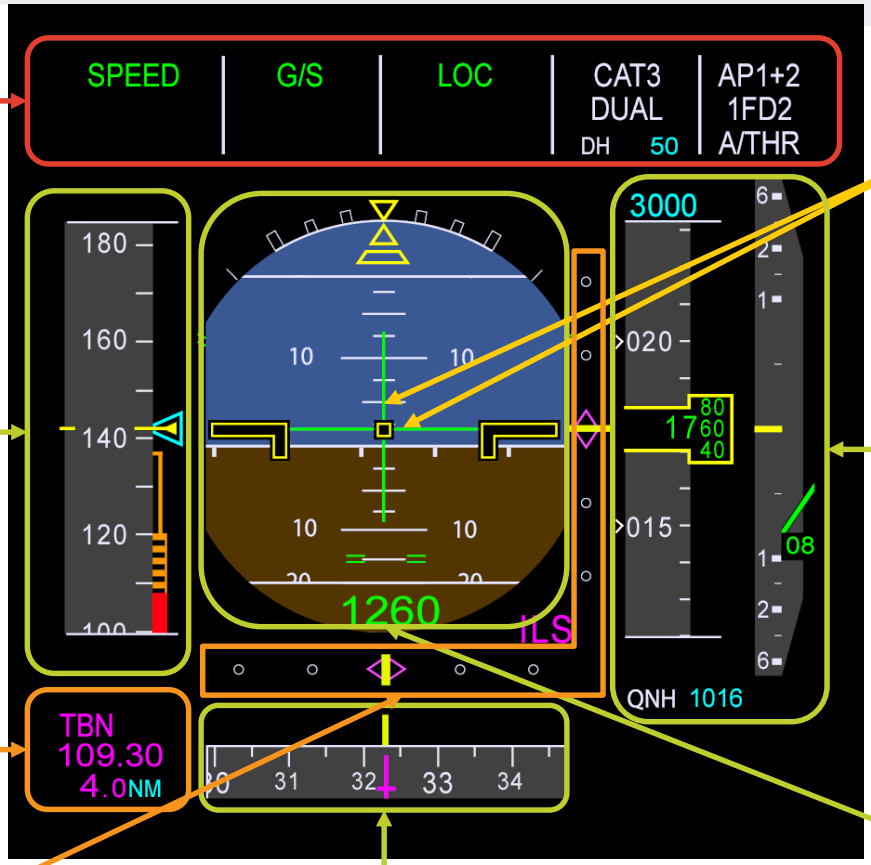
  Eg: altitude preset




- **Push** = « the pilot gives back the controls to the FMS »
  - ➔ managed mode and guidance done though flight plan

  Eg: speed target dealt by FMS

# Restitution of the A/C and AFS state on the PFD




**FMA zone**

- *Columns A, B, C: engaged and armed modes (thrust, vertical, lateral)*
- *Column D: autoland status*
- *Column E: autoflight status (AP, FD, ATHR)*

**Guidance zone**

- *FD pitch and roll bars*
- *…*

**Airspeed zone**

- *Speed*
- *Speed target*
- *Flight domain and characteristic speeds*
- *…*

**Altitude and vertical speed zone**

- *Altitude and vertical speed*
- *Altitude and vertical speed targets*
- *Pressure reference*
- *…*

**Left corner zone**

- *Mach if above 0,5*
- *Approach data in approach phase*

**Attitude zone**

- *Pitch and roll angles*
- *HRA below 2500ft*
- *…*

**Deviation zone**

- *LS deviations*
- *…*

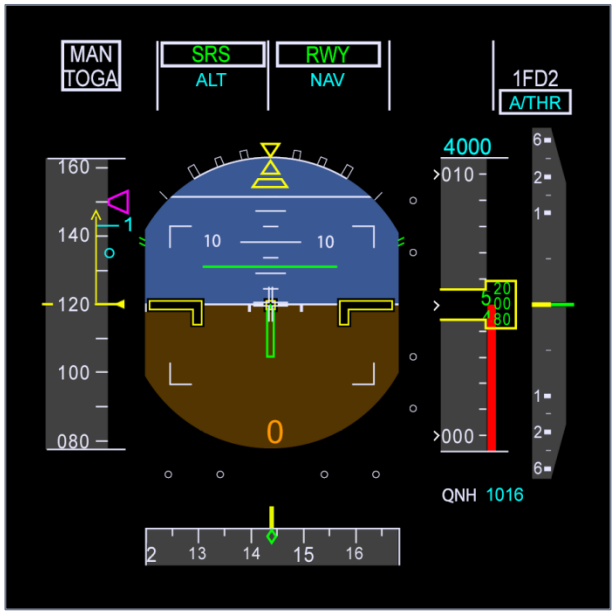
**Heading zone**

- *Heading/track*
- *Heading/track target*
- *Runway course*
- *…*

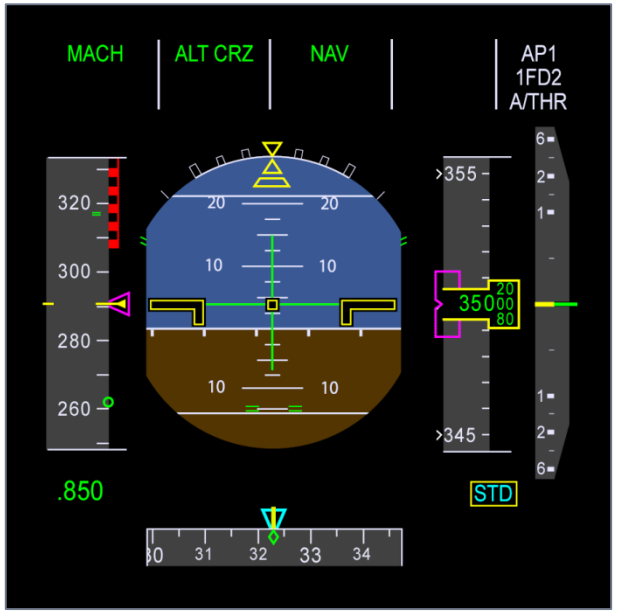
*AFS: Auto Flight System = AP + ATHR*
*LS: Landing System*

*FMA: Flight Mode Annunciator*

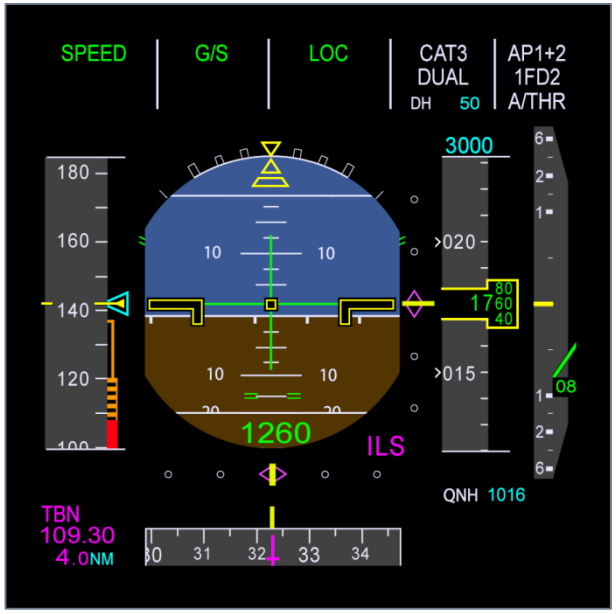
# Restitution of the A/C and AFS state on the PFD: examples




TAKE-OFF




CRUISE




APPROACH

# AP/FD vertical « cruise » modes

Important

- For level changes
  - V/S / FPA — Acquire and hold the **vertical speed / flight path angle** target

    ***Fixed vertical speed / flight path angle set by the crew ➔ ATHR in Speed/Mach mode***
    ***Airspeed controlled by ATHR through engines (thrust evolution)***
    ***Engagement and target selection by acting (pull and turn) on the VS/FPA FCU rotactor***

  - OPEN CLB / DES — Acquire and hold the **speed/mach** target in climb / descent
  - CLIMB / DES — Acquire and hold the **vertical profile** target

    ***Fixed thrust (max climb/idle) ➔ ATHR in Thrust mode***
    ***Airspeed controlled by AP through elevators (flight path angle evolution)***
    ***Engagement by acting (pull/push and turn) on the "altitude" FCU rotactor***

- For level hold
  - ALT* — Acquire **altitude** target (transition mode before ALT)
  - ALT — Hold **altitude** target

    ***Fixed altitude set by the crew ➔ ATHR in Speed/Mach mode***
    ***Airspeed controlled by ATHR through engines (thrust evolution)***
    ***Automatically engaged when the aircraft gets close enough to the target***

# Level change in Vertical Speed (V/S) mode

***Altitude target selected on FCU: 7000 ft***

*Turn the rotactor to display 7000ft*

*Turn the rotactor to display +2000 ft/min*


*Pull the rotactor to engage V/S*

*Automatic engagement of the altitude hold mode*

*Automatic engagement of the altitude capture mode*

***Initial altitude target: 5000 ft***

| 1 | 2 | 3 | | |
|---|---|---|---|---|
| ALT \| NAV | | V/S +2000 \| NAV<br>ALT | ALT* \| NAV | ALT \| NAV |

*ALT mode is armed*

# AP/FD lateral « cruise » modes

- HDG — Acquire and hold the **heading** target
- TRK — Acquire and hold the **track** target

***Engagement of these modes by pulling the associated FCU rotactor***
***Target selection by turning this rotactor***

- BANK — Acquire and hold the **bank angle** target (only for military aircraft)

***Specific mode implemented on A330 MRTT & A400M***
***Engagement by pulling the "bank" FCU rotactor***
***Target selection by turning this rotactor***

- NAV — Acquire and hold the **FMS horizontal profile**

***"Managed" mode:*** ***armed by pushing the "hdg/trk" FCU rotactor***
***automatically engaged when A/C close enough to FMS path***

# Heading change to intercept & capture FMS flight plan

***Lateral flight plan built by the FMS***

*Turn the rotactor to display 45°*

1


2 *Push the rotactor to arm NAV*

*Automatic engagement of the navigation mode*

1

| ALT | HDG |
|---|---|

2

| ALT | HDG<br>NAV |
|---|---|

*NAV mode is armed*

| ALT | NAV |
|---|---|

# AP/FD « approach » modes

- LOC* Acquire **LOC** beam (transition mode before LOC)
- LOC Hold **LOC** beam

> ***Armed by pushing "LOC" or "APPR" FCU push-button***
>
> ***Automatically engaged when A/C close enough to LOC beam***

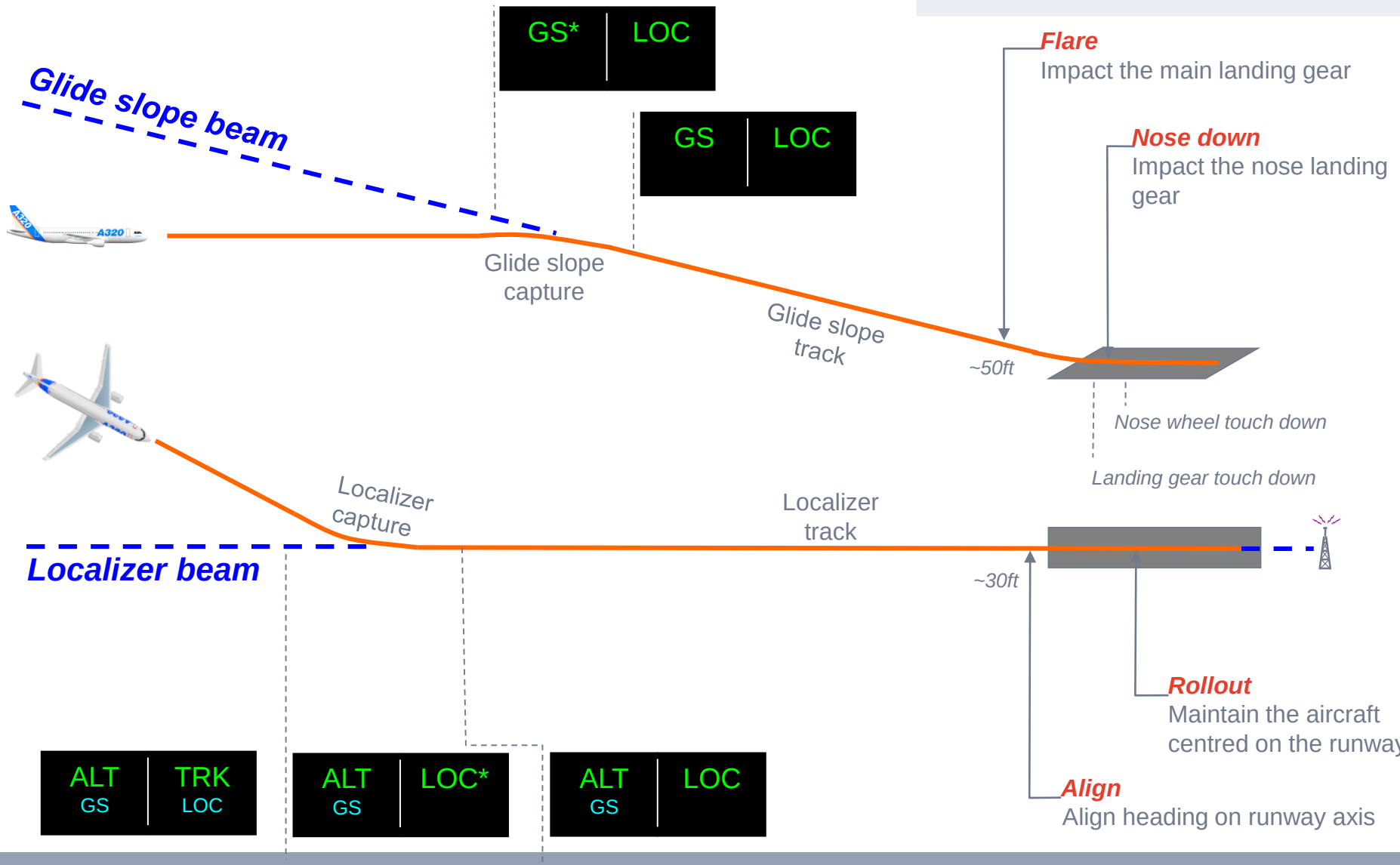
- GS* Acquire **GLIDE** beam (transition mode before GS)
- GS Hold **GLIDE** beam

> ***Armed by pushing "APPR" FCU push-button***
>
> ***Automatically engaged when A/C close enough to GLIDE beam***

*Lateral guidance only*


*Both lateral and vertical guidance*

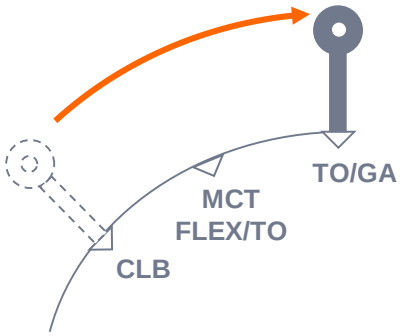
# AP / FD modes in approach and landing



# AP/FD modes dedicated to take-off and go-around

- SRS — Acquire and hold the **speed target**

  ***SRS: "speed reference system"***
  ***Engaged by moving the thrust levers on the TOGA notch***
  ***Speed target: FMS take-off speed / current speed at go-around***
  ***Combined with a constant thrust (TOGA or FLEX)***



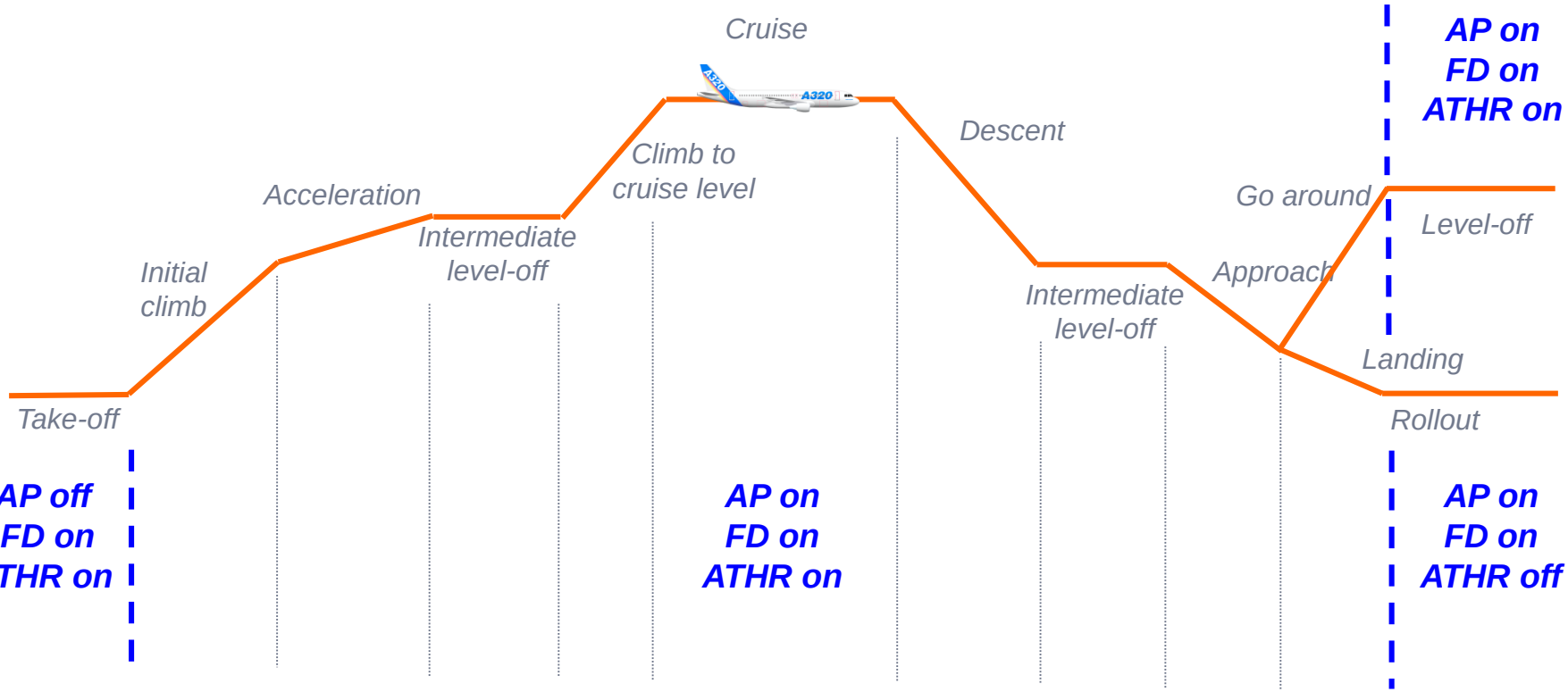

- RWY — Hold **runway axis** at take-off

  ***No guidance during take-off, only FD displayed on PFD***
  ***Order displayed computed with the ILS LOC axis***

- GA TRK — Hold memorized **track** at go-around

  ***Automatically engaged once SRS mode is engaged***
  ***Track target: current track at go-around***

# Typical AP/FD/ATHR modes sequence




| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **LONGI** | SRS | CLB | ALT | CLB | ALT | OP DES | ALT | G/S | FLARE<br>GA | NOSE DOWN<br>ALT |
| **LAT** | RWY | NAV | NAV | NAV | NAV | HDG | HDG | LOC | ALIGN<br>GATRK | ROLLOUT<br>HDG |
| **ATHR** | THR | THR | SPD | THR | SPD | THR | SPD | SPD | SPD<br>THR | RETARD<br>SPD |

*If in Go-Around*

# 3 – Introduction to autoflight control laws

# Autoflight control laws principles

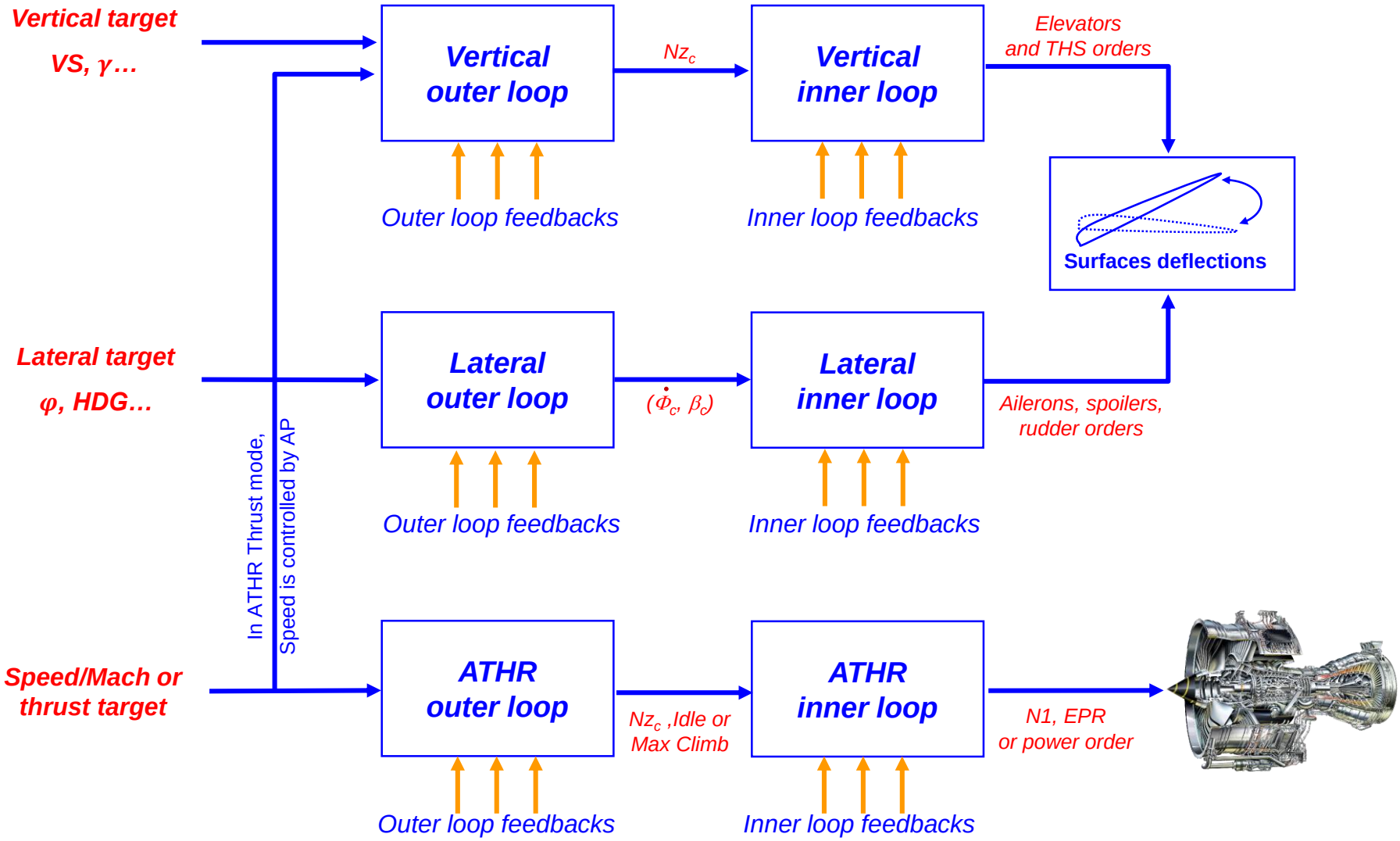
- The inner loop is dedicated to control
  - **Control the A/C attitude** (same scope as EFCS)
  - Limit the outer loop targets in amplitude and speed to limit the effects of a failure
  - Use A/C accelerations, attitude and attitude rates as main feedbacks
  - Compute orders: surfaces deflection

- The outer loop is dedicated to guidance
  - **Control the center of gravity position** to follow the flight plan
  - Limit FCU or FMS targets in amplitude and speed to limit the effects of a failure
  - Use A/C position and speed vector as main feedbacks to compute orders
  - Send them to the inner loop (AP) or displays (FD): load factor, bank angle

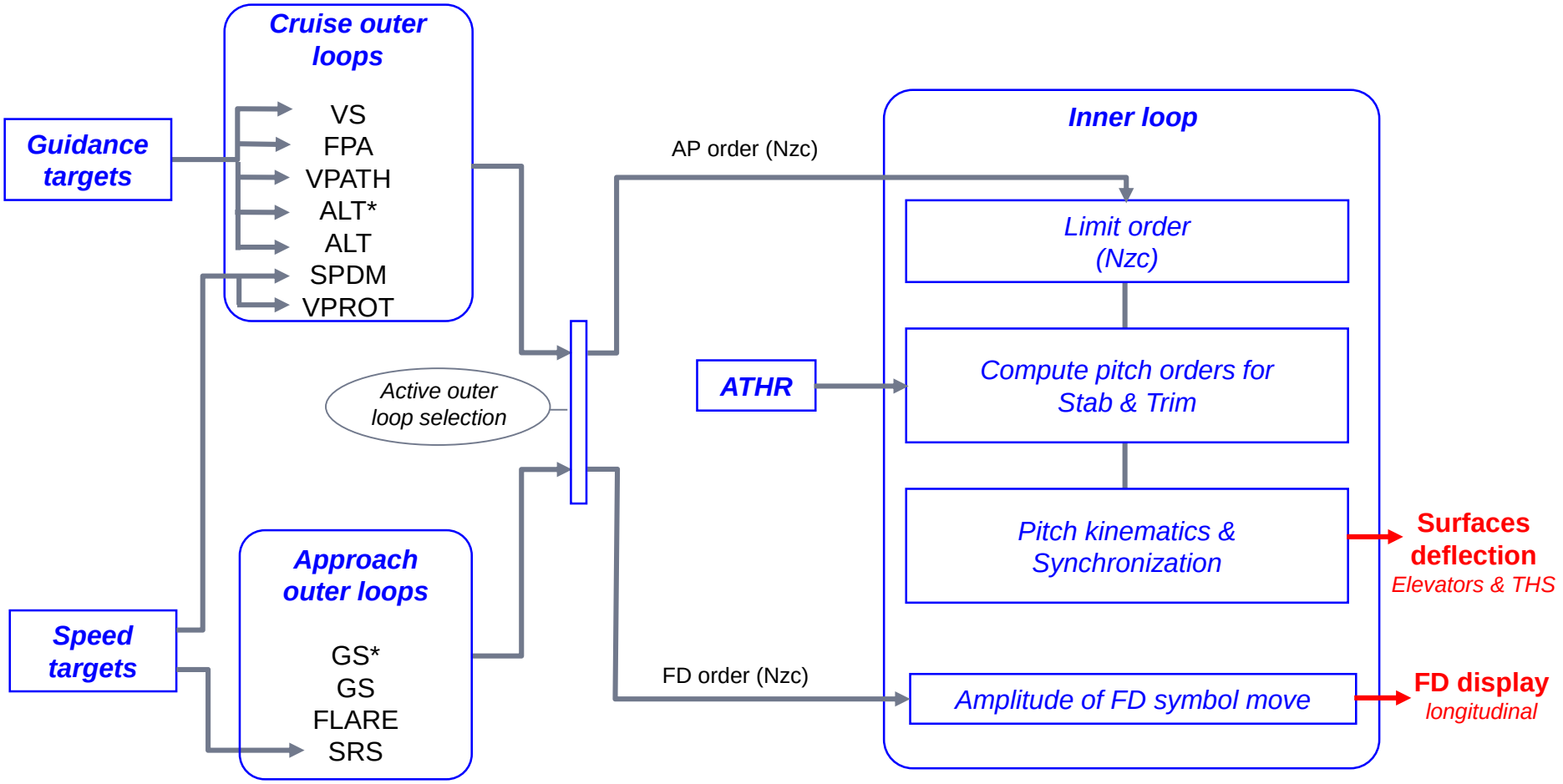
- A control law is associated to each mode
  - The link between modes and control laws is defined in « operational logic »
  - Different feedbacks are used at guidance level and control level

***Autopilot orders are executed via inner loops, in charge of controlling the surfaces to their commanded deflections***

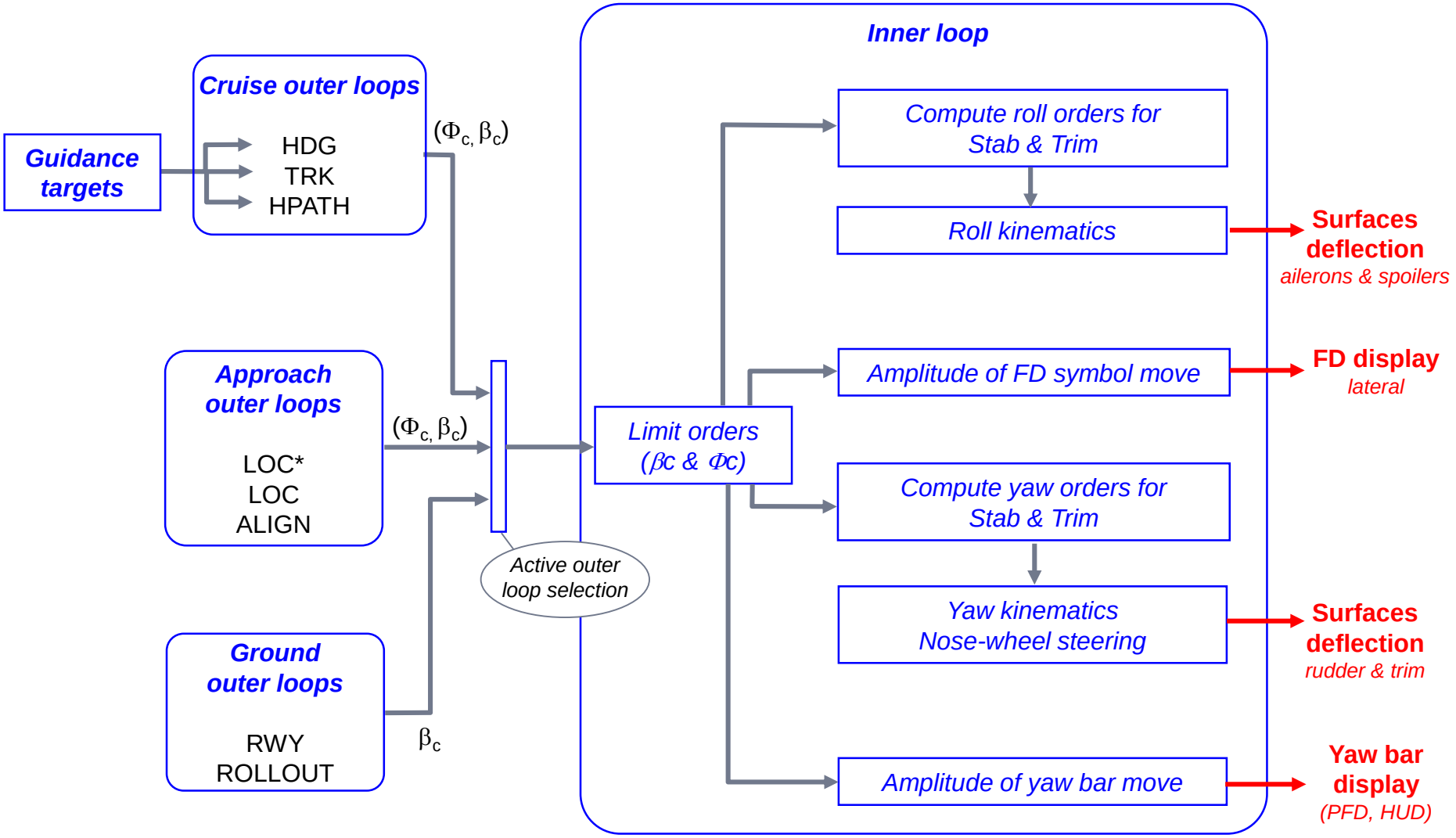
# Functional breakdown of Flight Control Laws



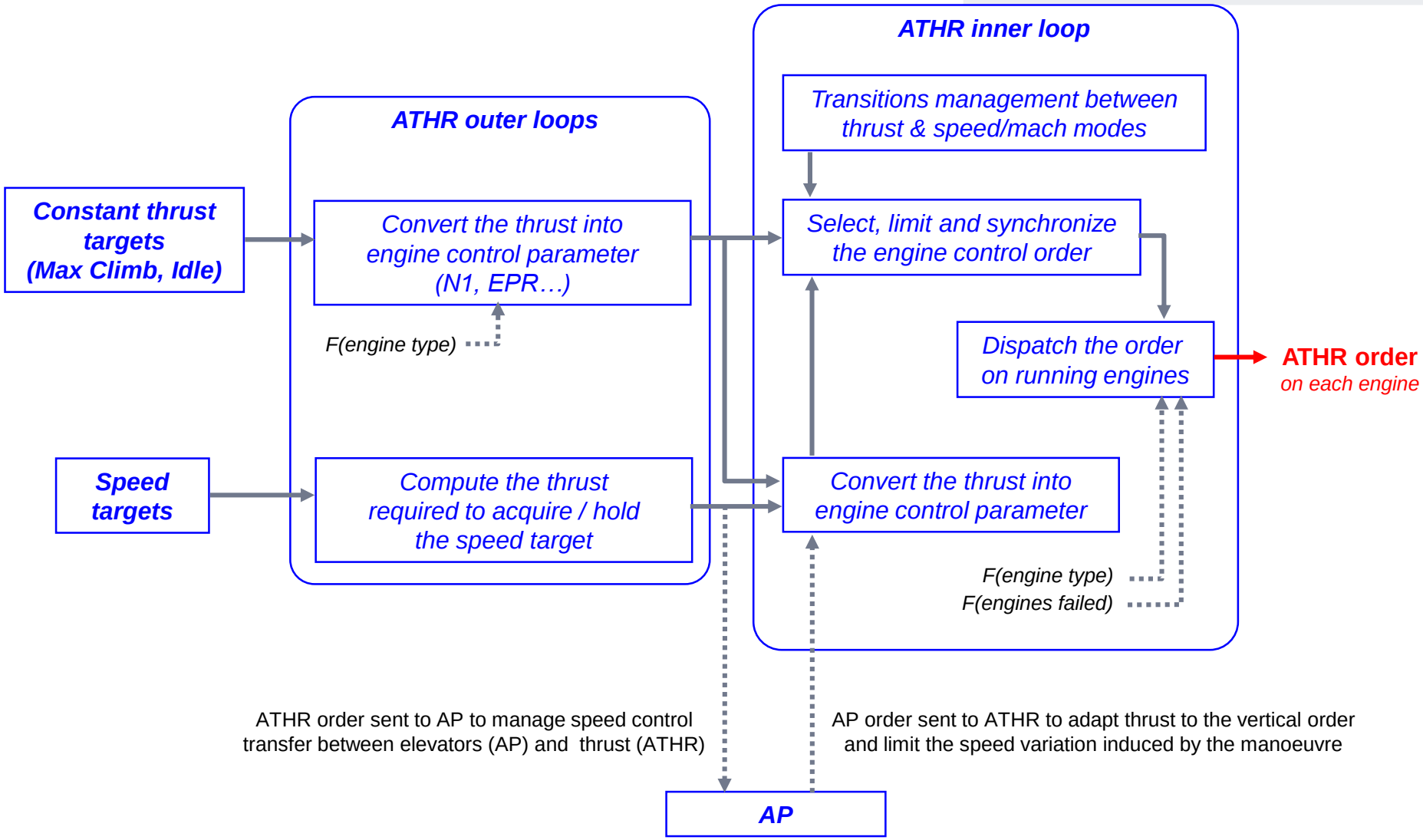
# Vertical control laws breakdown



# Lateral control laws breakdown



# Thrust control laws breakdown




N1: Rotation speed of the engine fans

EPR: Engine Pressure Ratio (=output pressure / input pressure)