Agenda (2/3)

- Module 4 – Design requirements and Safety process
  - 4-1 Requirements
  - 4-2 Safety process
- Module 5 – Aircraft power systems
  - 5-1 Hydraulic power systems
  - 5-2 Electric power systems
- Module 6 – Aircraft Control systems Architectures
  - 6-1 Hydro Mechanical Systems
  - 6-2 Fly by wire systems
  - 6-3 Fly by wire systems new generation
  - 6-4 A320 FAL Visit

Outlines

- Generals : Control surfaces & Cockpit controls
- Mechanical control systems (ATR)
- Hydromechanical control systems (A300/A310/B737 etc)
- First generation Fly by Wire systems (A320/A330/ A340/B777)
- New generation, hybrid power sources, full Fly By Wire systems (A380/A400M/A350/B787)
- Future trends, smart and more electric actuation

First generation Fly by Wire systems

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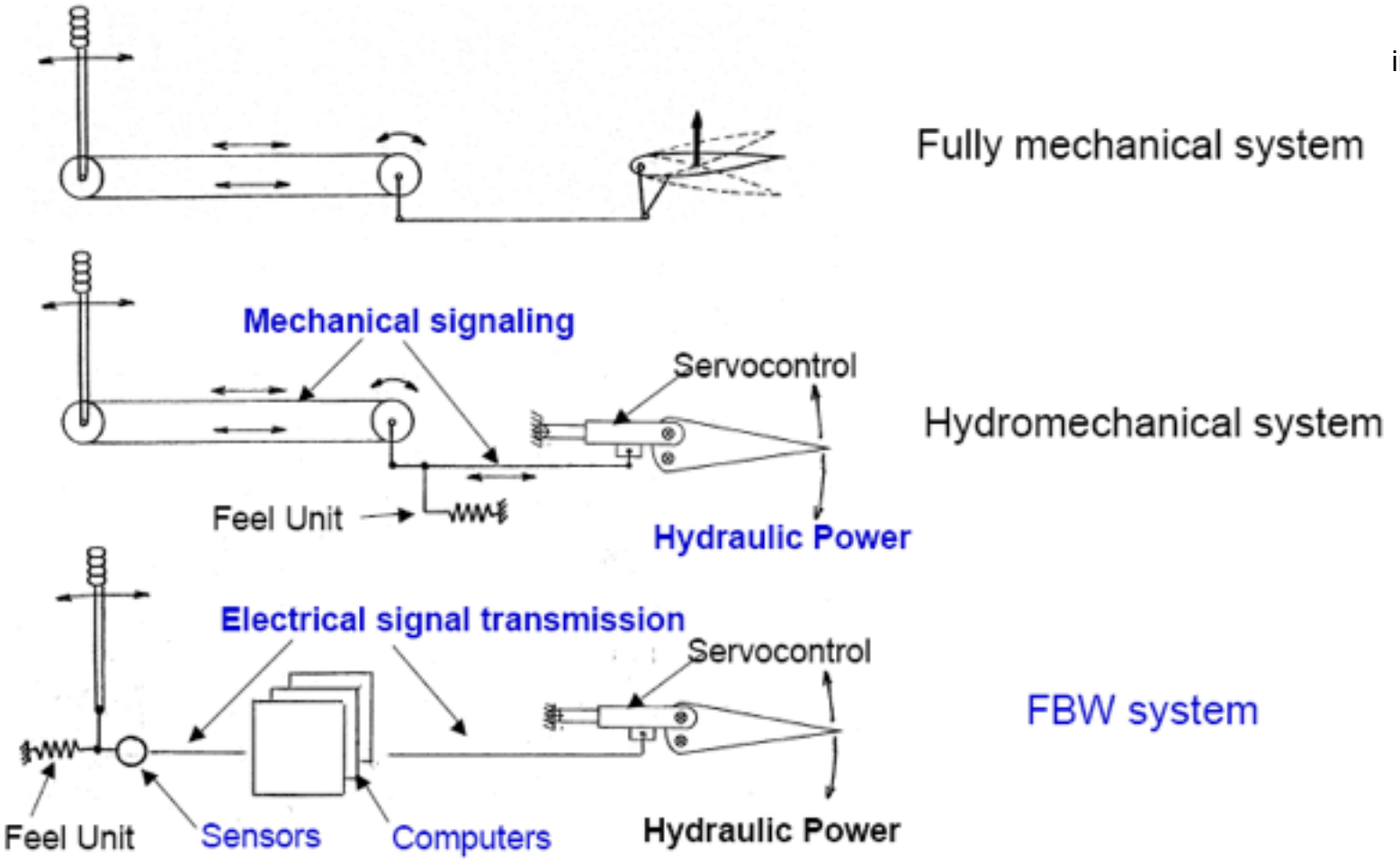


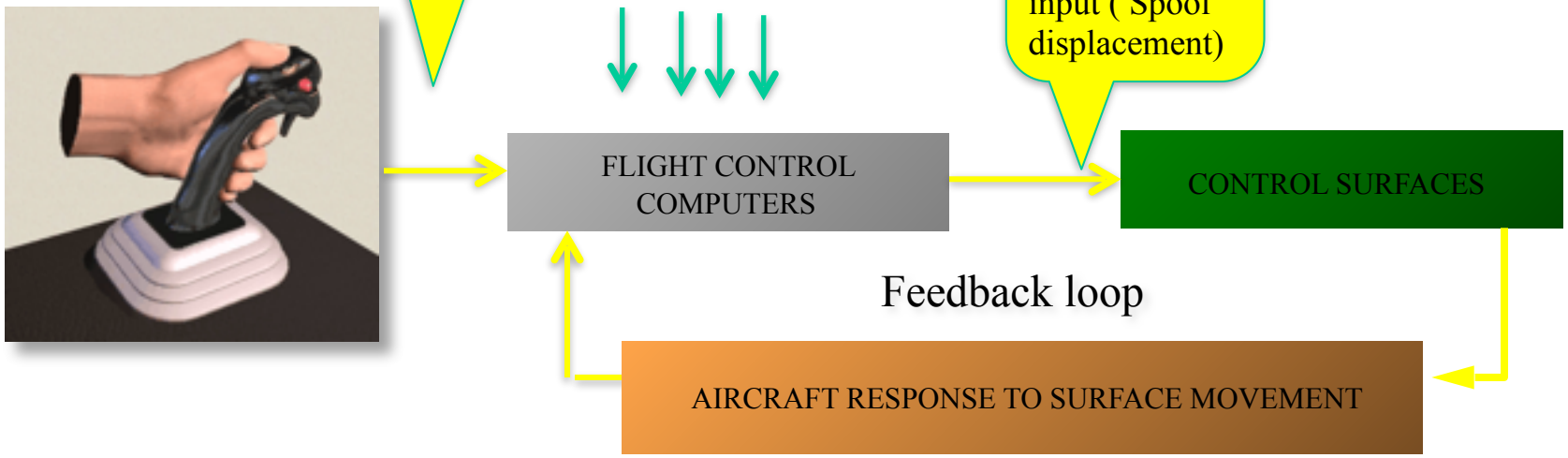
Why Fly by wire was introduced?

- Hydro mechanical systems are complex, and heavy, they create high cost in indicial build and also in aircraft maintenance.
- Industry was looking for means to simplify and ways to enhance the system performance
- New ways to design are always created together with the availability of new technologies
- At the beginning of 1980 computer technologies has reached a state of maturity which made it feasible to use it for aircraft applications
- The Airbus A320 was the first commercial application of digital fly by wire systems. (now nearly Industry standard)

Fly by wire systems

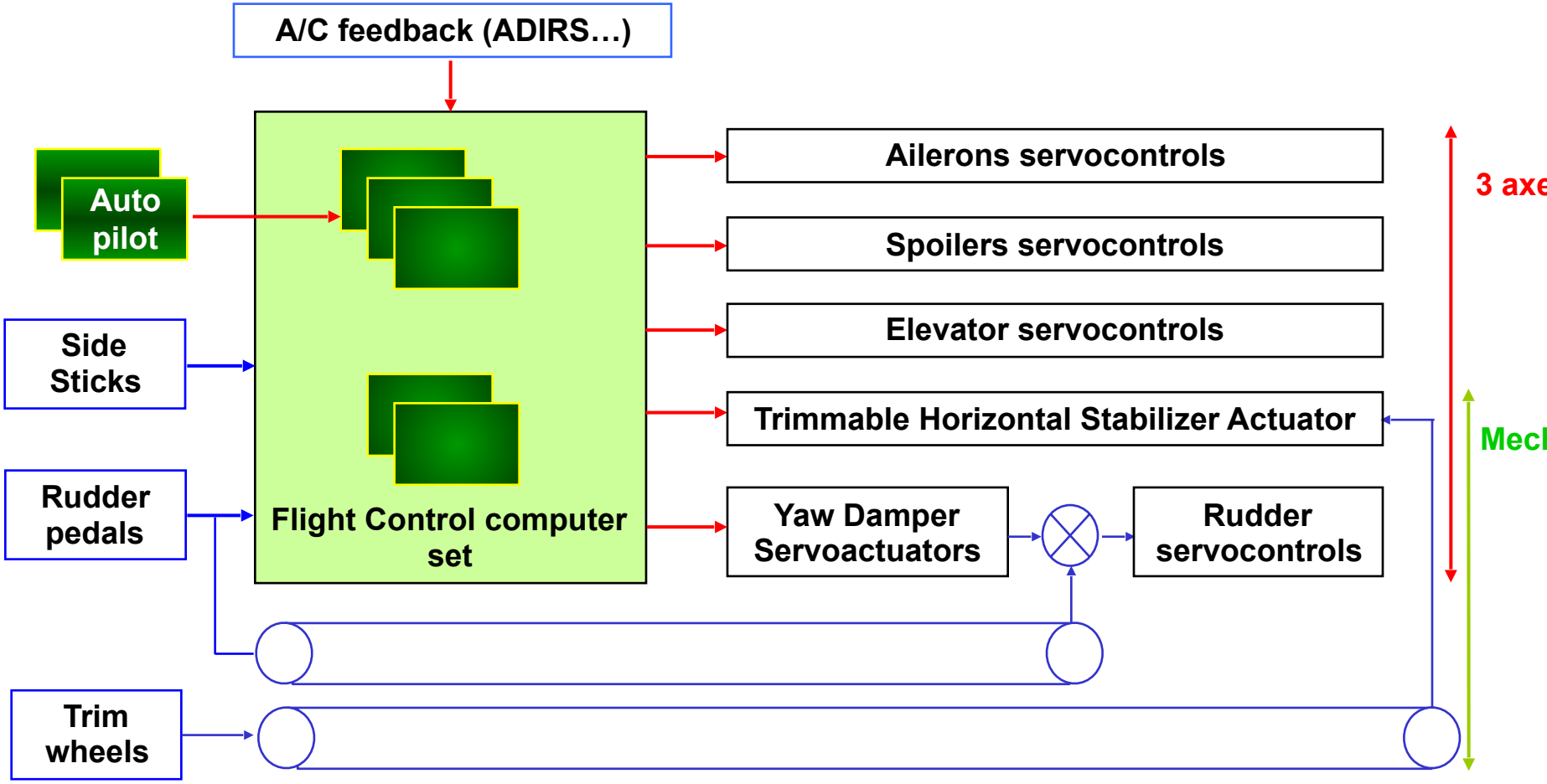
The main difference to conventional controls are:

- No mechanical link between piloting device and the surface actuation system
- The flight control system know and consider the Aircraft response (feedback loop)
- The flight control system know and consider many other aircraft data

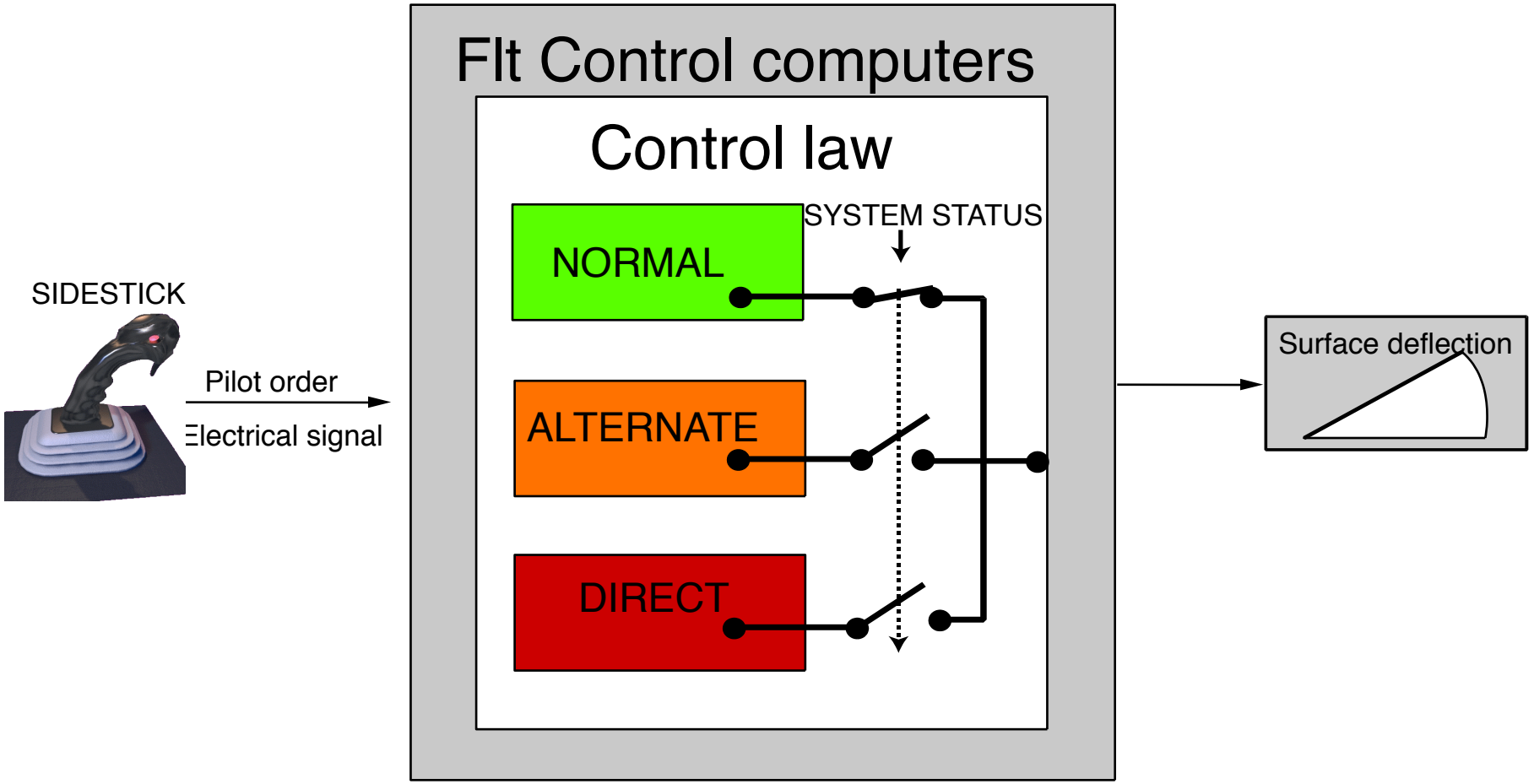


First generation Fly by Wire systems

- A320 System architecture overview



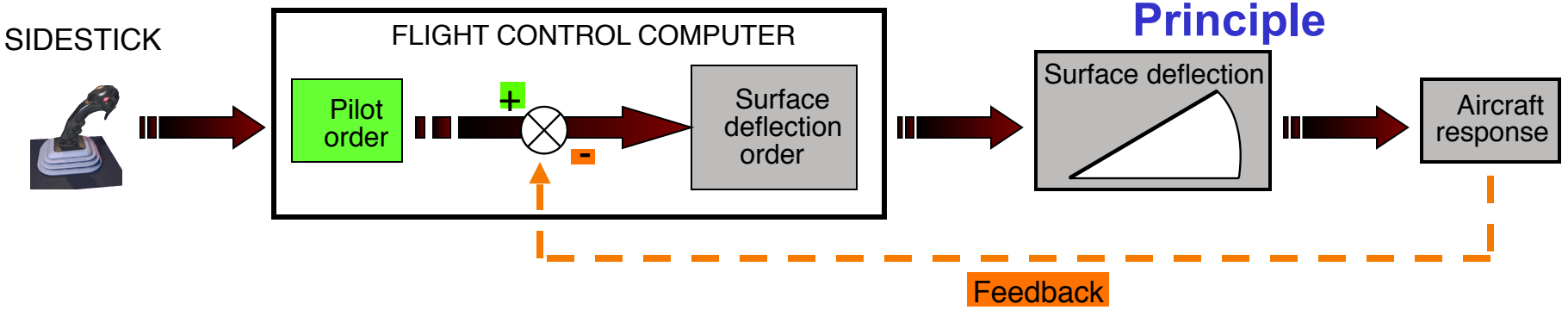
Fly-By-Wire control laws - Principle



Control laws level depend upon Flight Control System status

Fly-By-Wire control laws - Principle

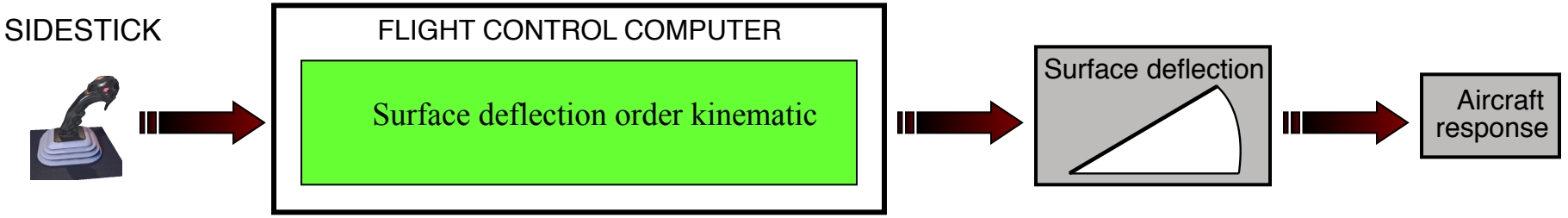
- **Normal and alternate law**



Pilot's input is converted into an A/C objective. No direct relationship between stick and surface.

The aircraft is servo looped

- **Direct law**

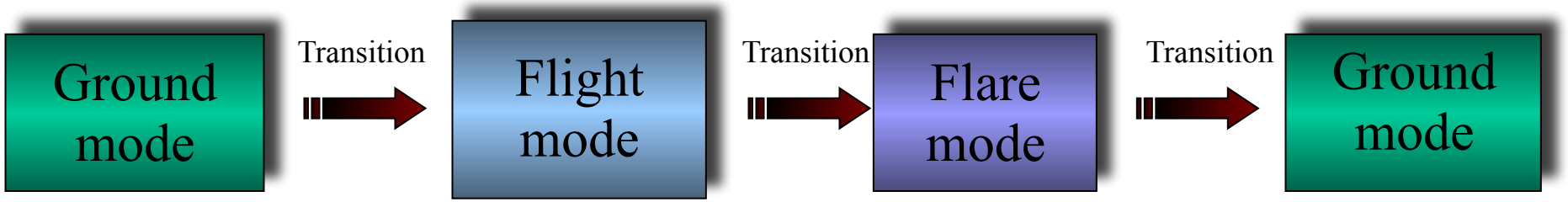


Pilot's input is directly converted into surface deflection orders.

Direct relationship (via adapted kinematics) between stick and surface.

Fly-By-Wire control laws - Principle

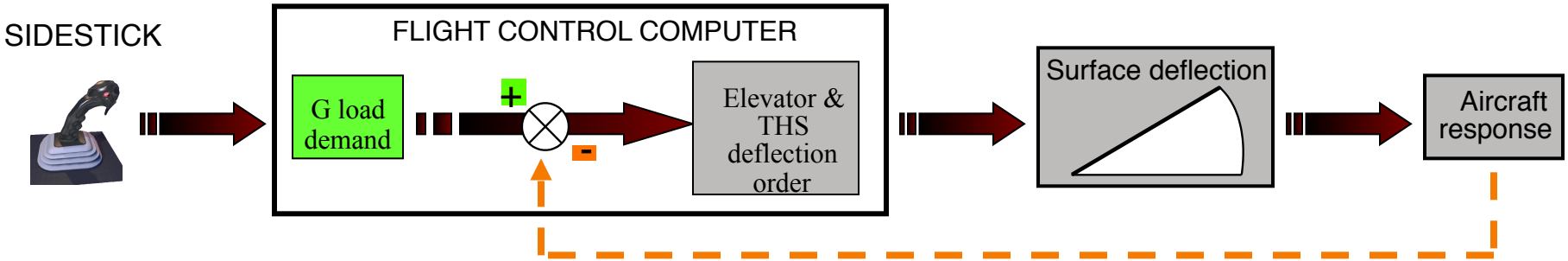
Control laws are **adapted** according **to the flight phases** and ground to air transition conditions.



Transitions from one mode to another are smooth and easy.

Fly-By-Wire control laws – Pitch control

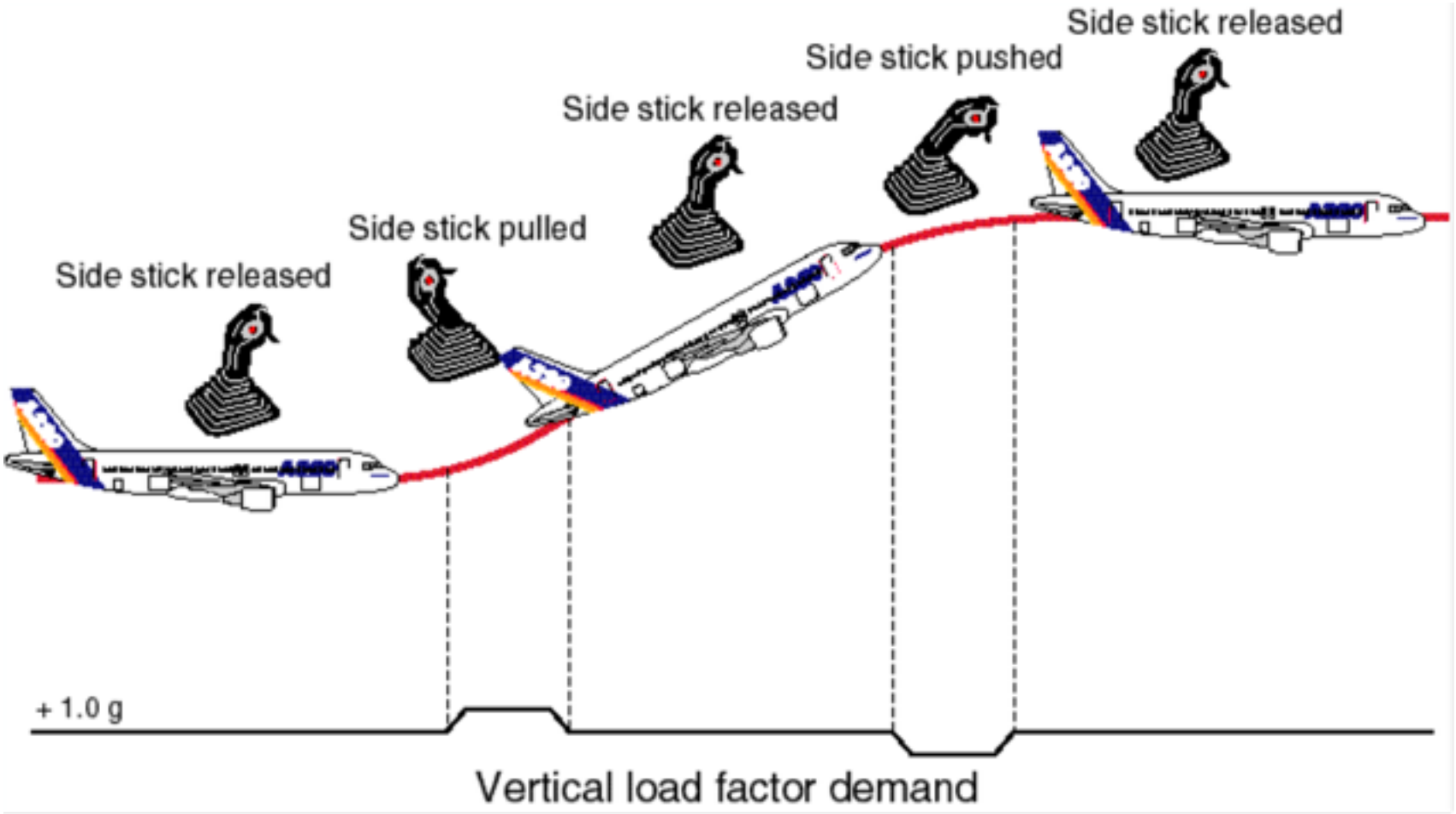
- A forward or aft **sidestick deflection results in a vertical load factor demand (G Load)**



- In short term, **commanded flight path is maintained**
  - Elevator and THS are automatically deflected to compensate for turbulences, thrust, configuration and speed changes.
  - Aircraft is automatically and continuously trimmed (neutral static stability)

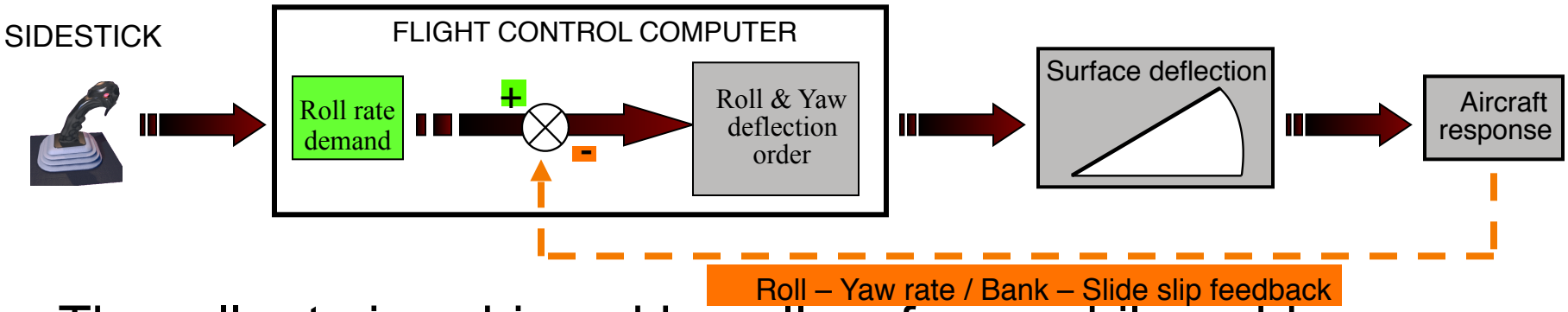
- In long term, pilot's action may be required to adjust flight path as desired.

Fly-By-Wire control laws – Pitch control



Fly-By-Wire control laws – Lateral control

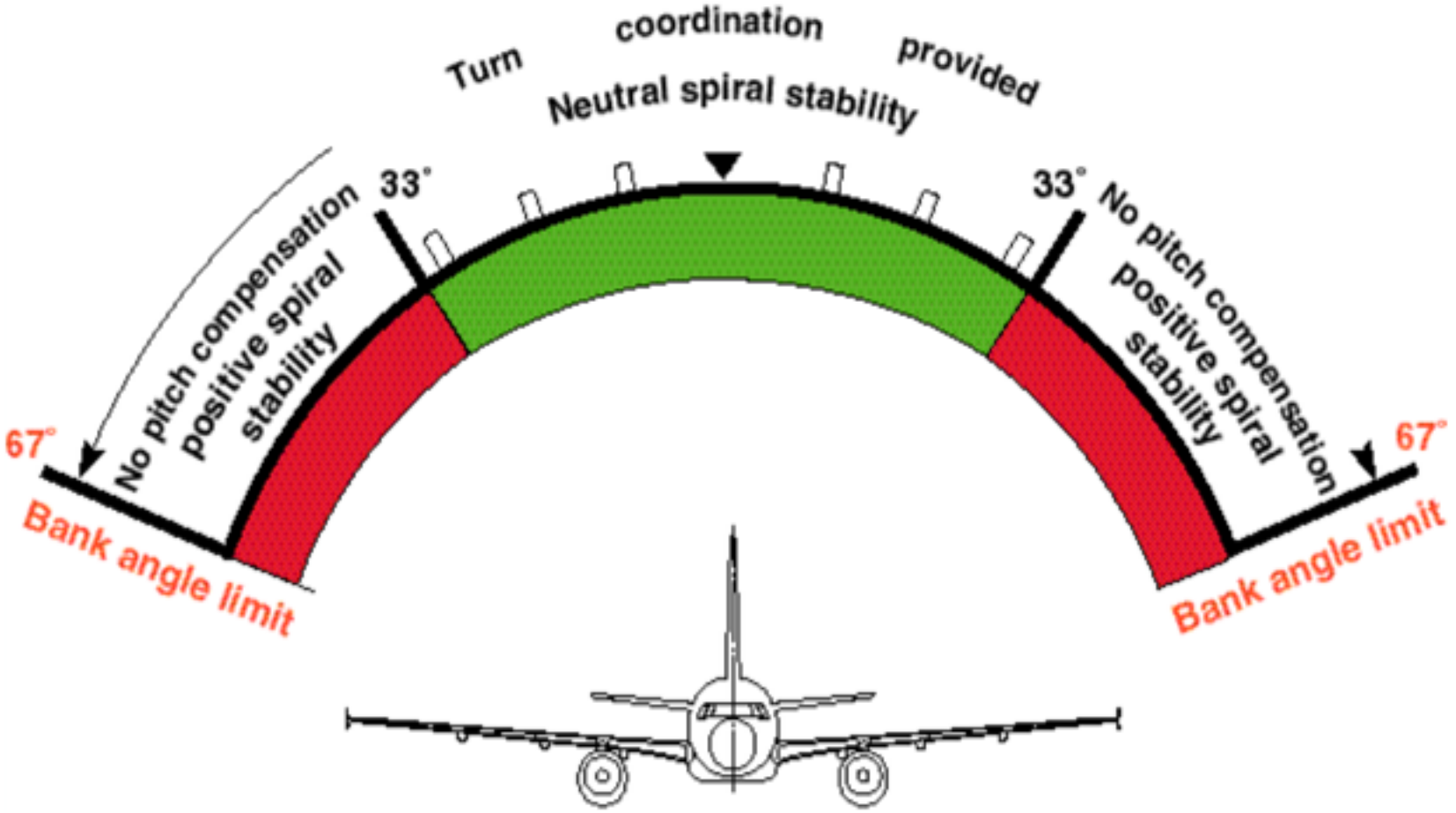
- A lateral **sidestick deflection results in a roll rate demand.**



- The roll rate is achieved by roll surfaces while rudder provides automatic turn coordination and yaw damping.

- The aircraft is laterally stable, **no aileron trim is required** (neutral spiral stability)
  - Roll and yaw surfaces are automatically deflected to cope with turbulences or aircraft asymmetry, using max deflection if required.

Fly-By-Wire control laws – Lateral control



Fly-By-Wire control laws

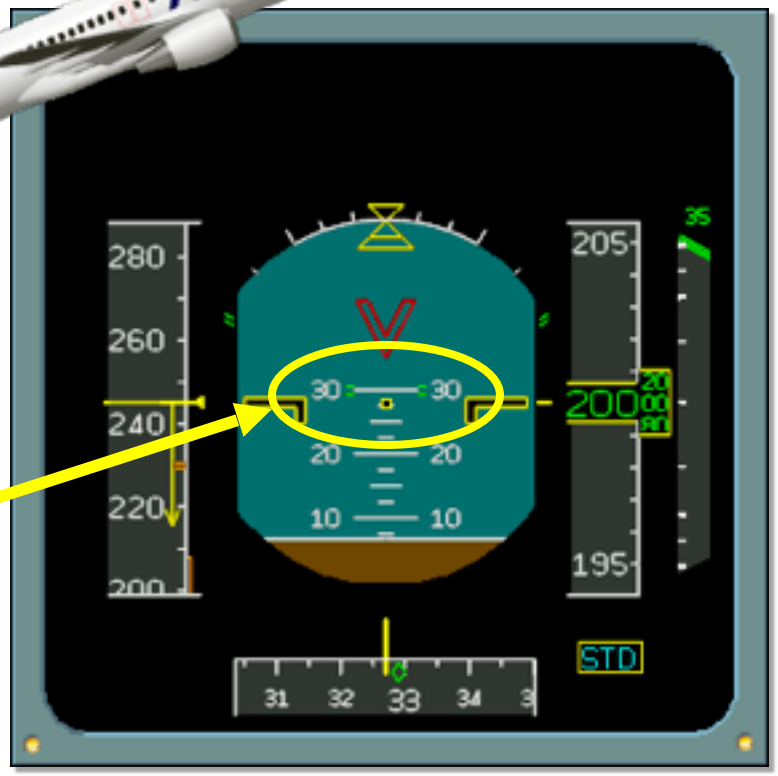
Within the normal flight envelope regardless of altitude,

speed, Cg or configuration,

- Aircraft is stable and highly maneuverable.
- Aircraft response is precise and consistent about all axis's.
- Provide balanced efforts in both pitch and roll.

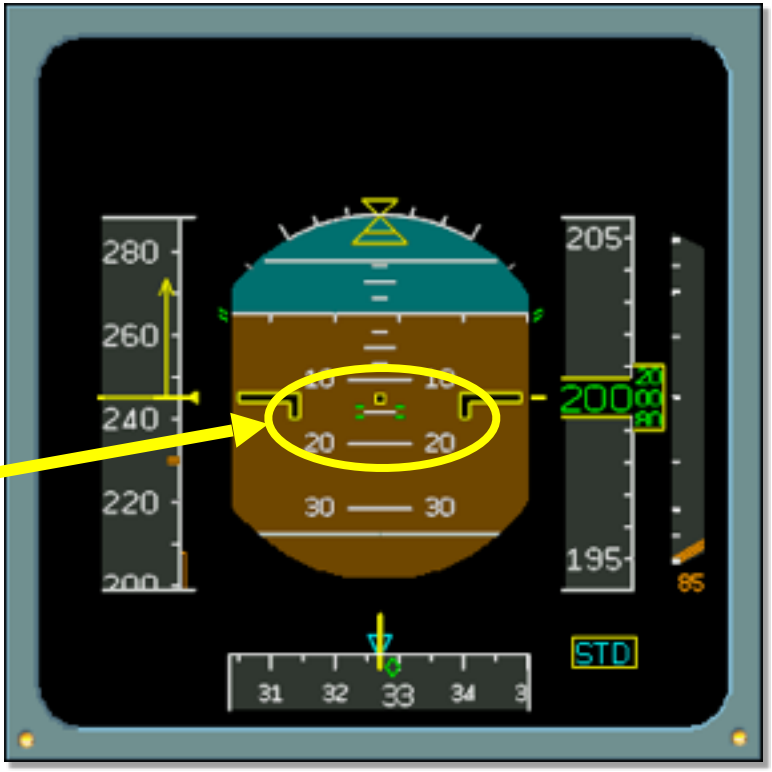
Pitch Attitude Protection

- Pitch authority is reduced at extreme attitudes
- Pitch up attitude limits
  - Flaps 0 to 3 - 30°(25°)
  - Flaps Full - 25°
- Enhance effectiveness of:
  - AOA and high speed
  - protection in extreme conditions



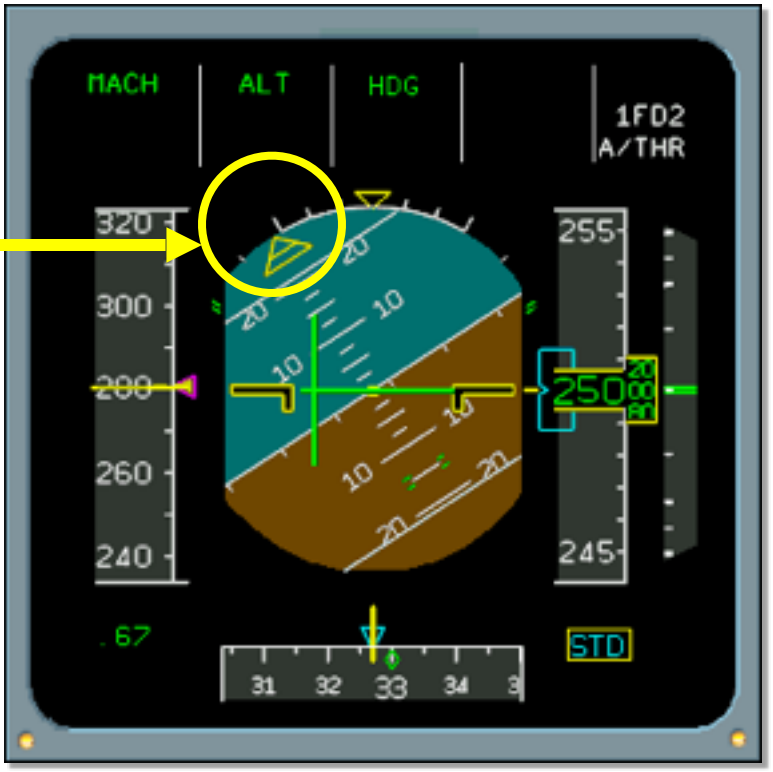
Pitch Attitude Protection

Pitch down attitude limit
-15°



Bank Angle Protection

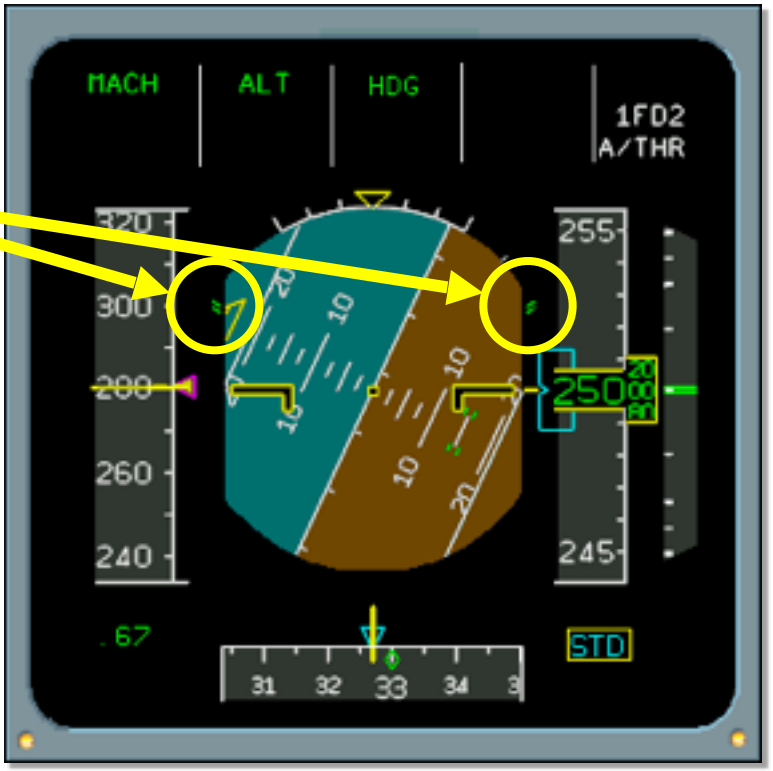
33° bank angle



- If side stick is released when the bank angle exceeds 33°, the aircraft will return to and maintain 33° bank angle.
- Automatic pitch compensation provided for bank angles up to 33°.

Bank Angle Protection

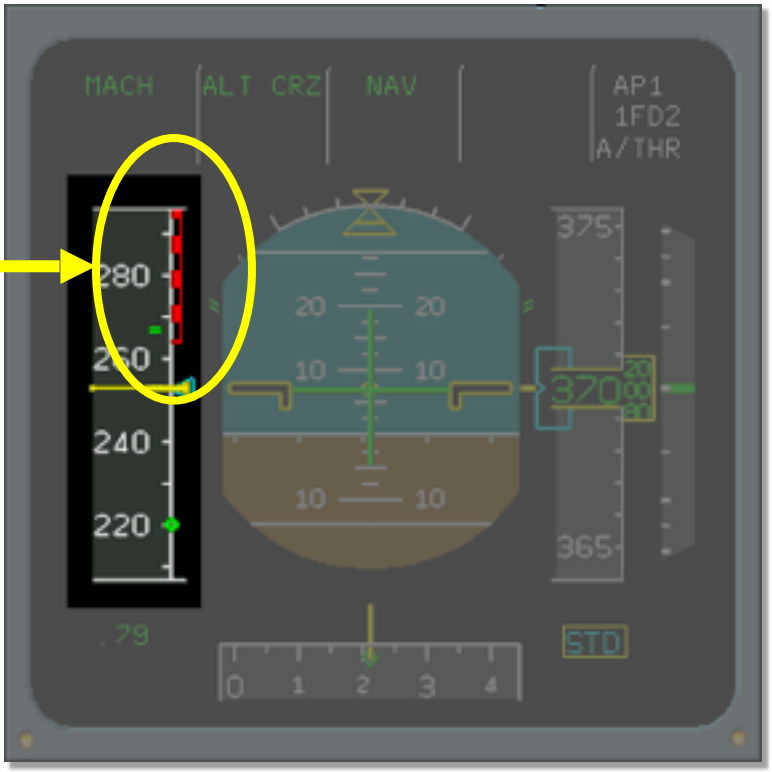
Max bank angle limits
+/- 67°



- AP disconnects and FD bars disappear when the bank is > 45°, FD bars reappear when bank angle is < 40°
- With full side stick bank angle is limited to 67° (or 45° if AOA or high speed protection).

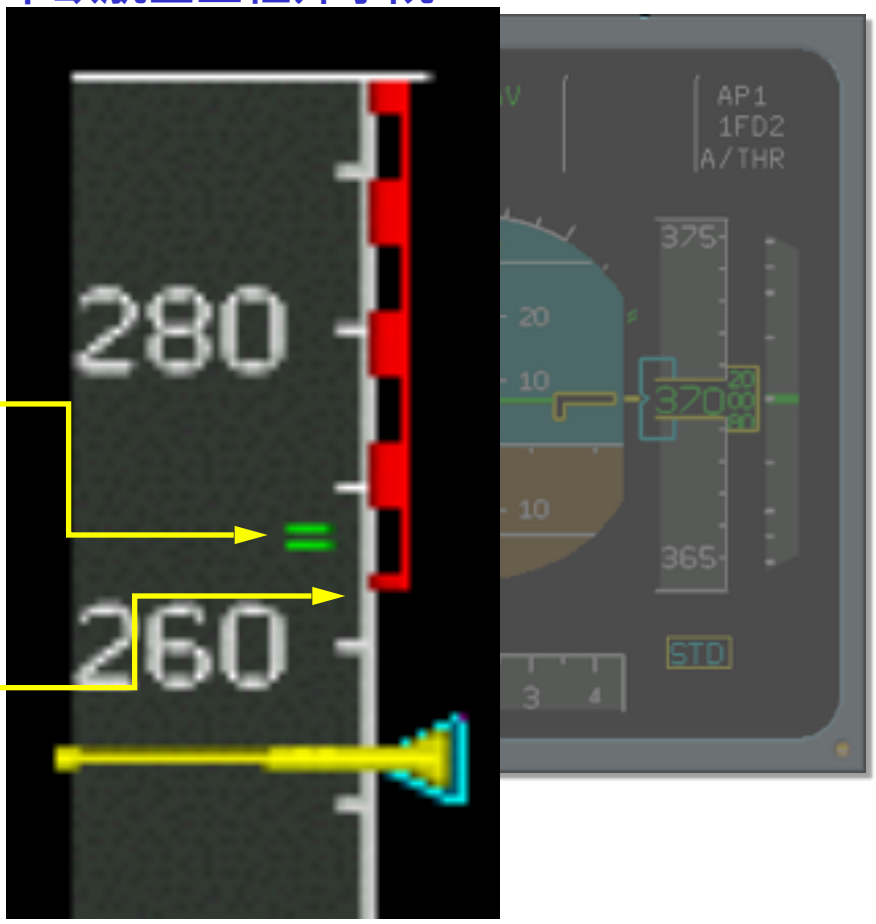
Over speed Protection

Vmo/Mmo limit



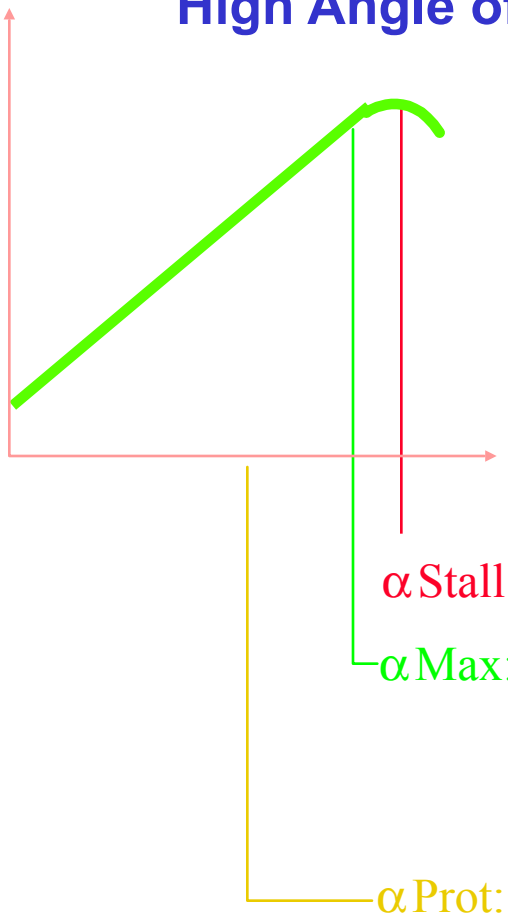
Protects the aircraft from exceeding Vmo/Mmo limit by introducing a positive load factor (nose - up demand) to the sidestick

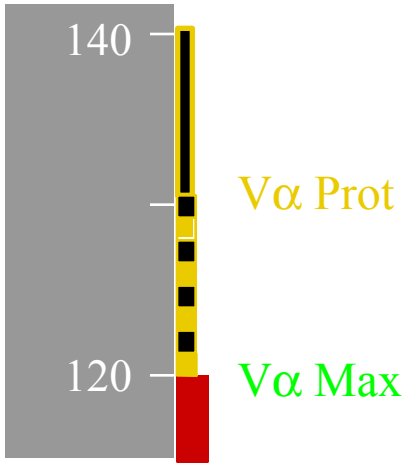
Overspeed protection



- Vmo/Mmo is shown as the bottom of the red/black barber pole
- Green dashes indicate the speed at which the protection is activated

High Angle of Attack protection





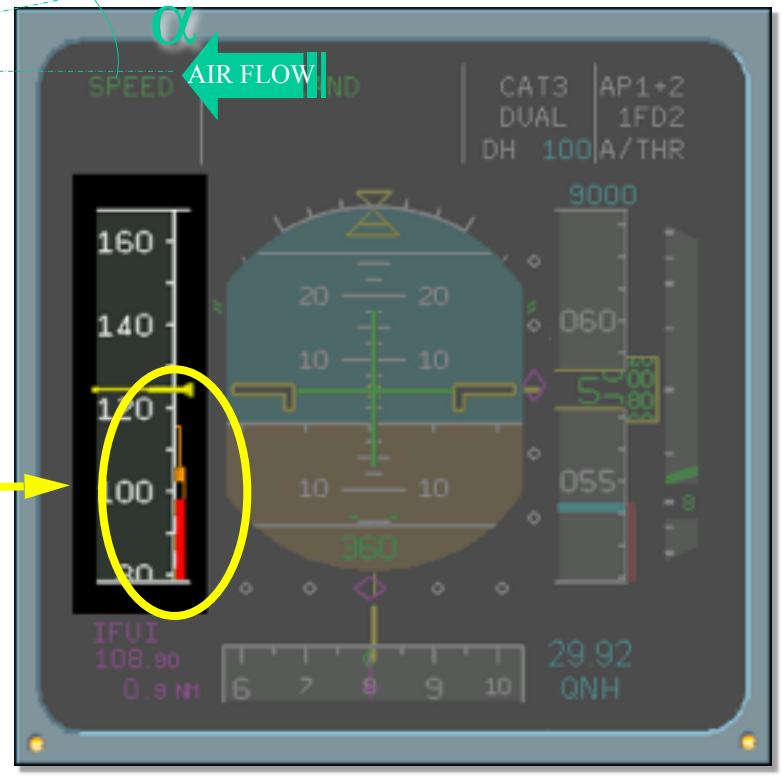
αStall : Sudden loss of lift and or aircraft control

αMax: Angle of attack reached with full aft stick (max aircraft performance)

αProt: Angle of attack from which stick input is converted into angle of attack demand (stick neutral αProt)

High Angle of Attack protection

High angle of attack limits

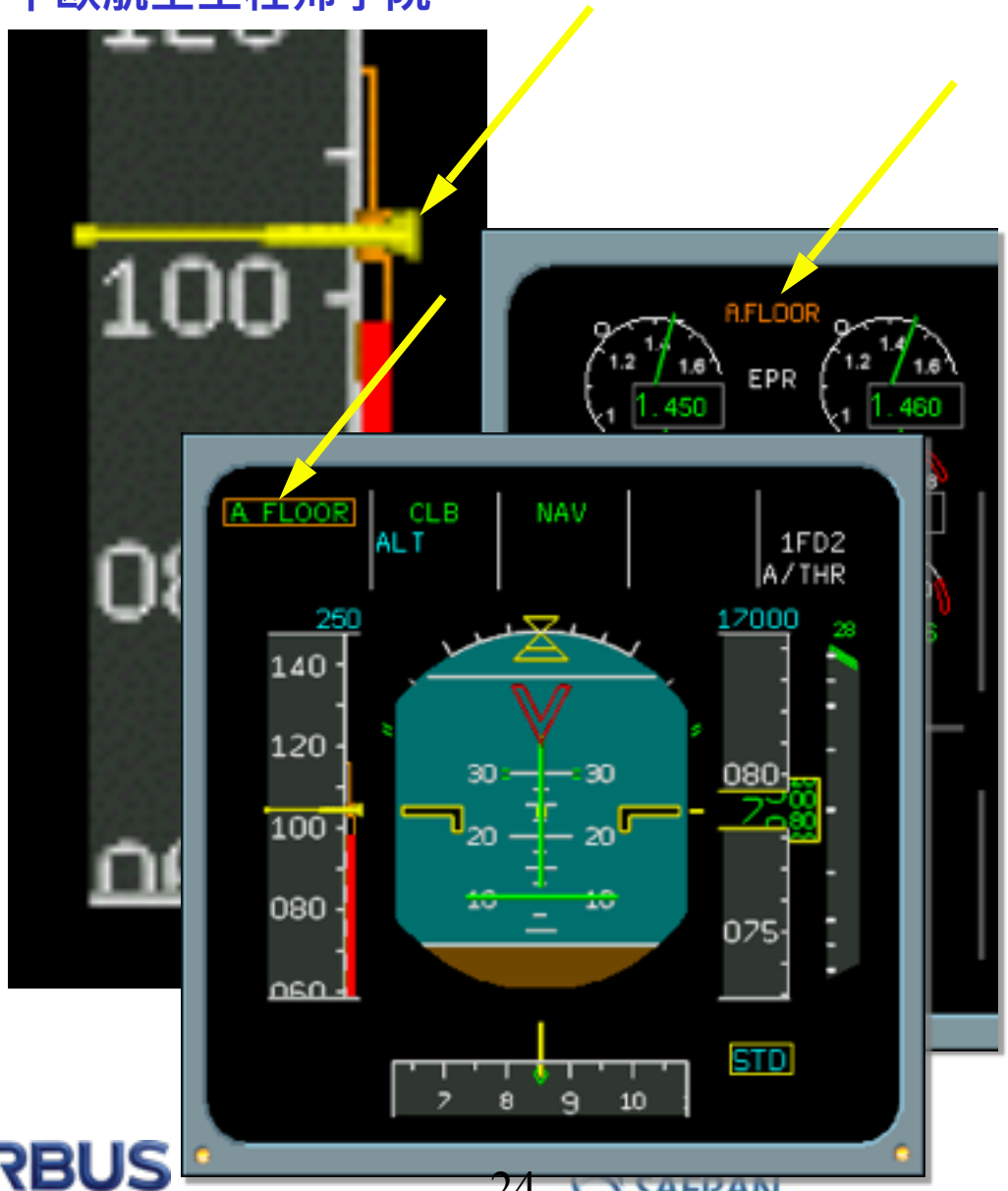


High Angle of Attack protection

- As speed decreases it reaches Vls, the lowest achievable speed with autothrust engaged
- Between αPROT & αMAX, Floor will activate, autopilot disconnects and speed brakes automatically retract if extended

High Angle of Attack protection

αFloor activated



Fly-by-wire protections

- Allow a pilot to:
  - Have full authority to consistently achieve maximum aircraft performance In certain extreme situations such as Windshear, heavy turbulence, potential midair, GPWS, or TCAS advisories
  - Reduce the risk of over-controlling and or overstressing the aircraft

Maximum aircraft performance is
easily achieved by use of instinctive,
simple procedures

Airbus Fly-By-Wire – Design considerations -Redundancy

Electrical generation and distribution

- Generation
  - **Two** engine-driven generators
  - **One** APU generator
  - **Two** batteries
  - **One** CSM / G (constant speed motor/generator) driven by hydraulic circuit (Blue), powered by its dedicated pump or RAT

- In case of electrical emergency configuration, **two Fly-By-Wire computers are still powered** and provide high level control law

- Additionally, **extensive segregation rules** have been applied to **minimise common** point risks.

Airbus Fly-By-Wire – Design considerations -Redundancy

Hydraulic generation and distribution

- **Three Hydraulic circuits** (Green , Blue, Yellow)
  - Green pressurized by an engine driven pump
  - Yellow pressurized by an engine driven pump and an electrical pump.
  - Blue pressurized by an electrical pump and RAT.
  - Green and yellow circuit can drive each other by means of the Power Transfer Unit (PTU)

- **Two electro-hydraulic servo-controls per surface**.

- In case of double hydraulic failure, high level control law still available with remaining flight controls.

Airbus Fly-By-Wire – Design considerations -Redundancy

Computer to actuator repartition

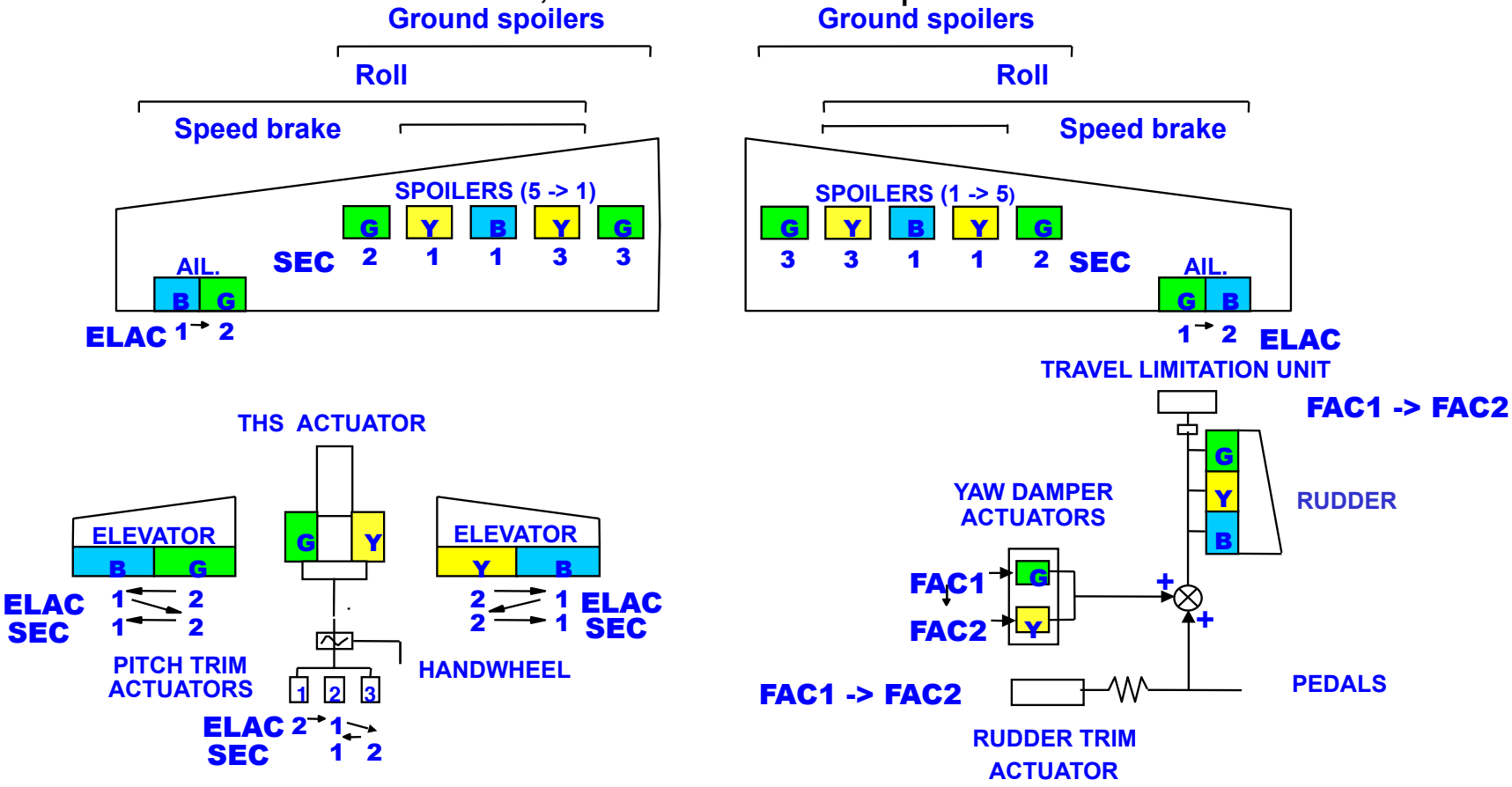
- The electrical signalling of the flight control surfaces is achieved by **7 digital computers.**
  - 2 **EL**evator and **A**ileron **C**omputers (**ELAC**)
  - 3 **S**poiler and **E**levator **C**omputers (**SEC**)
  - 2 **F**light **A**ugmentation **C**omputers (**FAC**)

- **Four computers** available **on elevator**

- **Two specific computers** are dedicated **to manage the data** from the flight control computers for indication, warnings, maintenance and recording purposes.
  - 2 **F**light **C**ontrol **D**ata **C**oncentrator (**FCDC**)

First generation Fly by Wire systems

A320 Power Source, Actuator and Computer Distribution



ELAC : Elevator and Aileron Computer **SEC** : Spoiler and Elevator computer **FAC** : Flight Augmentation Computer

Airbus Fly-By-Wire – Design considerations – Mechanical back-up

A flight control mechanical back-up is provided:

- For Pitch Control: Pitch Trim Wheel
- For Yaw/Roll Control: Rudder pedals

Control the aircraft during a temporary loss of all computers. (design of 1982)

Today's fly by wire control systems have no mechanical back up because of the proven confidence in the electrical system.

First generation Fly by Wire systems

- Overall benefits of FBW systems

•Simpler system, free of backlash, friction, hysteresis, jamming,…

•Generate direct and indirect weight savings

•Provide a safe, accurate and comfortable flight within the normal flight envelope regardless of altitude, speed, Cg or configuration:

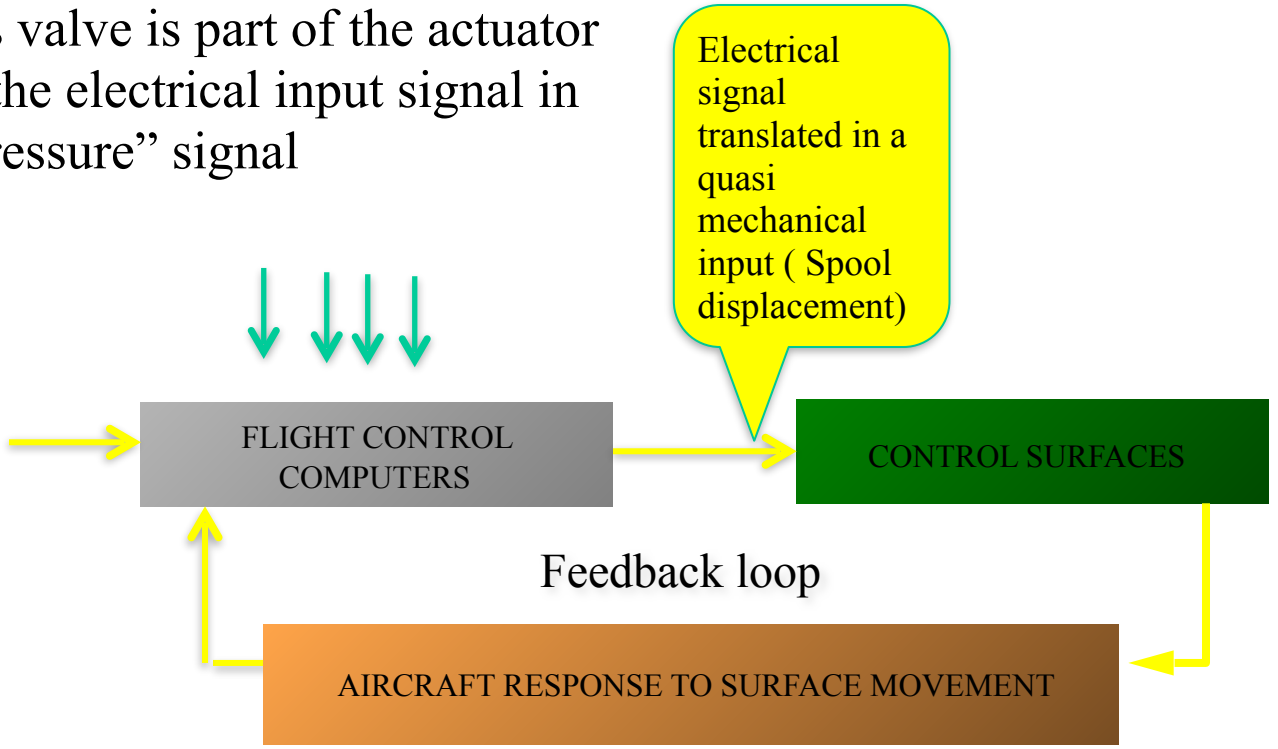
- Precise and consistent aircraft response
- Stable and highly maneuverable aircraft
- Full authority to pilot to achieve the best aircraft performance with intuitive and immediate procedure
- Reduced risk of over controlling / overstressing the aircraft

•Allow the various models to achieve an unmatched level of operational commonality, which makes them all fly and feel alike, resulting in:

- Reduction of the overall maintenance costs
- Reduction of the transition training time.
- Cross-Crew-Qualification and Mixed-Fleet-Flying
- Considerable savings for operators
- Enhanced overall flight safety.

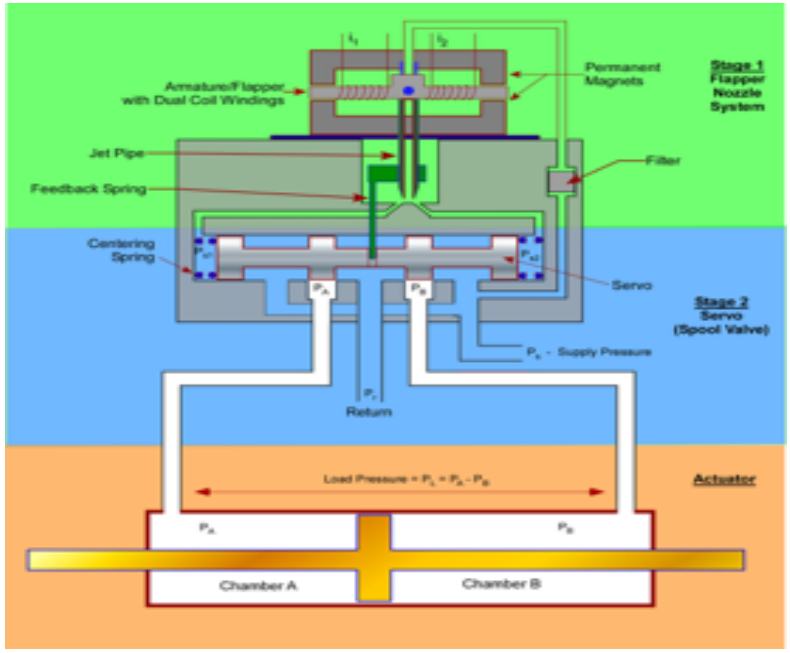
Fly by wire systems

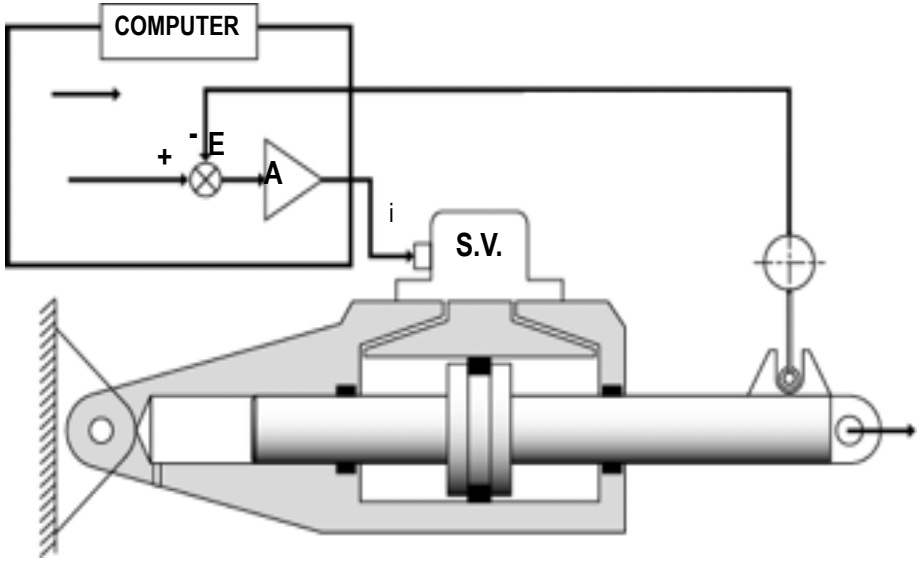
If we focus on the actuation side of a fly by wire system, on of the key component is the servo valve. This valve is part of the actuator and it translates the electrical input signal in a “mechanical/pressure” signal



First generation Fly by Wire systems

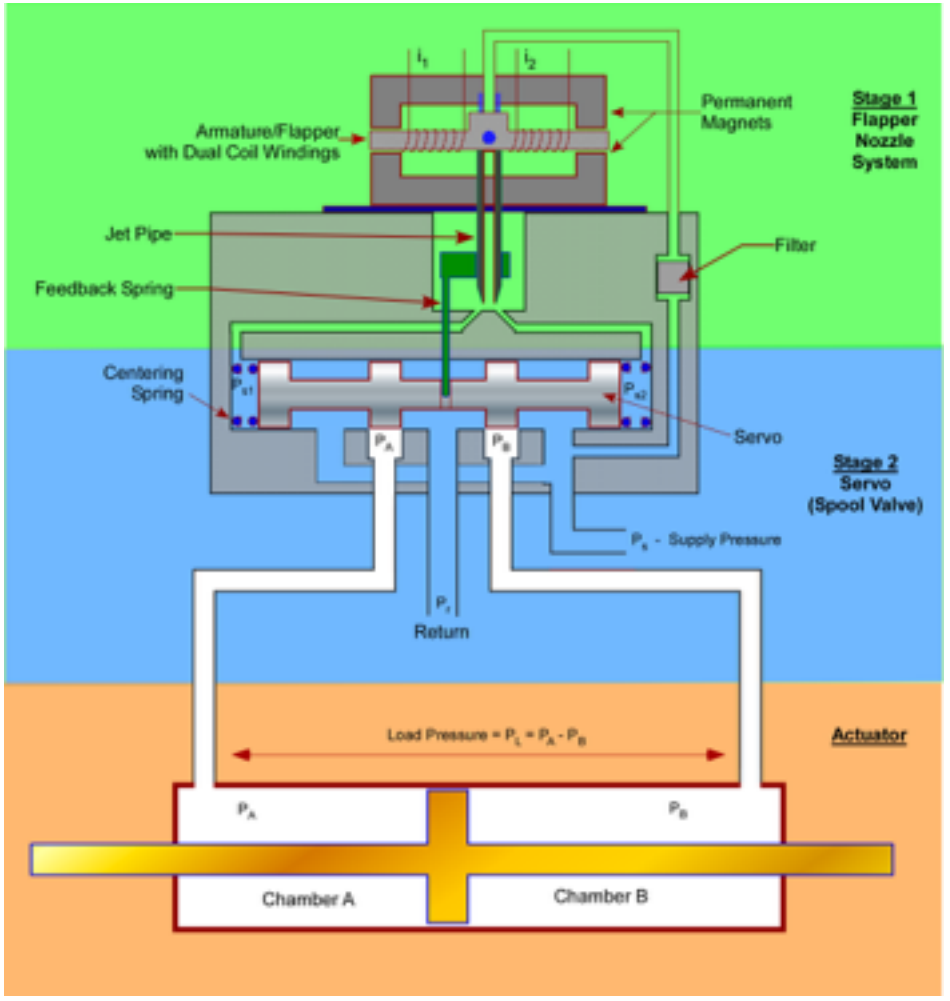
- One of the key component is the Electro Hydraulic Servo Valve
- The jet pipe converts kinetic energy of the moving fluid into static pressure
- Input current controls the flapper position



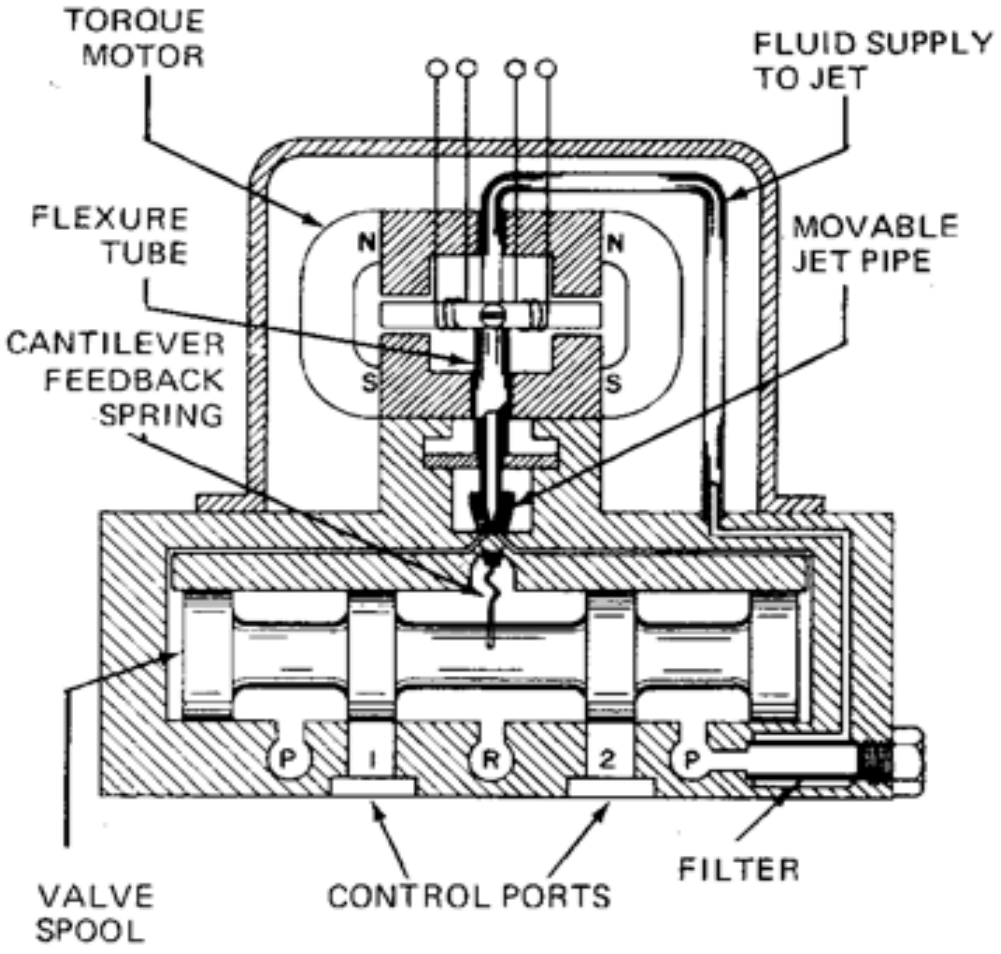


Servo valve Principal

- The jet pipe converts kinetic energy of the moving fluid into static pressure
- Input current controls the flapper position +/-



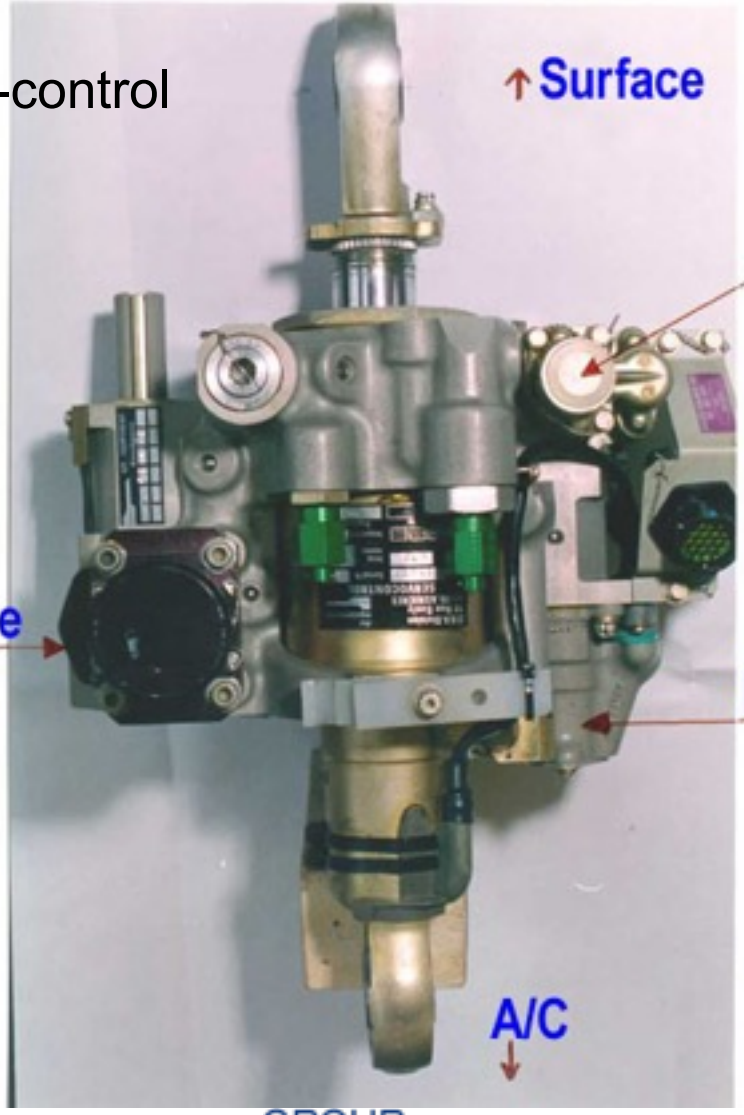
First generation Fly by Wire systems



First generation Fly by Wire systems

- Fly By Wire servo-control

  A320 aileron



First generation Fly by Wire systems

- Fly By Wire servo control

Operating modes for a typical fbw Actuator

- **Active** : normal operating mode for one actuator per control surface ; needs hydraulic supply and electrical signalling
- **Stand-by**: normal operating mode for the actuator adjacent to the active one
  default mode in case of loss of electrical signalling

  In stand-by mode, the actuator provides a velocity dependent **damping** force
- **Self-centering** (SA / LR elevators, A340 500/600 ailerons)
  - in case of loss of electrical signalling, available hydraulic power is used to position and hold a zero deflection
  - must affect two adjacent actuators simultaneously
  - is used when zero hinge moment position might bring uncomfortable flight perturbation or reduce remaining manoeuvrability
- When **depressurized** fluid is trapped within the actuator and **damping** is provided. An accumulator compensates for fluid thermal retraction

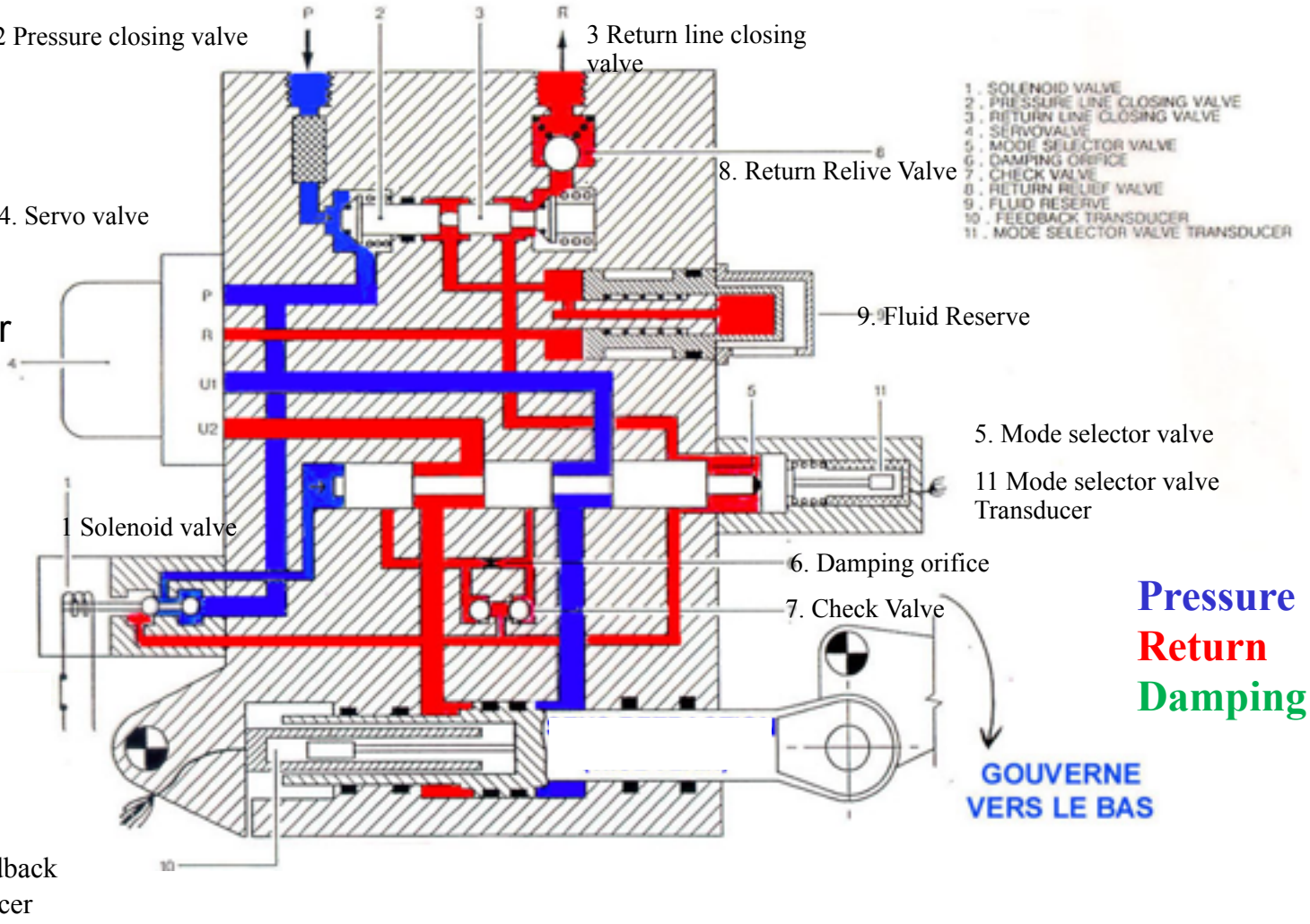
First generation Fly by Wire systems

- Fly By Wire servocontrol

  A320 aileron

Active mode

normal operating mode for one actuator per control surface ; needs hydraulic supply and electrical signalling



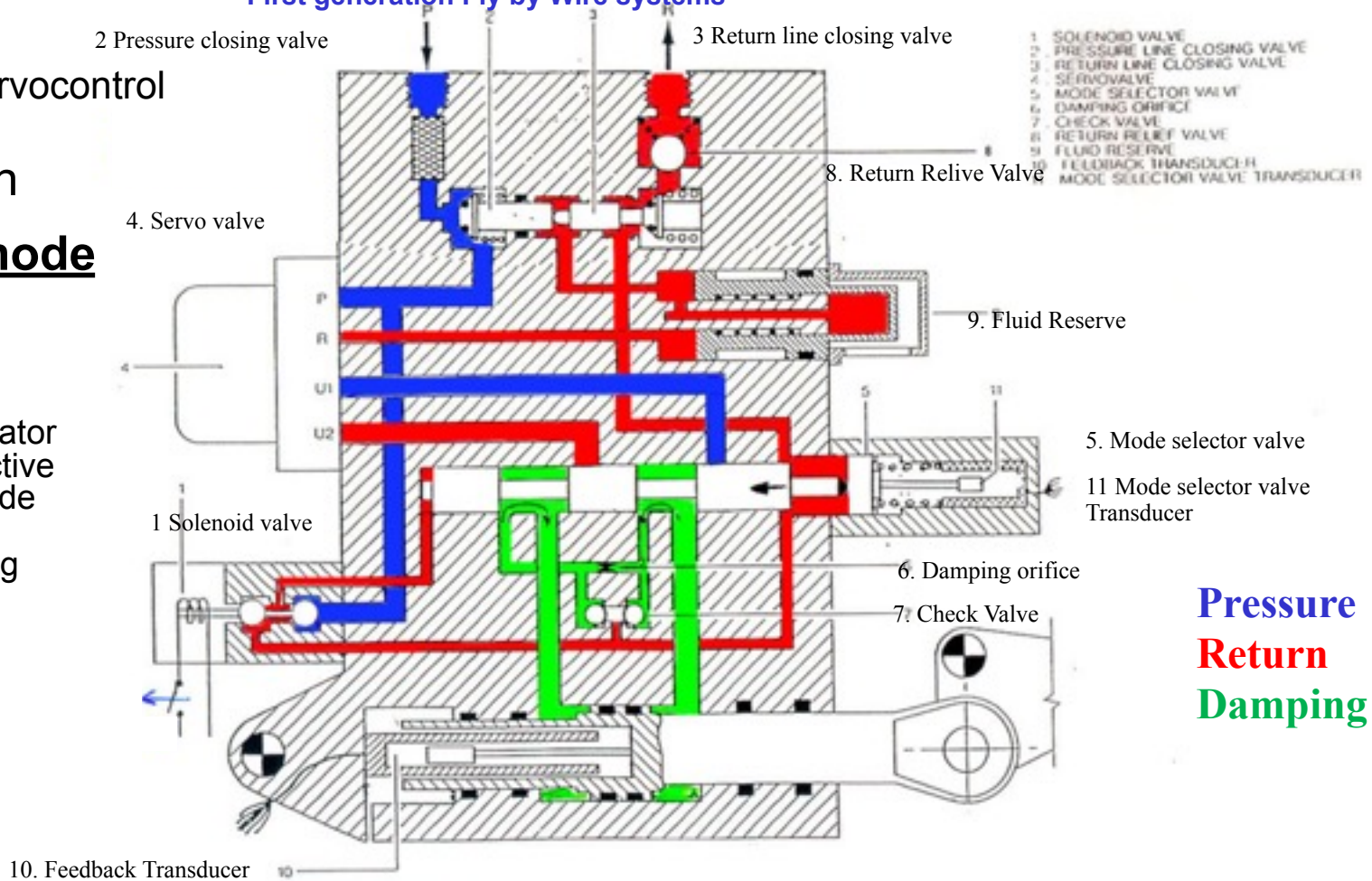
First generation Fly by Wire systems

- Fly By Wire servocontrol

A320 aileron

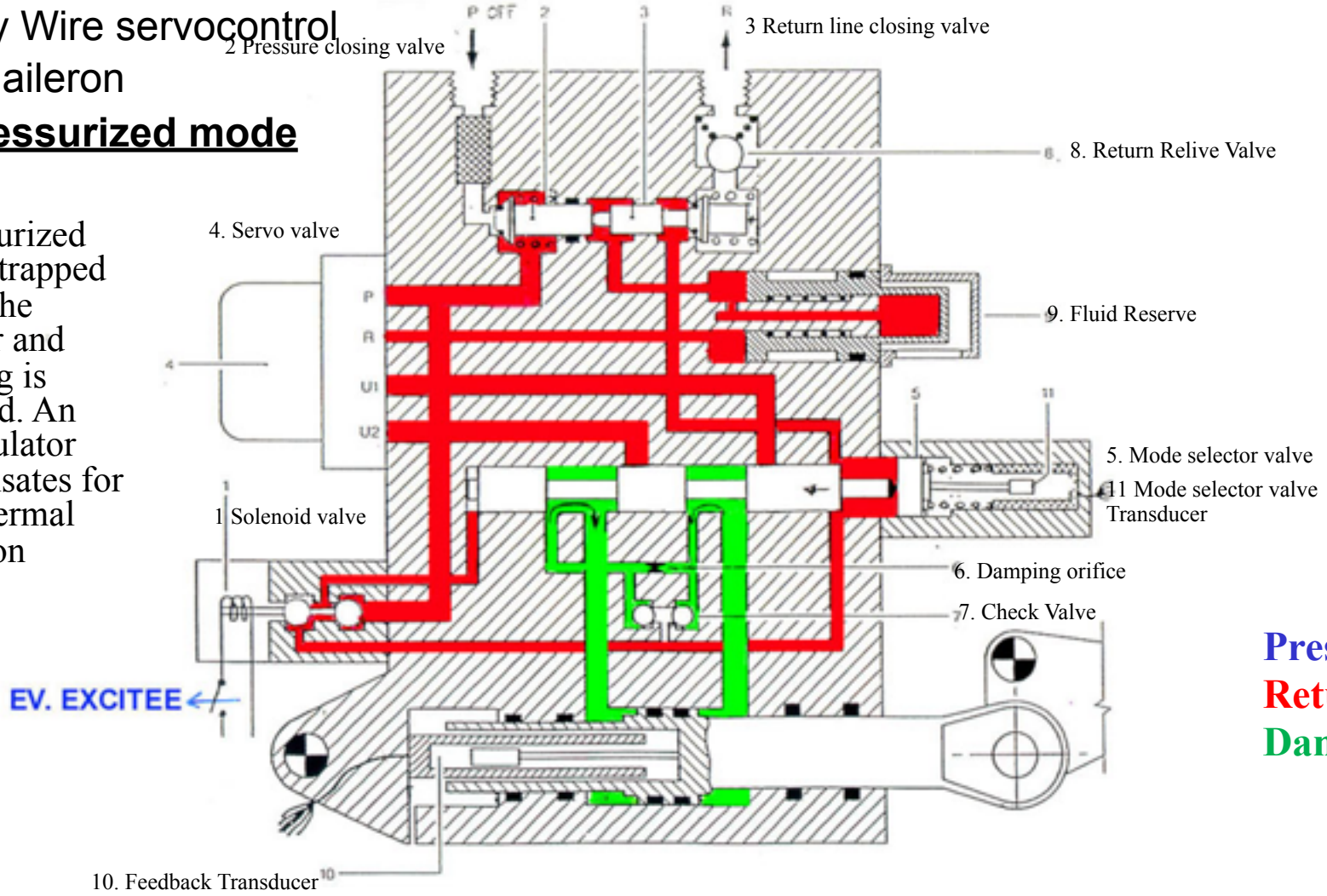
Stand-by mode

normal operating mode for the actuator adjacent to the active one or default mode in case of loss of electrical signalling



- Fly By Wire servocontrol
  A320 aileron
  Depressurized mode

When depressurized fluid is trapped within the actuator and damping is provided. An Accumulator compensates for fluid thermal retraction



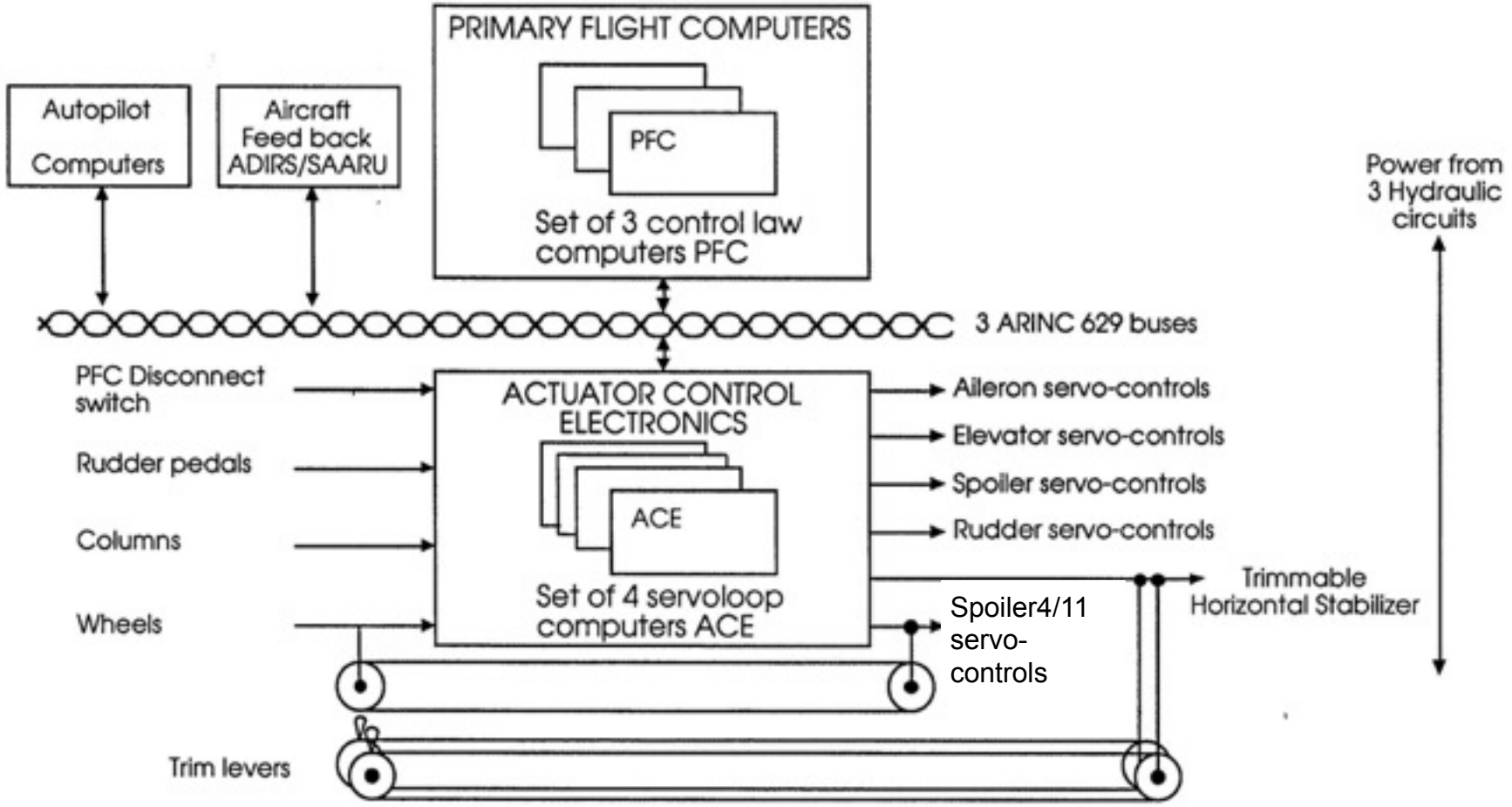
- End of session 6.2 fly by wire first generation
- Annex:

1. fly by wire on other Aircraft
2. Additional info to equipment of flight control systems and there power supply

- Annex 1
- Other fly by wire Aircraft (B777)

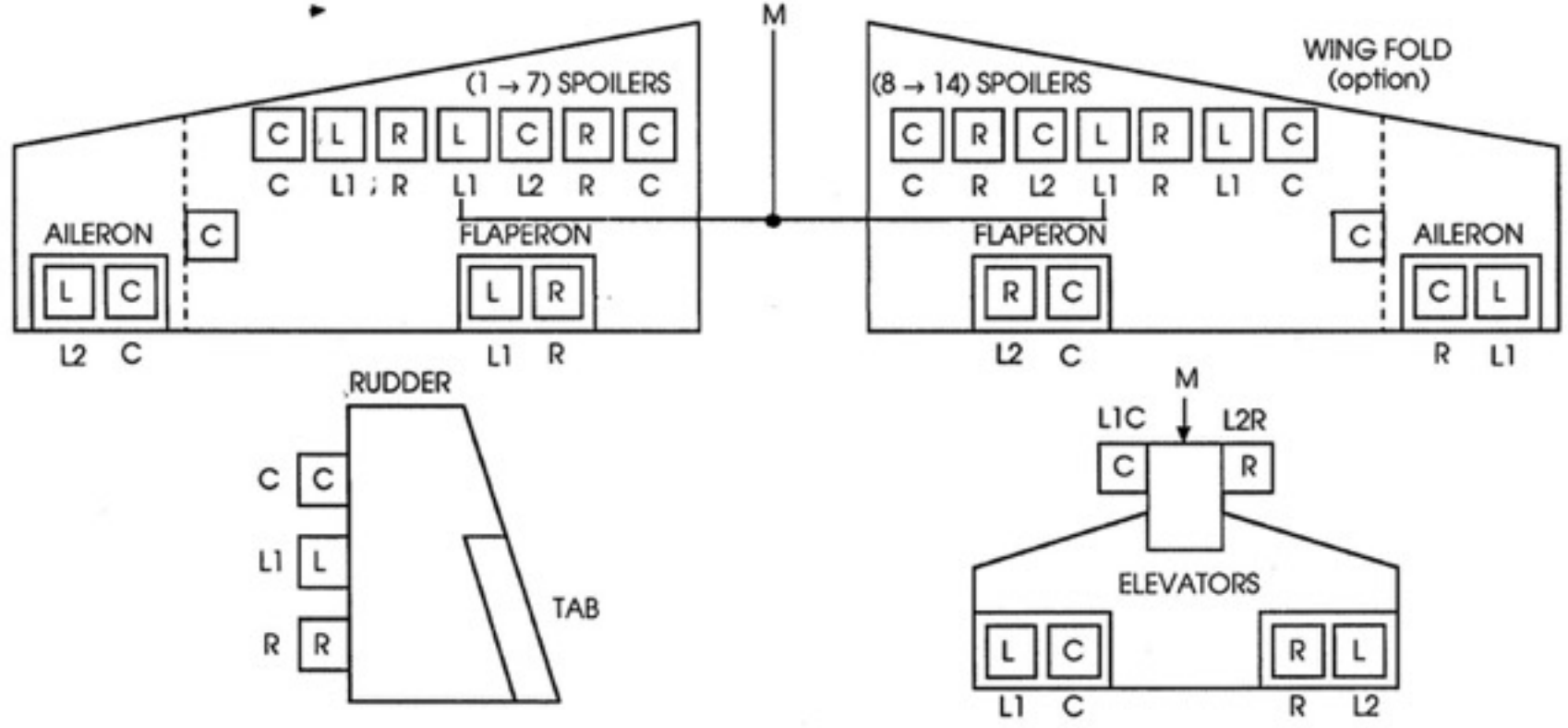
First generation Fly by Wire systems

- B777 System architecture overview



First generation Fly by Wire systems

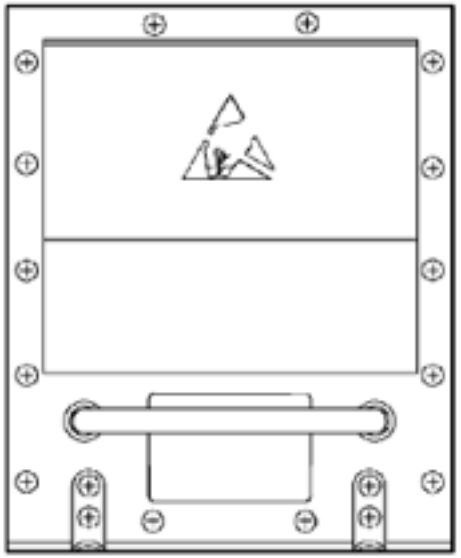
- B777 Power Source, Actuator and Computer Distribution



First generation Fly by Wire systems

- Flight Control Computers overview
  - B777 computers

2 Types of computers :

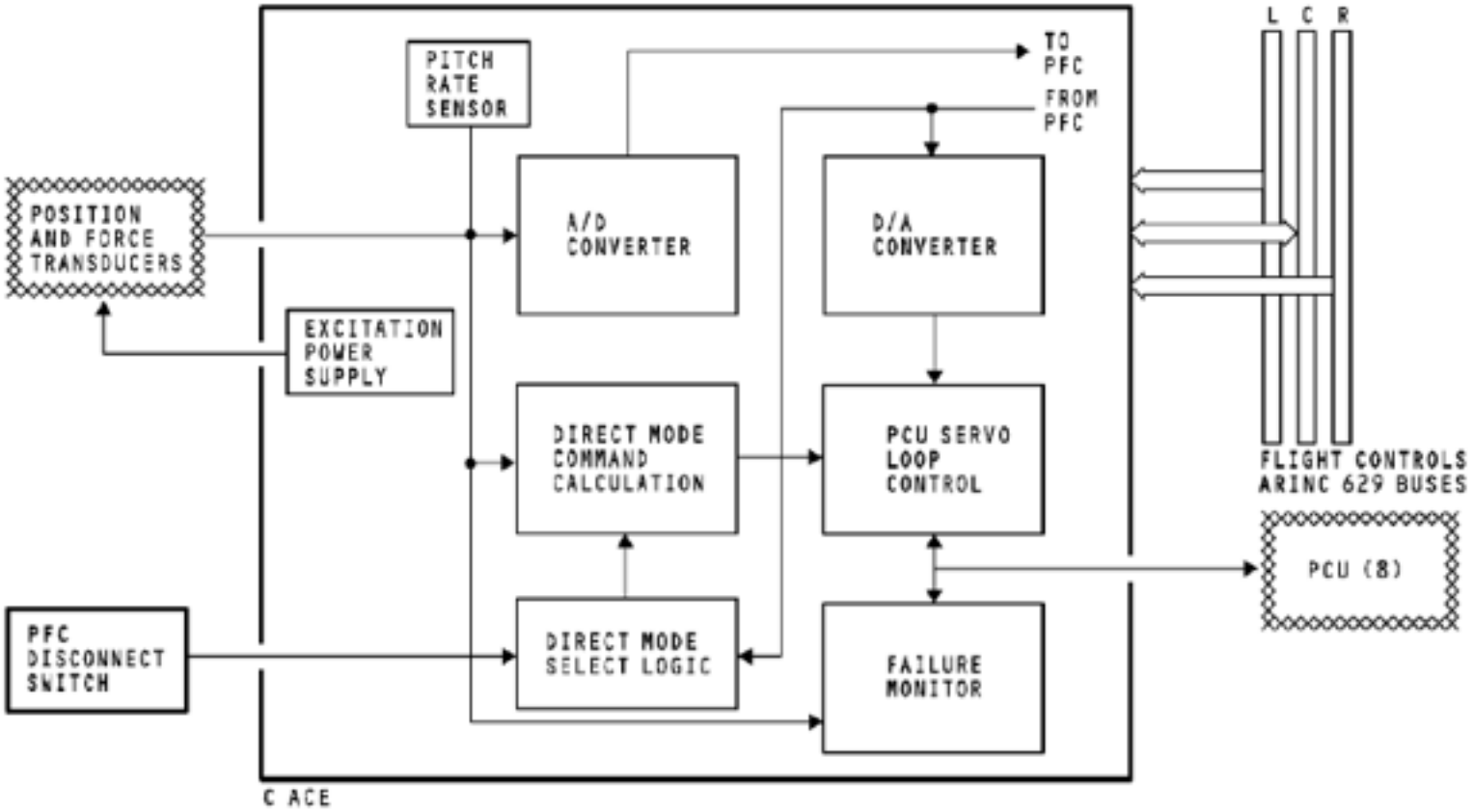


Actuator Control Electronics (ACE)

The primary functions of the ACE are:
- A/D converter
- D/A converter
- Direct mode select logic
- Direct mode command calculation
- PCU servo loop control
- Excitation power supply.

First generation Fly by Wire systems

- B777 computers
- Flight Control Computers overview



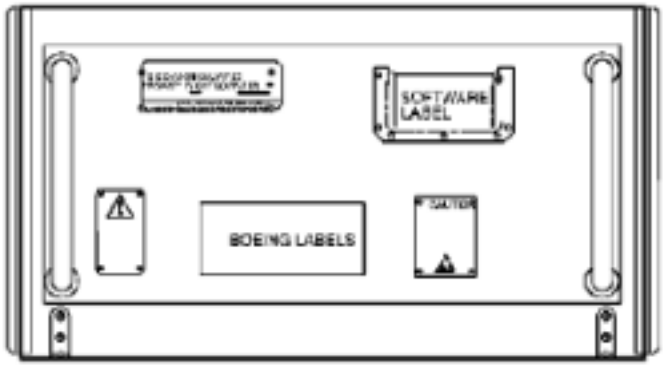
First generation Fly by Wire systems

- Flight Control Computers overview

  - B777 computers

The primary flight computers (PFC)

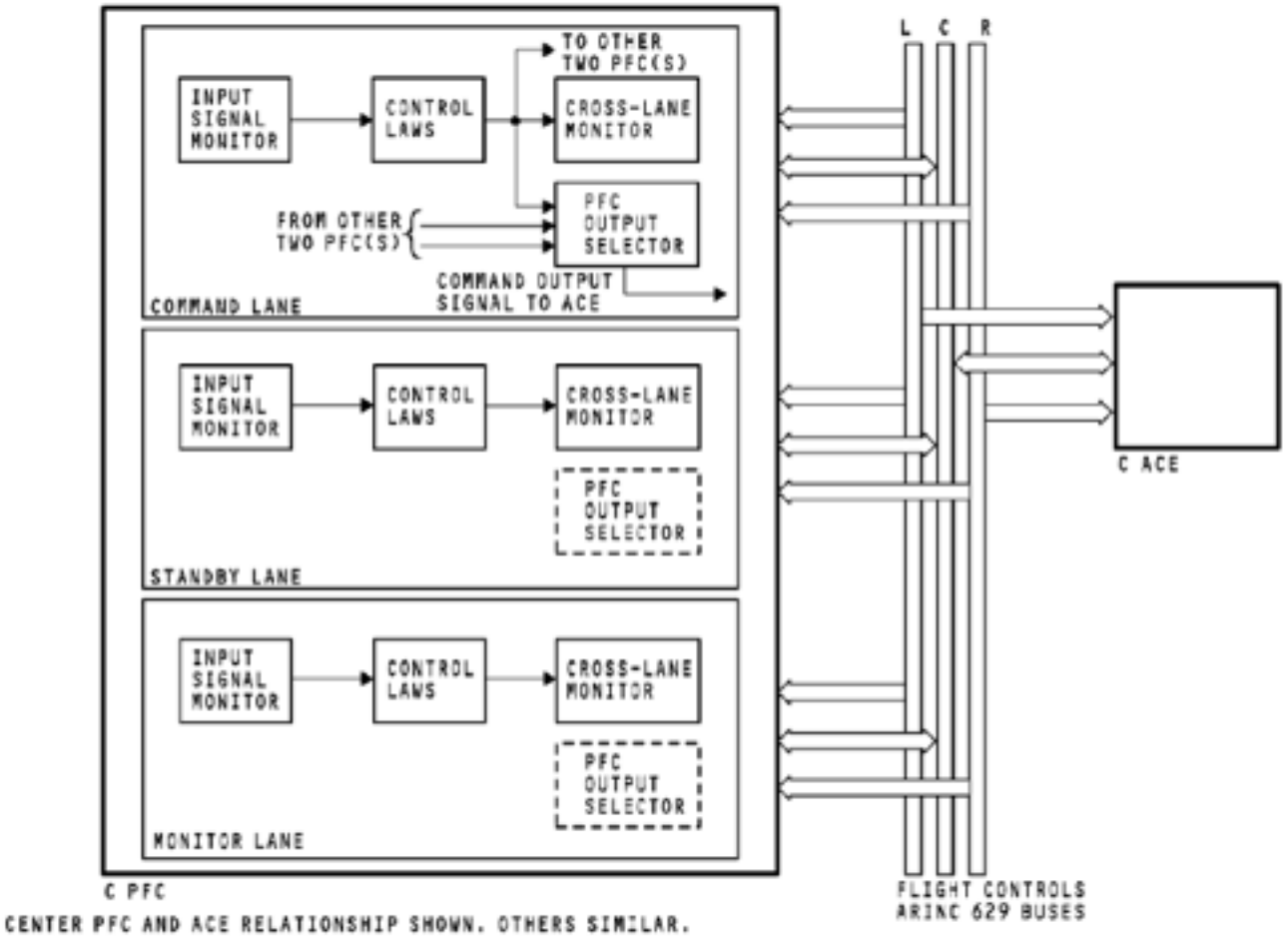
* Calculate control surface commands using pilot and autopilot inputs
•Calculate commands for variable elevator feel
•and backdrive actuators
* Supply stability augmentation
* Supply flight envelope protection
* Send signals for flight deck annunciations
* Send signals for maintenance messages.



First generation Fly by Wire systems

Flight Control Computers overview

- B777 computers

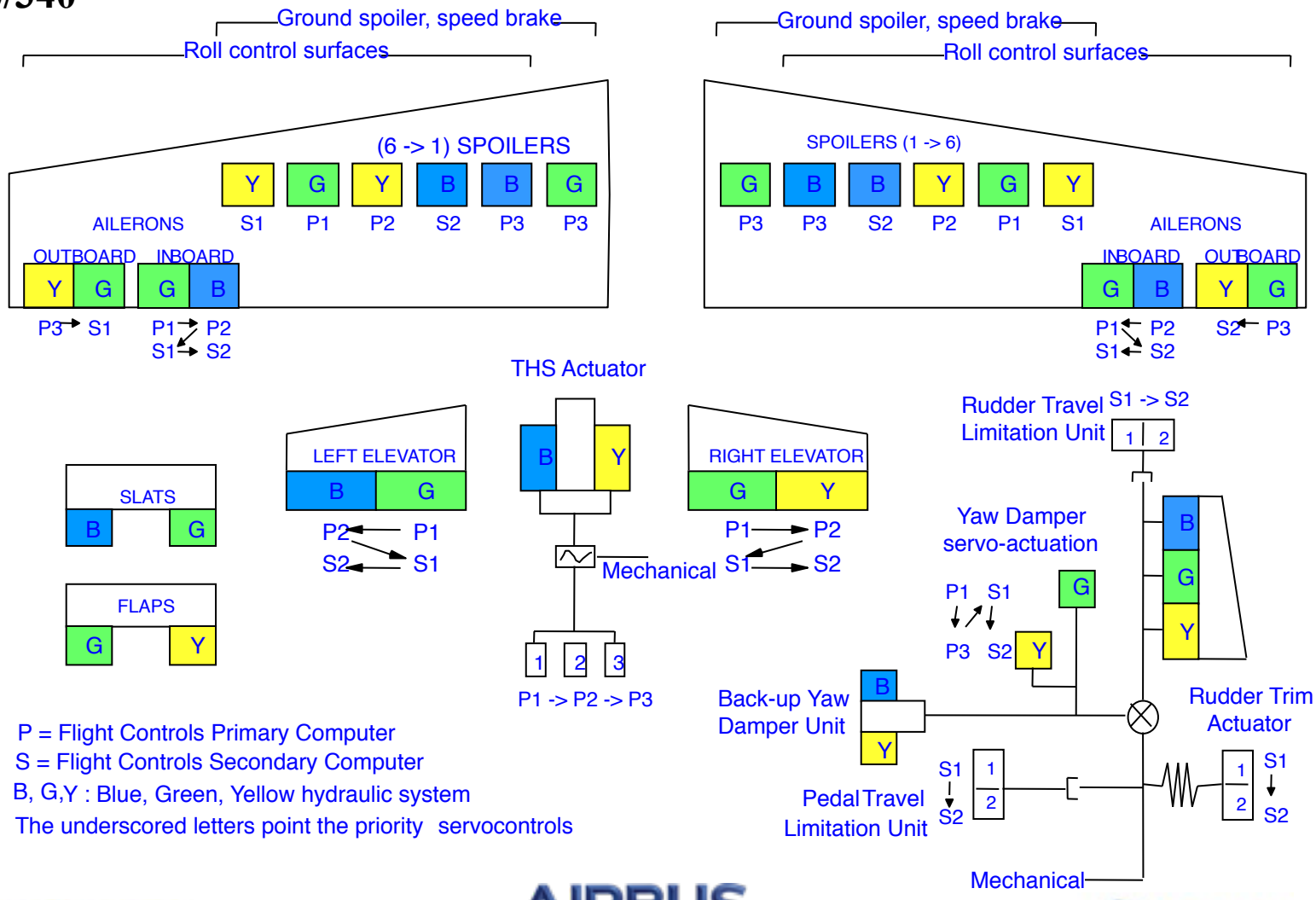


Primary Flight Computers (PFC)

- Annex 2
- Fly by wire equipment

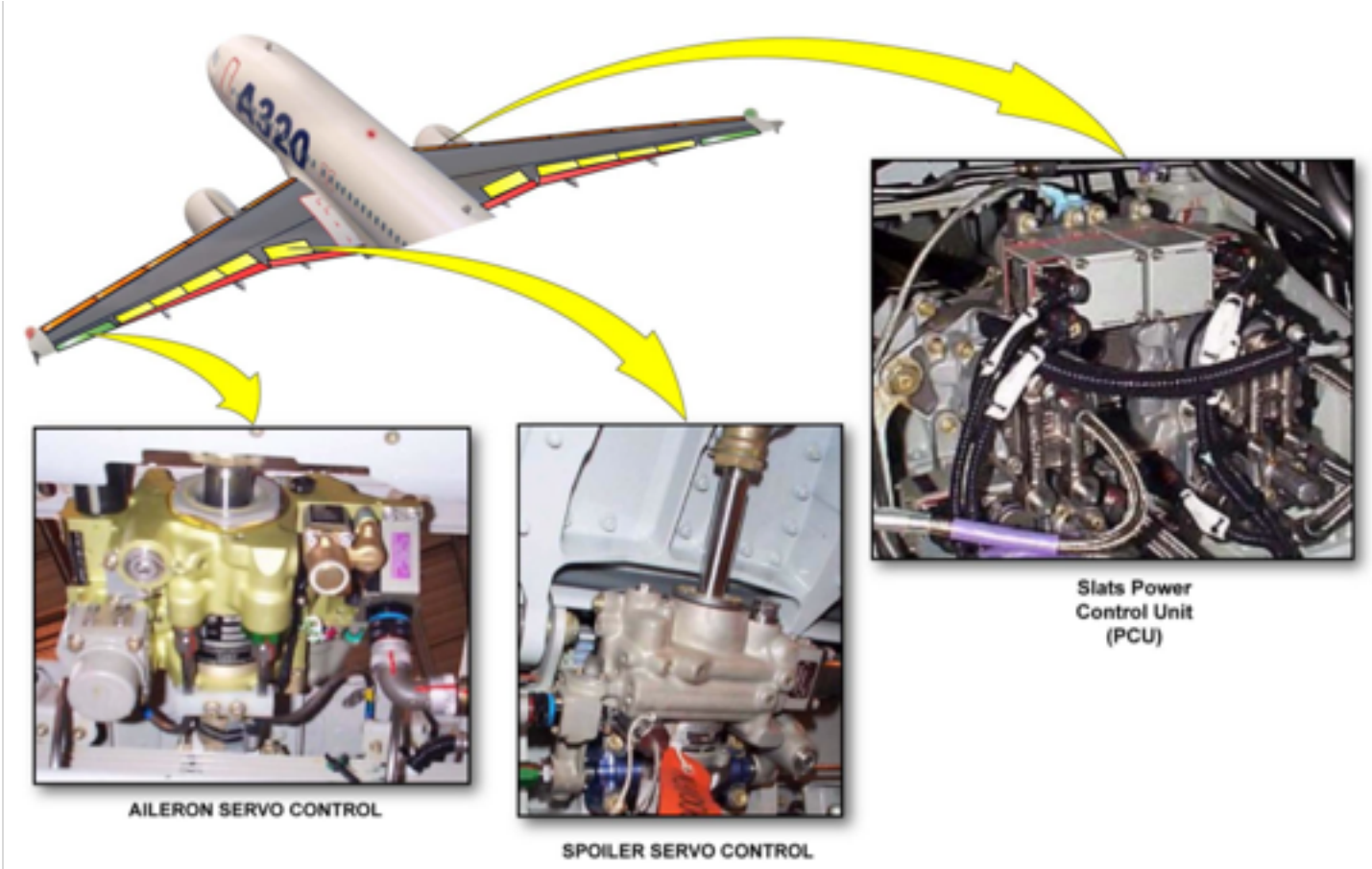
First generation Fly by Wire systems

A330/340

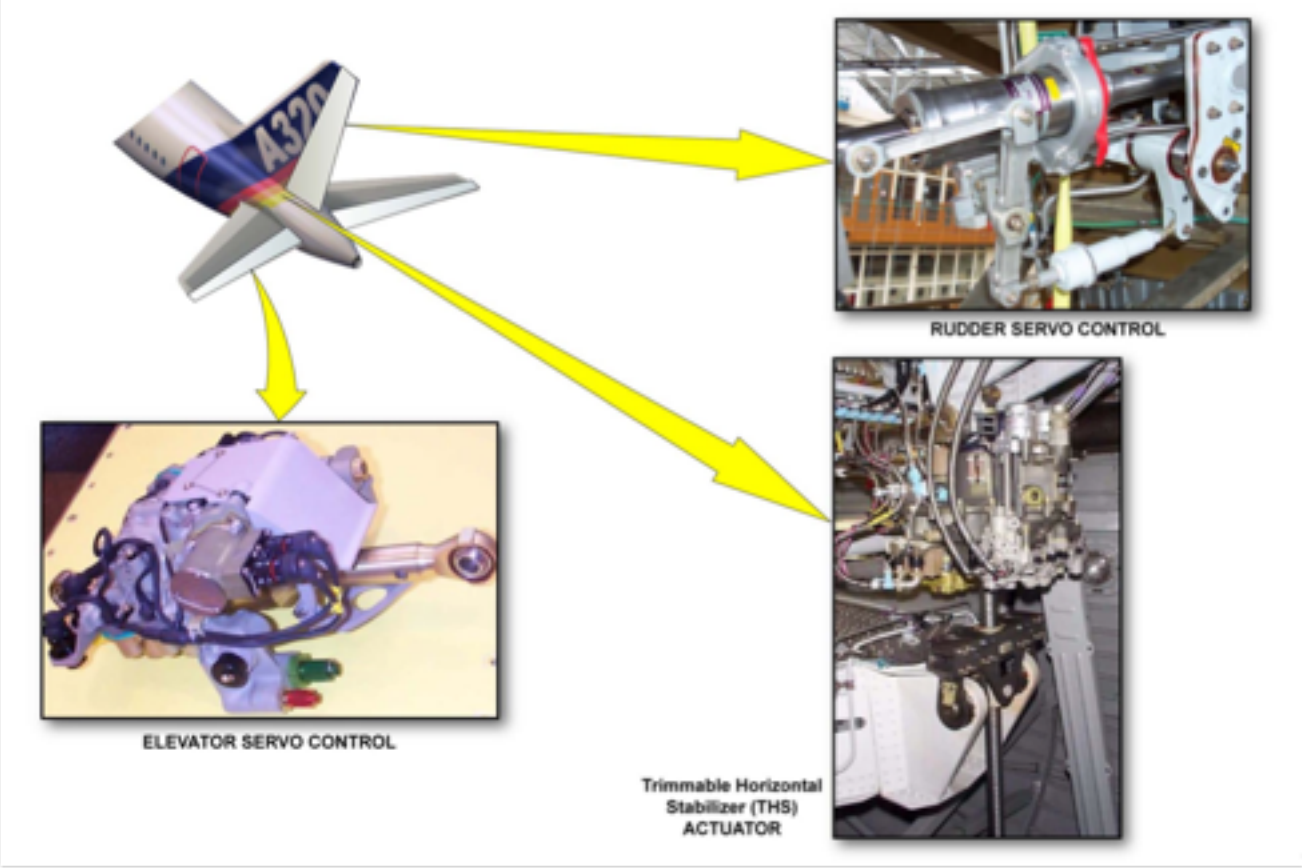


P = Flight Controls Primary Computer
S = Flight Controls Secondary Computer
B, G,Y : Blue, Green, Yellow hydraulic system
The underscored letters point the priority servocontrols

Fly by wire equipment, other


A320
Slats Power Control Unit (PCU)
AILERON SERVO CONTROL
SPOILER SERVO CONTROL

ACTUATORS


A320
RUDDER SERVO CONTROL
ELEVATOR SERVO CONTROL
Trimmable Horizontal Stabilizer (THS) ACTUATOR

ACTUATORS

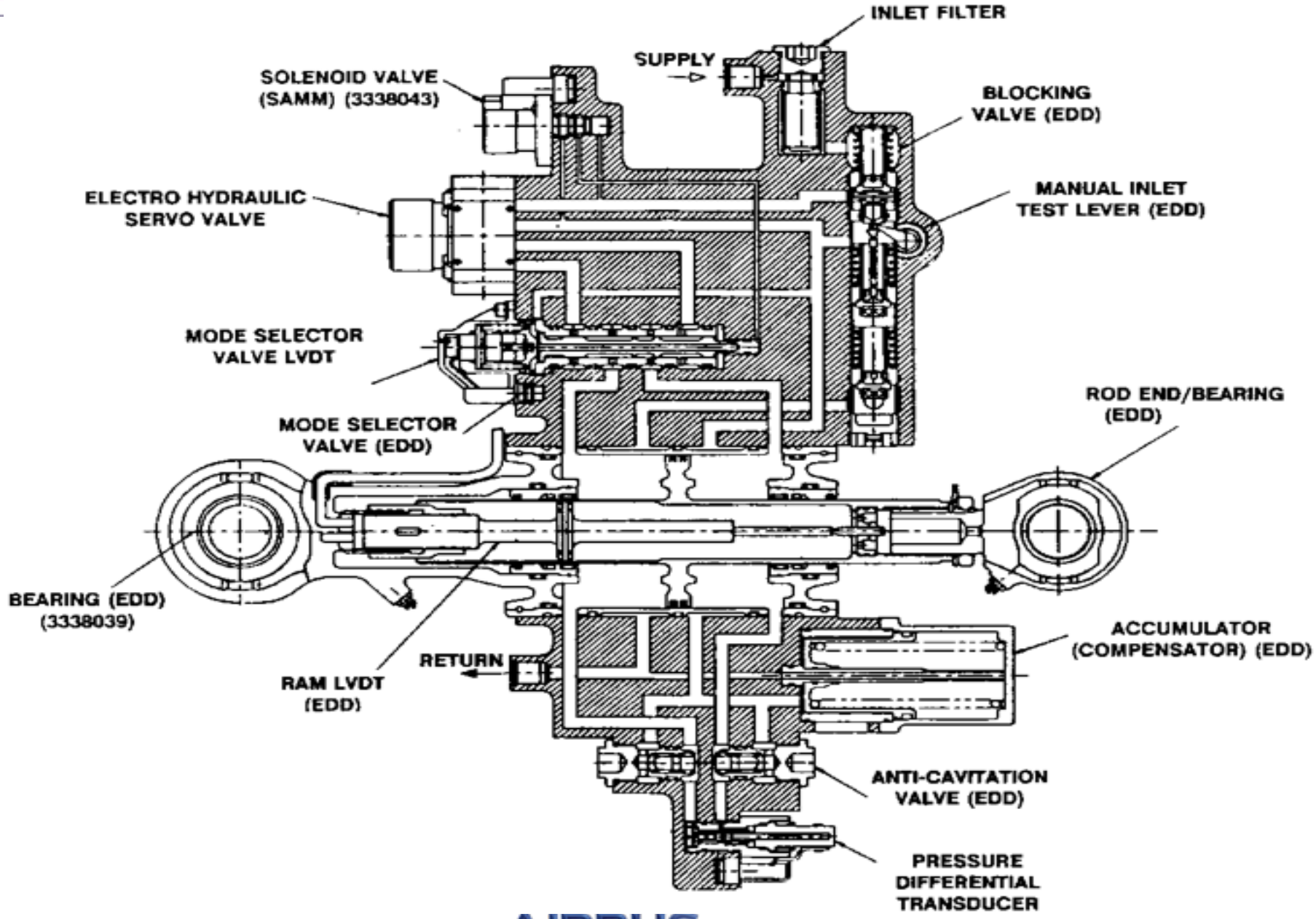
Specific issues with Actuators

The spharical bearing problem

Issues

A320 elevator actuator

Grease free Teflon bearings are not resistant enough to withstand the harsh enviroment Will be replaesce by roler bearings


INLET FILTER
SUPPLY
SOLENOID VALVE (SAMM) (3338043)
BLOCKING VALVE (EDD)
ELECTRO HYDRAULIC SERVO VALVE
MANUAL INLET TEST LEVER (EDD)
MODE SELECTOR VALVE LVDT
MODE SELECTOR VALVE (EDD)
ROD END/BEARING (EDD)
BEARING (EDD) (3338039)
RETURN
RAM LVDT (EDD)
ACCUMULATOR (COMPENSATOR) (EDD)
ANTI-CAVITATION VALVE (EDD)
PRESSURE DIFFERENTIAL TRANSDUCER

Flight control

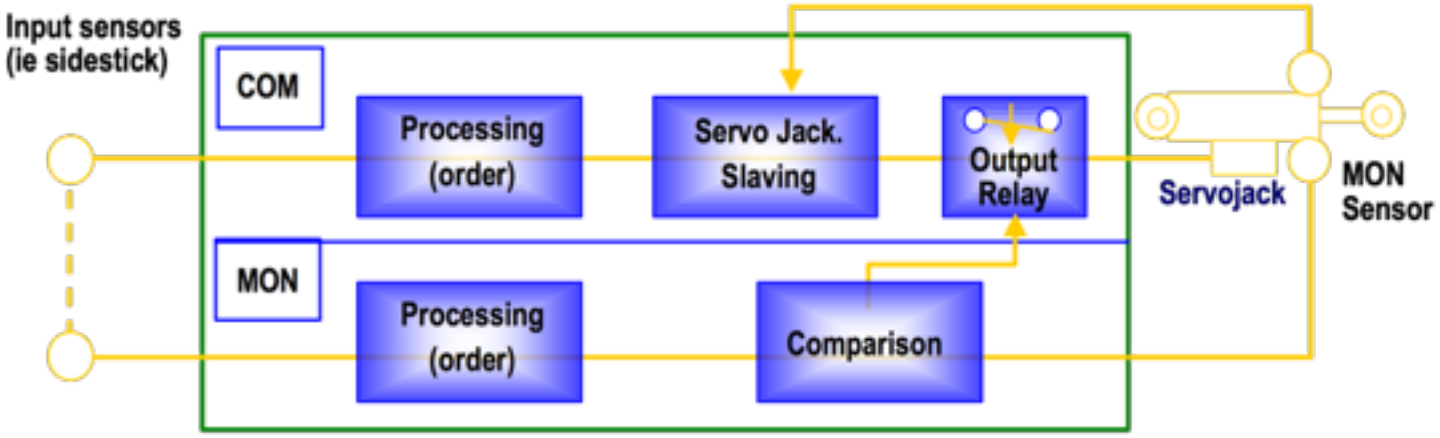
- Max requirements concerning pilot actions (from ICAO)
  - ➢ roll 22.5 daN *diameter of wheel in m
  - ➢ yaw 90 daN
  - ➢ pitch 135 daN
- Example:
  - ➢ A340 aileron actuator provides more than 160 kN force.
  - ➢ A380 rudder actuator force will be >300 kN

First generation Fly by Wire systems

- Flight Control Computers overview

  - Airbus computers
    - Flight control digital computers achieve
      - control law computation, which include flight envelope protection
      - actuator closed loop control
      - Associated monitoring and reconfiguration functions

- Flight Control Computers overview
  - Airbus computers
  - Flight control computers feature a COM/MON arrangement



- Any single failure leading to a COM/MON disagreement greater than a threshold (confirmed tbd seconds) is passivated
- After a single failure, the function is lost
  - with one COM/MON computer ➔ fail passive architecture
  - With two COM/MON computers and automatic switchover ➔ fail operative architecture(DUAL/DUAL configuration)

First generation Fly by Wire systems

- Flight Control Computers overview

  - Airbus computers
  - Flight control computers are dissimilar to overcome common mode failure or generic error in software
  - Two COM/MON computers are the minimum to provide a fail operative architecture
  - If dispatch with one computer failed is desired, then three COM/MON computers, or two triplex assemblies (3 triplex lanes is one computer) are needed
  - The actual number of computers is also the result of the architecture for actuators power loops computation :

    ✓ SA family : 2 ELAC, 3 SEC
    ✓ LR family : 3 PRIM, 2 SEC

Fly by wire first generation

- End of session
- Thank you
- Any question?