GENERAL PRESENTATION OF AIRBUS FLIGHT CONTROLS

IYCCC

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AIRBUS

Agenda

- INTRODUCTION
- DESCRIPTION OF FLIGHT CONTROL SYSTEMS
  - THE MEMBERS: CONTROL SURFACES TO BE MOVED
  - THE MUSCLES: ACTUATORS
  - THE BLOOD: POWER SOURCES
  - THE SENSES: FLIGHT CONTROL COMPONENTS
  - THE BRAIN: COMPUTERS WHICH CONTROL
- AIRBUS FAMILY RANGE
- FLIGHT CONTROL ARCHITECTURE
  - ARCHITECTURE: A SYNOPTIC VIEW
  - PROBLEM OF AN FBW ARCHITECTURE
  - PROBABILITY against CLASSIFICATION (1309)
  - SPECIFIC RISKS
  - FLIGHT CONTROL INSTALLATION/SEGREGATION

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INTRODUCTION

- ROLE OF THE FLIGHT CONTROL SYSTEM

To ensure the link between the flight control components and the control surfaces of the aircraft with the following aims:

– Improve controllability thanks to the use of automatic controls lightening the pilot's workload (protections, laws with integrator, etc.)

– Improve performance by optimising the response of the aircraft

– Robustness to failures and automatic reconfigurations

– Optimisation to reduce weight (detection of failures which degrade the structures, etc.)

– Reduction in costs and development cycles

– But especially never compromise:

SAFETY!

Safety first is the first of the three points which describe the department's mission

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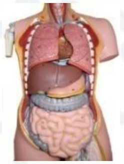
  - THE SENSES: FLIGHT CONTROL COMPONENTS
  - THE BRAIN: COMPUTERS WHICH CONTROL



- AIRBUS FAMILY RANGE
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  - ARCHITECTURE: A SYNOPTIC VIEW
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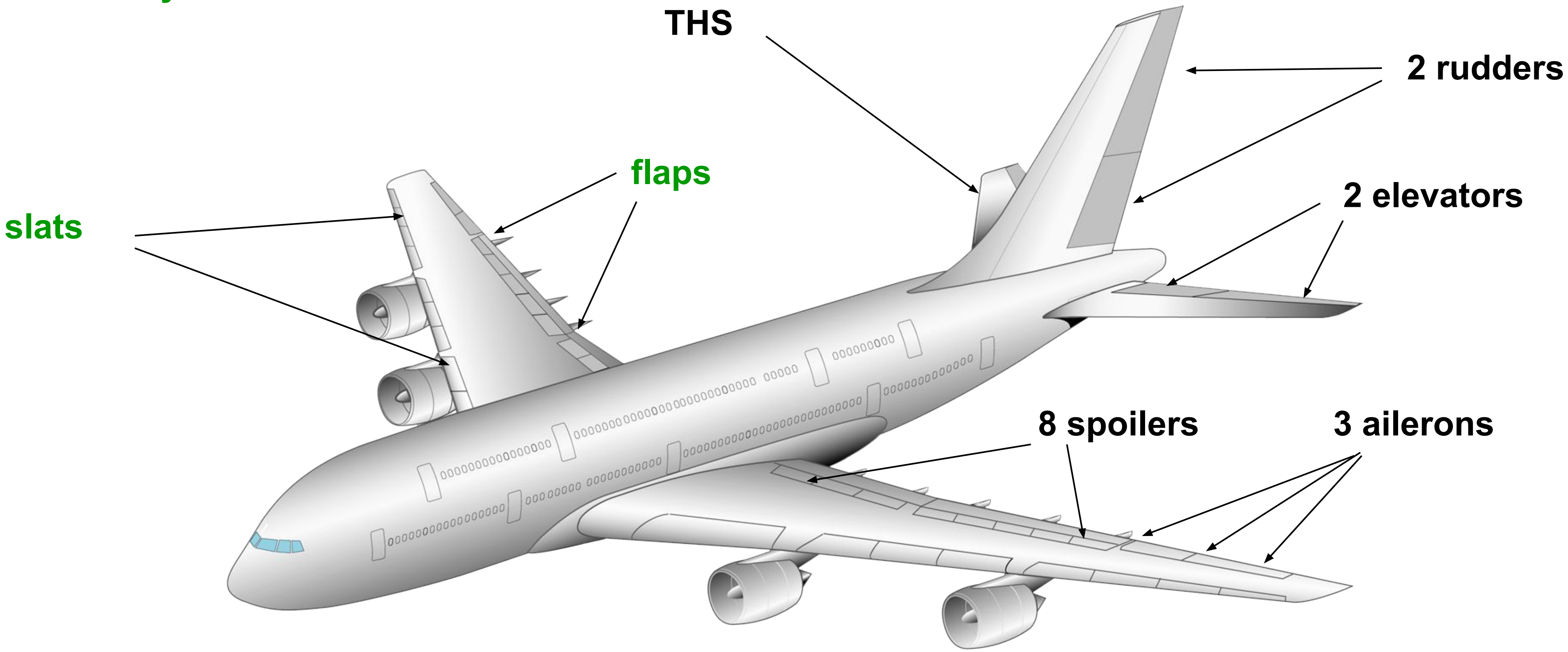
THE MEMBERS: CONTROL SURFACES TO BE MOVED

primary
secondary



A380 as an example. Number of surfances depend on aircraft design.

THE MEMBERS: CONTROL SURFACES TO BE MOVED

- WING EDGE CONTROL SURFACES

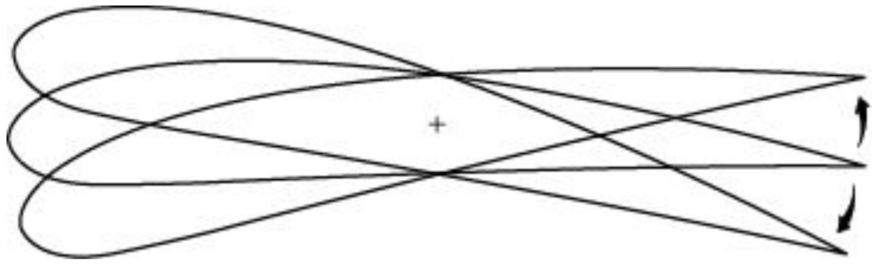
➔ Principle:
- Profile camber modification
- Local lift modification
- Linear behaviour at low deflections
- Little drag at low deflections

➔ Control surfaces:
- Elevators
- Ailerons
- Rudder

➔ Precautions:
- At zero hinge moment, free control surface capable of generating flutter

THE MEMBERS: CONTROL SURFACES TO BE MOVED

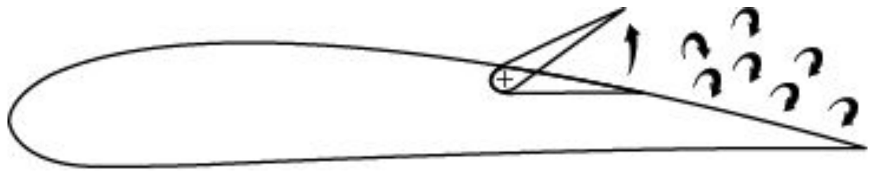
•FULLY MOBILE CONTROL SURFACES



- ➔ Principle:
  - – Modification of angle of attack airfoil
  - – Complete modification of lift
- ➔ Examples:
  - – THS
  - – "canard"
- ➔ Precaution:
  - – The positioning of the centre of lift and the point of rotation is a tricky subject (drag/manoeuvrability optimisation)
  - – Caution in case of free rotation, considerable effects on aircraft

THE MEMBERS: CONTROL SURFACES TO BE MOVED

- CONTROL SURFACES ON WING

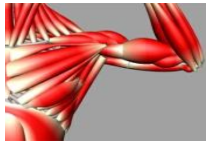


➔ Principle:
  - Delaminates the flow and generates local turbulent flows where lift is normally created
  - Locally destroys the lift
  - Significantly increases the drag
  - Nonlinear

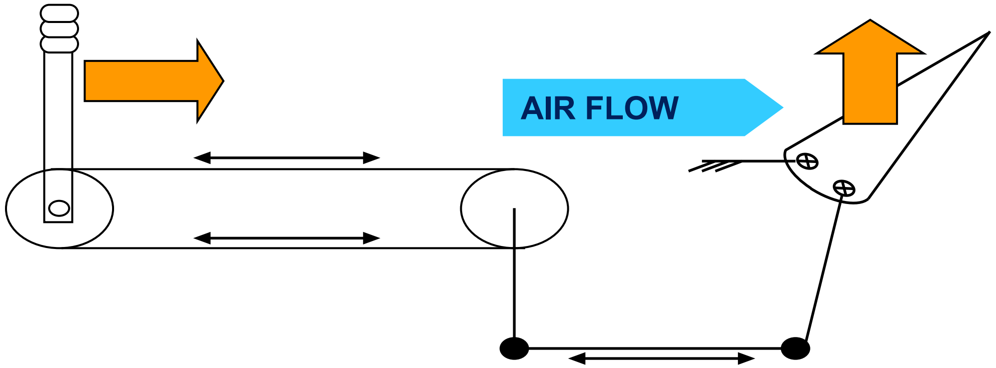
➔ Example:
  - Ground Spoilers, speed brakes (symmetrical) and roll (antisymmetrical)

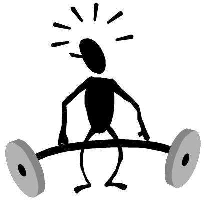
➔ Precaution:
  - Substantial loss in the efficiency of the spoilers if flaps are extended.

THE MUSCLES: ACTUATORS

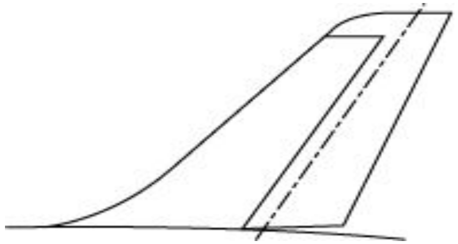


- MECHANICAL SYSTEM
  - Direct link between the pilot control and the surface. All the effort required to move the surface is provided by the pilot.

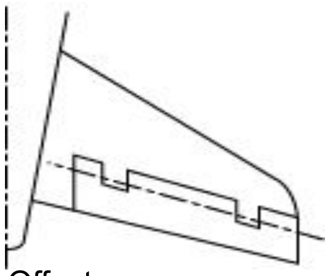




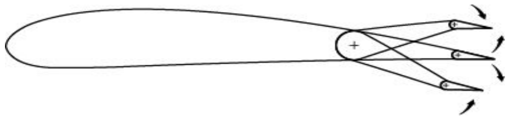
A few means to relief the pain …



Compensation
Aera (horn)



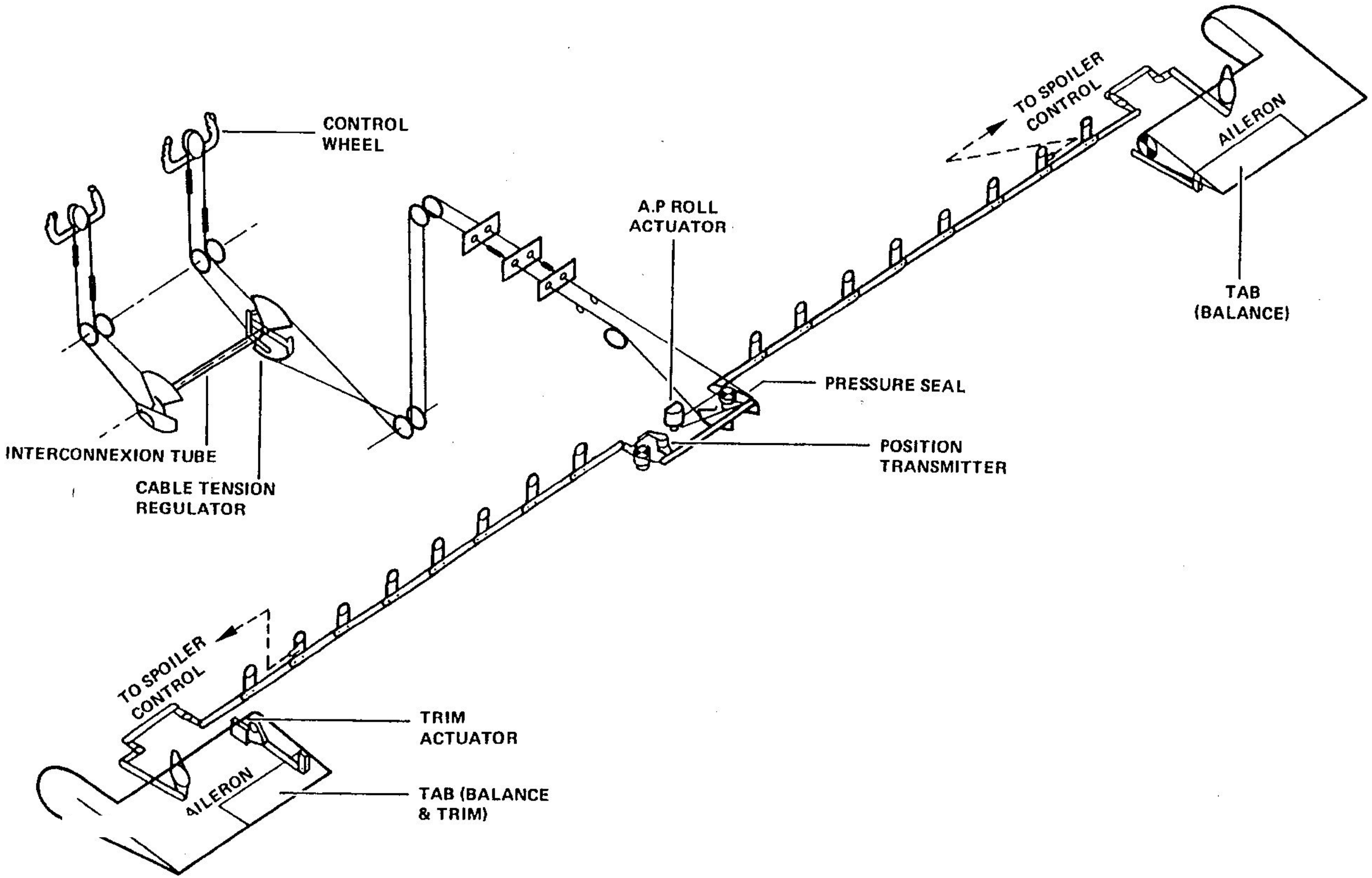
Offset
Hinge line



Tabs

THE MUSCLES: ACTUATORS

- MECHANICAL SYSTEM
  - Example: ATR roll axis



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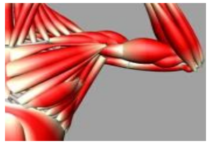
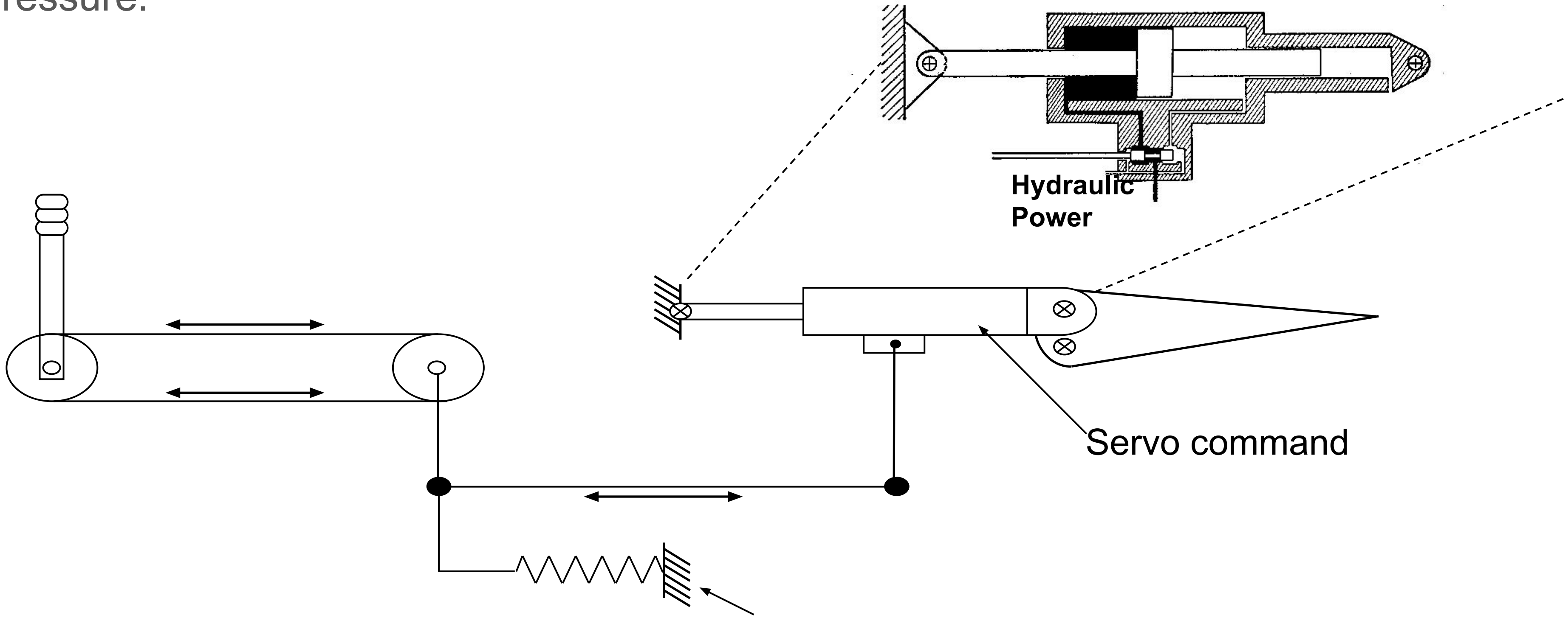
THE MUSCLES: ACTUATORS



- HYDROMECHANICAL SYSTEM
  - Pilot control is mechanically linked to a servo command. The effort required to move the surface is provided by hydraulic pressure.



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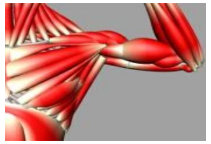
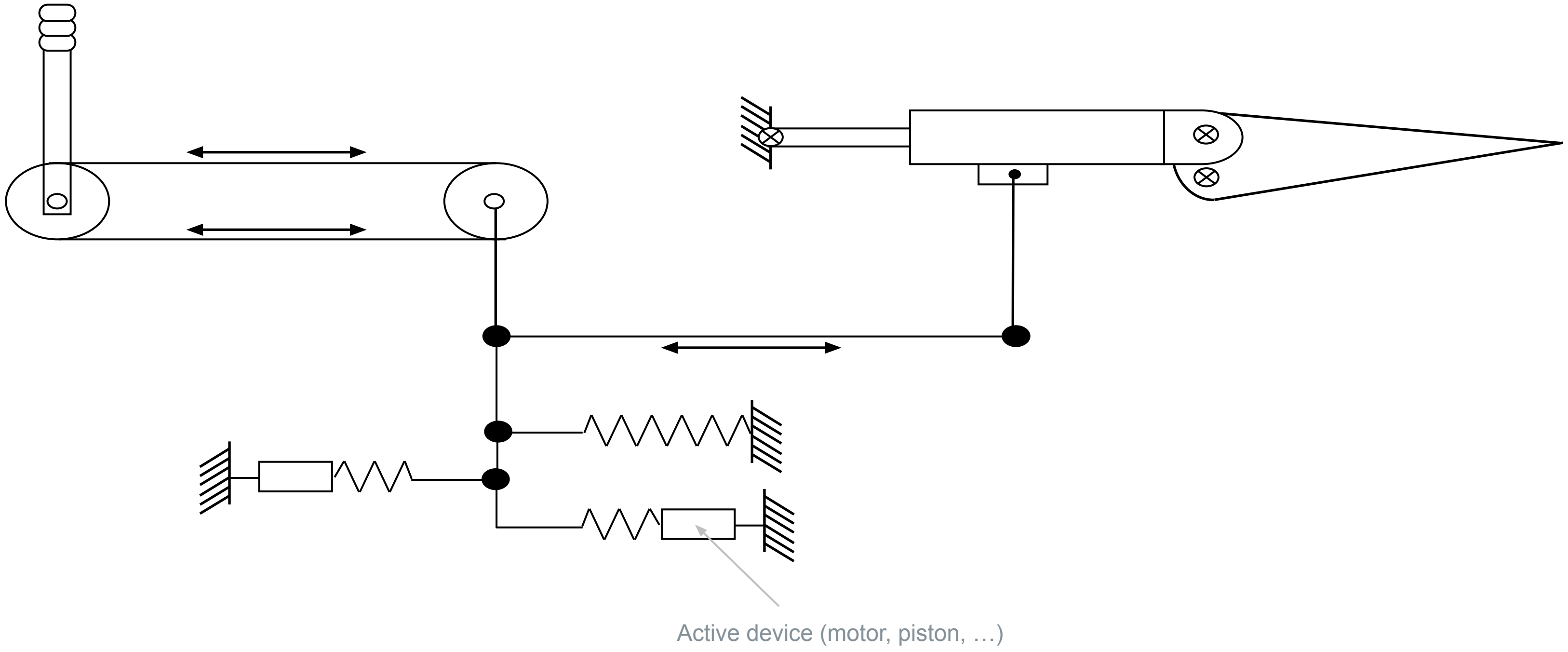
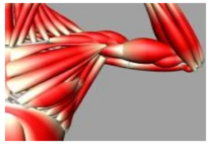
THE MUSCLES: ACTUATORS



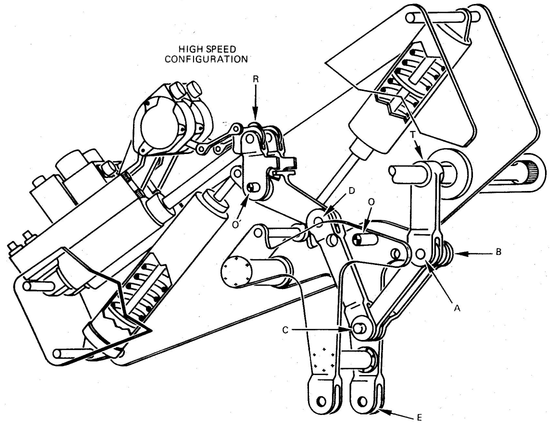
- HYDROMECHANICAL SYSTEM
  - It is possible to move surfaces (and corresponding pilot control), using automatism
    - Auto pilot
    - Artificial stability



THE MUSCLES: ACTUATORS



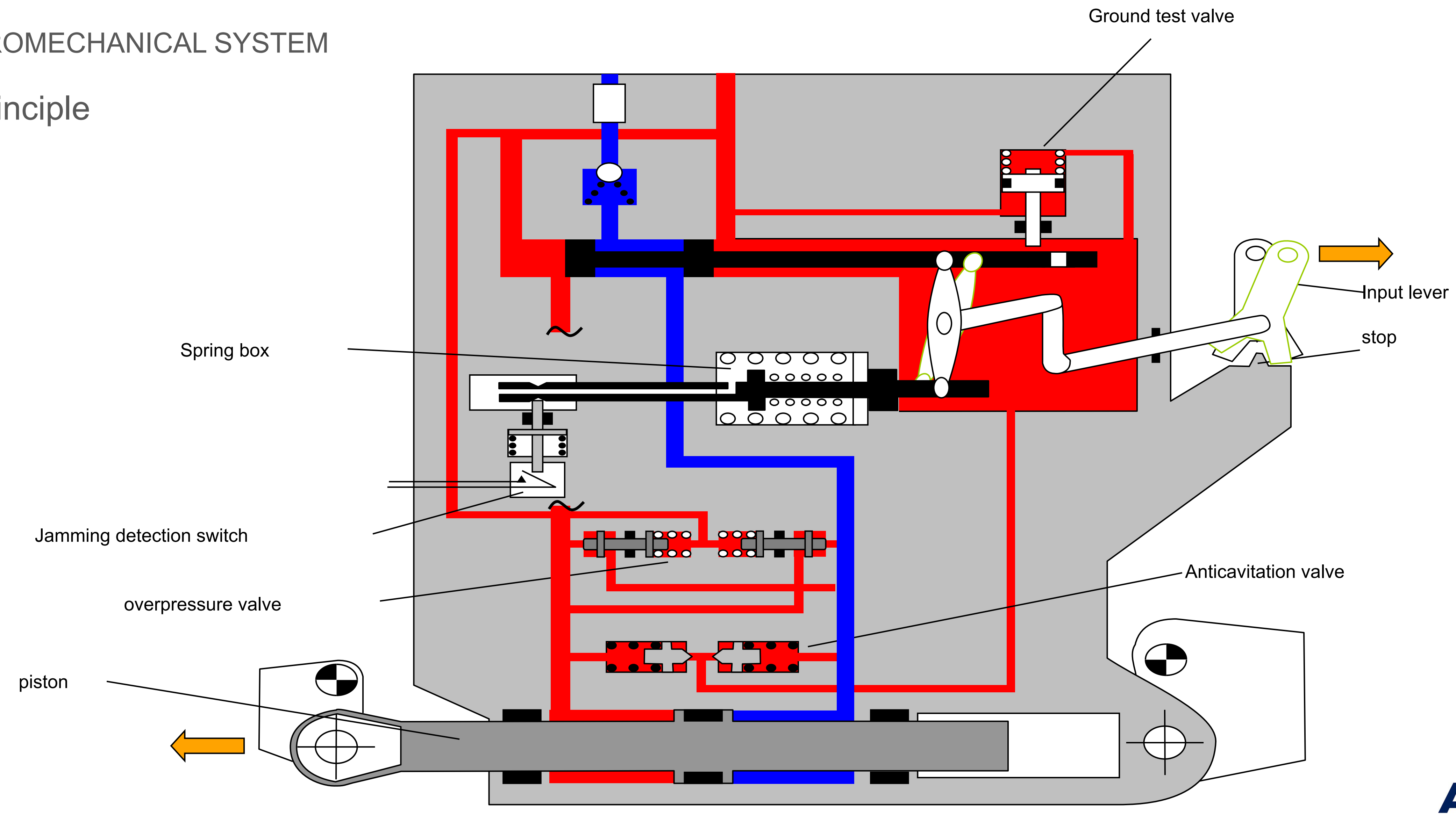
- HYDROMECHANICAL SYSTEM
  - The only forces felt by the pilot are the friction forces
    - feedback for the pilot not sufficient
    - need for artificial feel
    - the forces (stiffness or damping) on the flight control components are essential elements in the general harmony perceived by the pilot
  - The aerodynamic forces no longer reach the pilot, the following must be used
    - mechanical limitation devices to avoid breaking the control surfaces at high speeds
    - variable forces in the flight control components
    - variable kinematics (relations between the movement of the flight control component and the movement of the control surface
    - variable stops



Roll on fly-by-wire controls …

THE MUSCLES: ACTUATORS

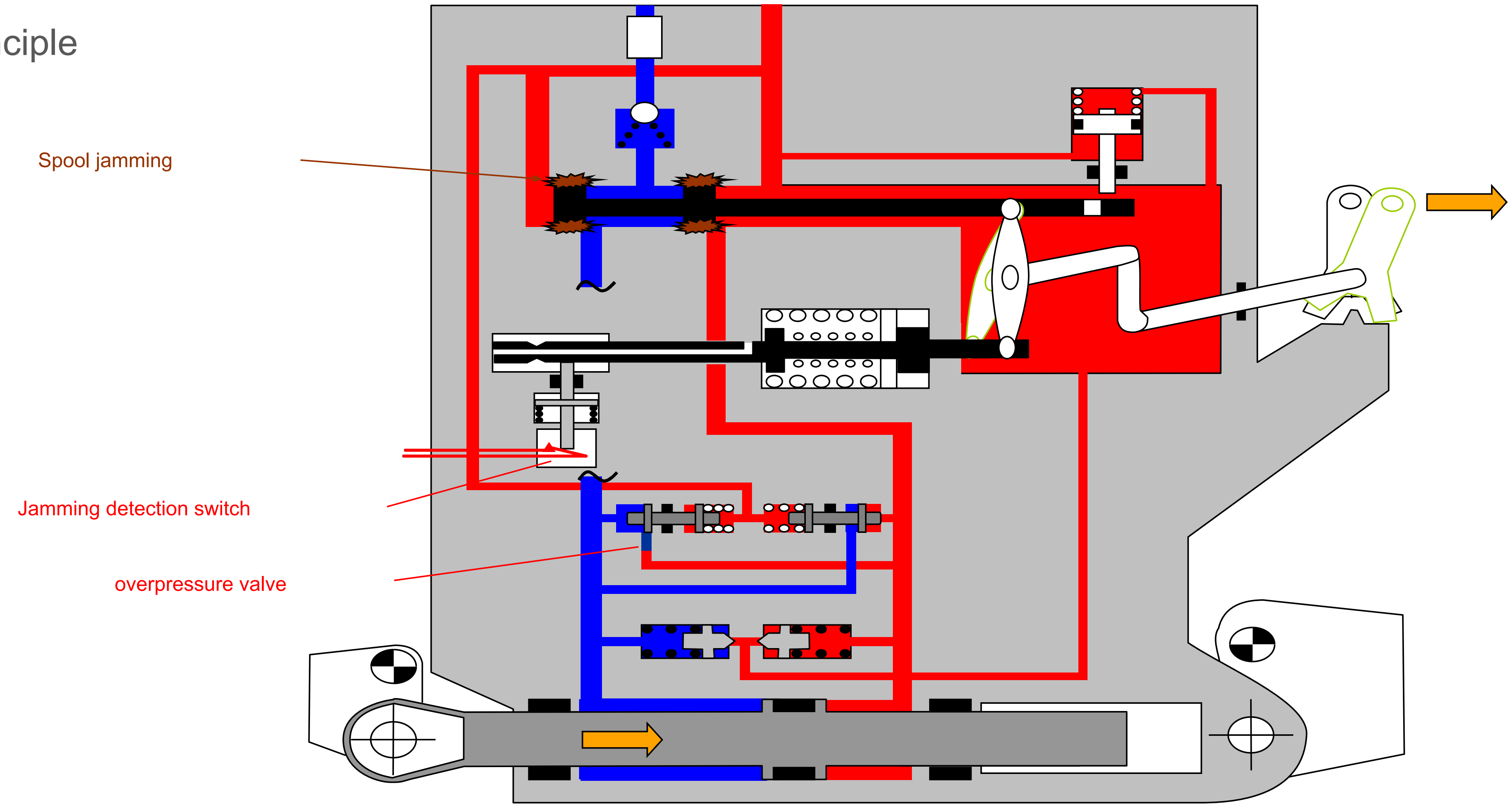
- HYDROMECHANICAL SYSTEM
  - principle



THE MUSCLES: ACTUATORS

jamming

- HYDROMECHANICAL SYSTEM
  - principle



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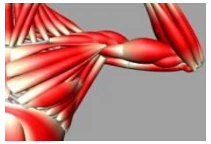
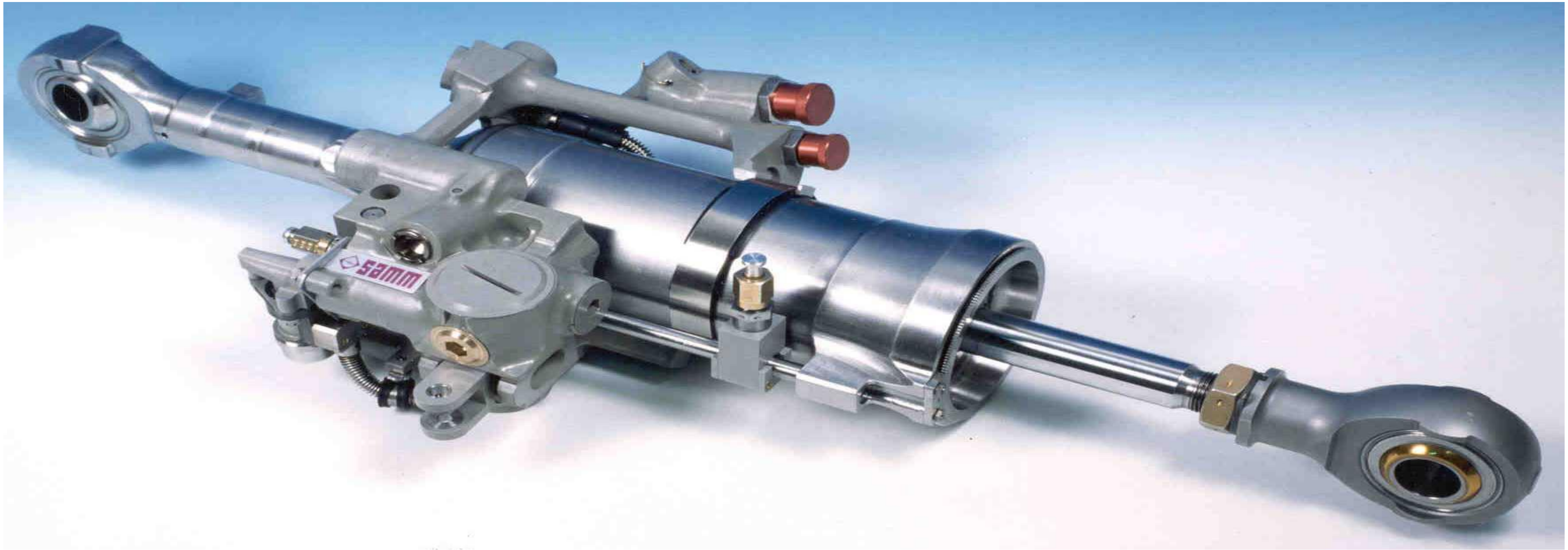
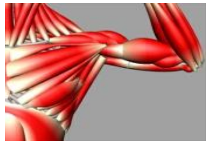


- HYDROMECHANICAL SYSTEM

  Example: rudder servocontrol A330/A340

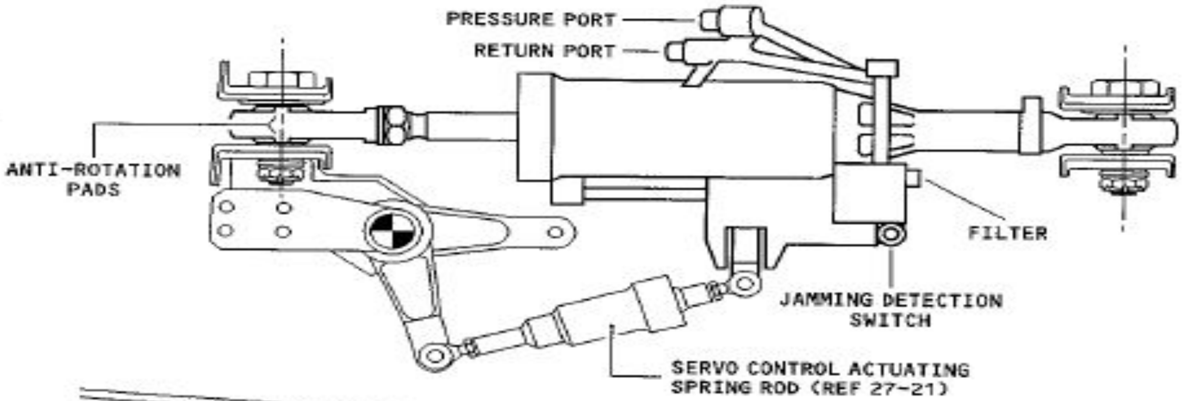


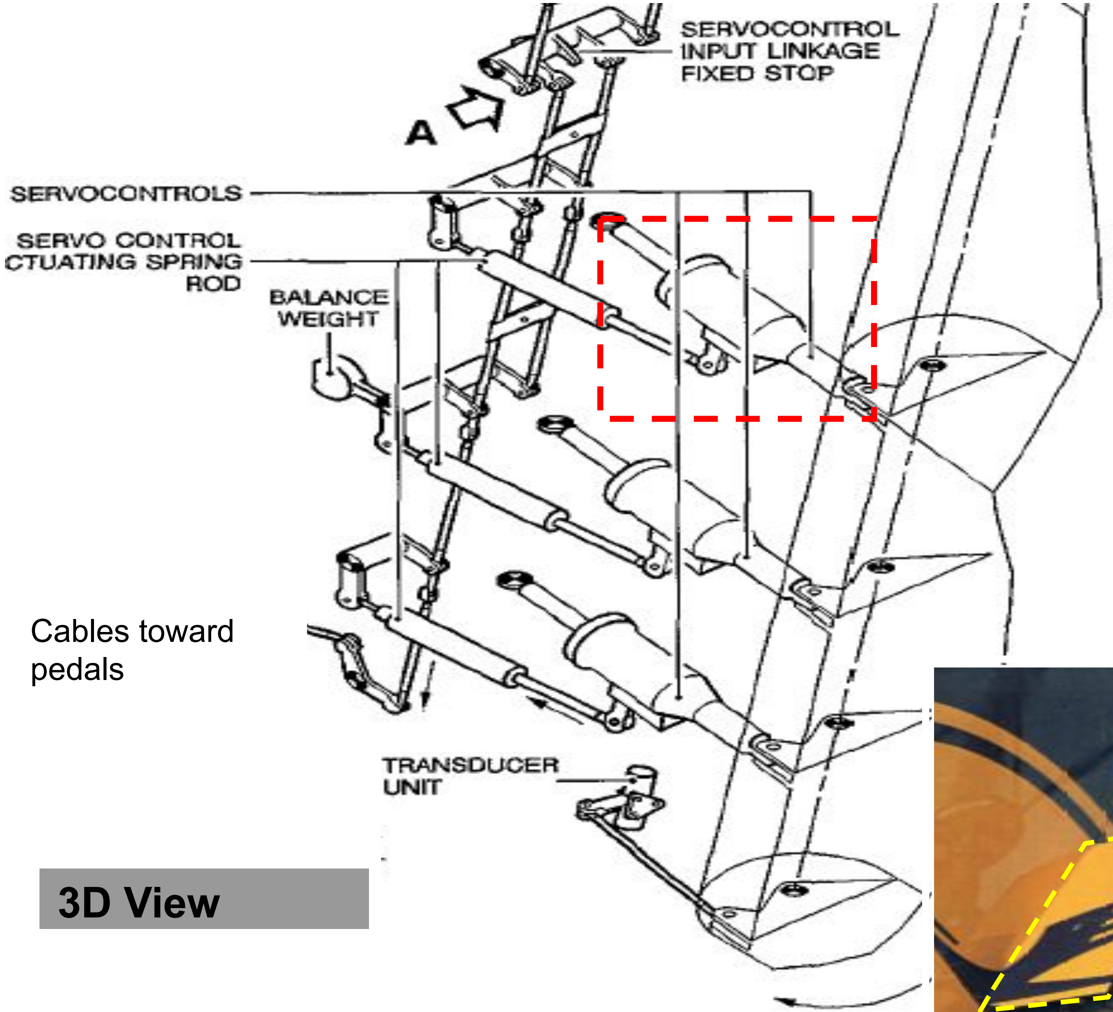


THE MUSCLES: ACTUATORS

- HYDROMECHANICAL SYSTEM

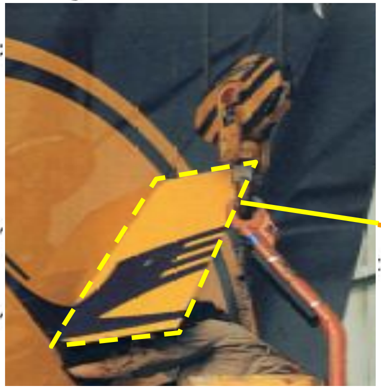
Side Vue



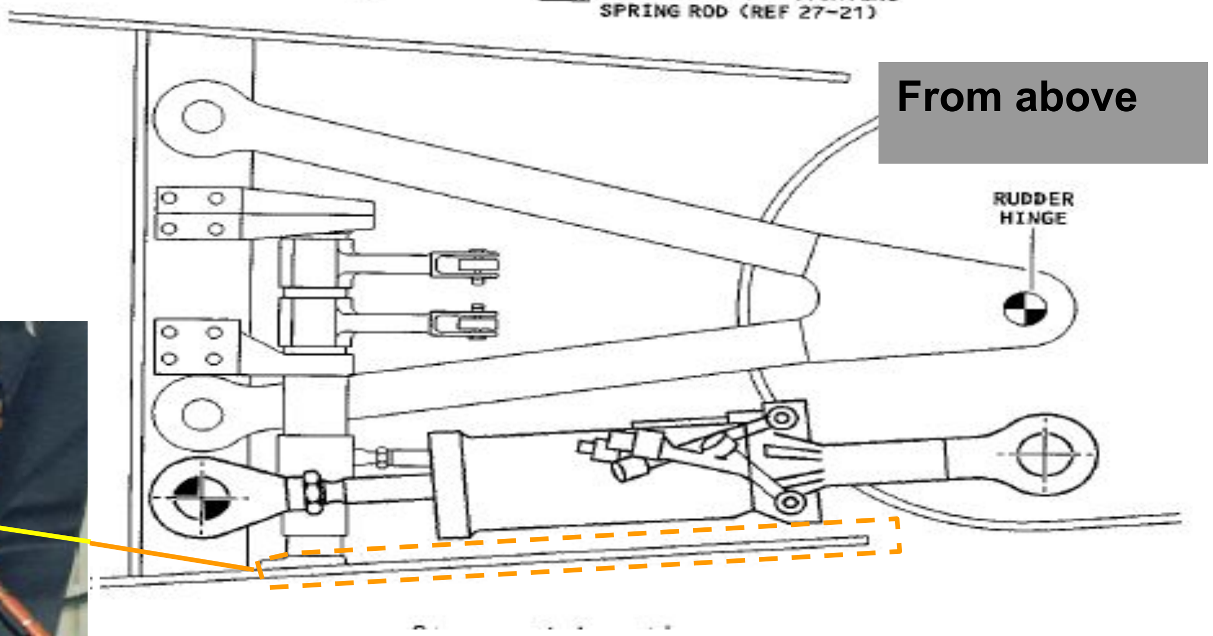


Cables toward pedals

3D View



From above



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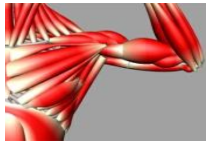

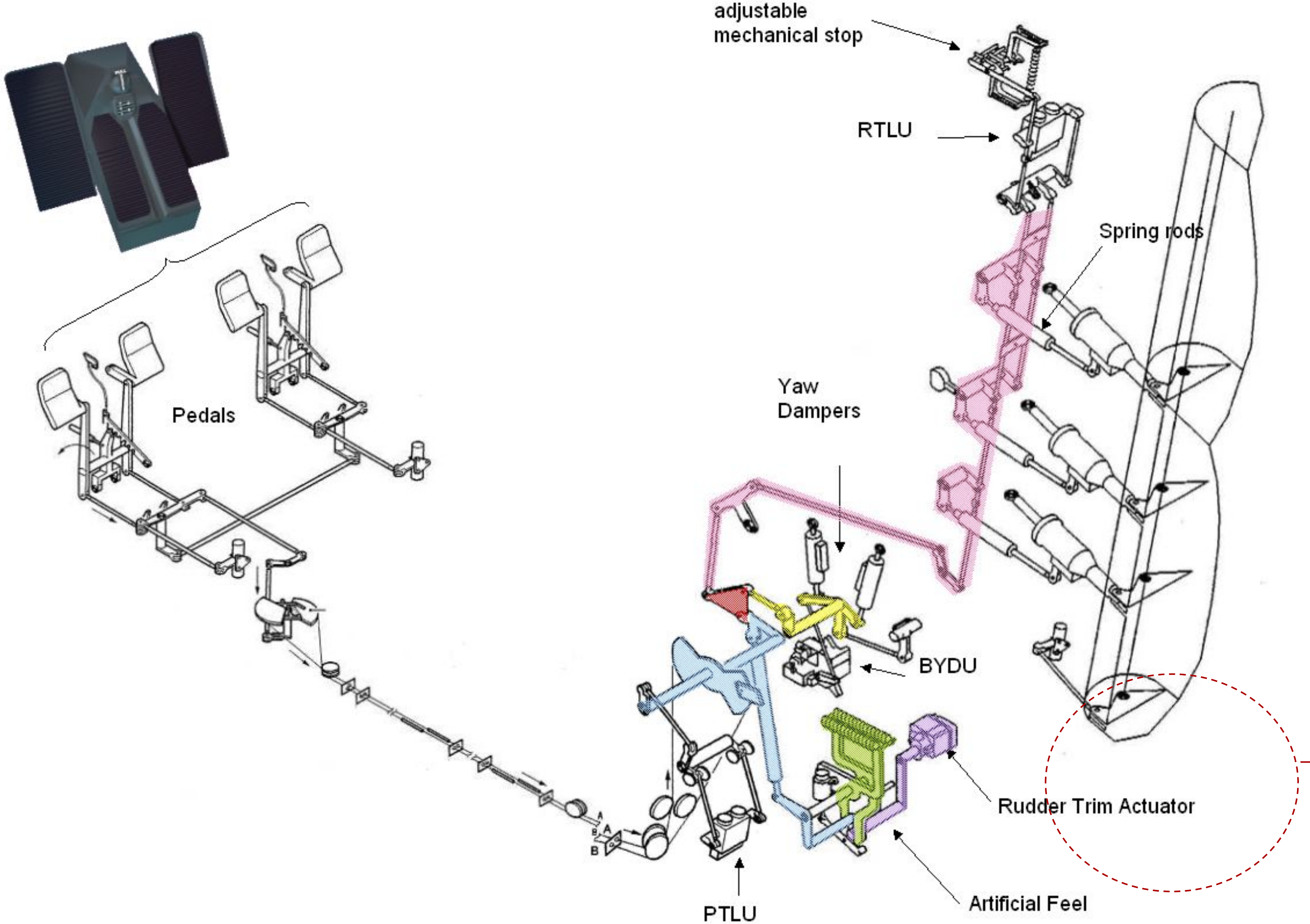

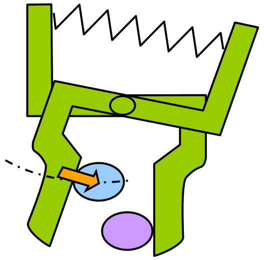

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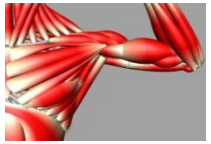
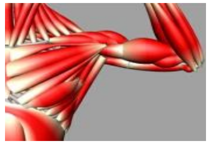


- HYDROMECHANICAL SYSTEM

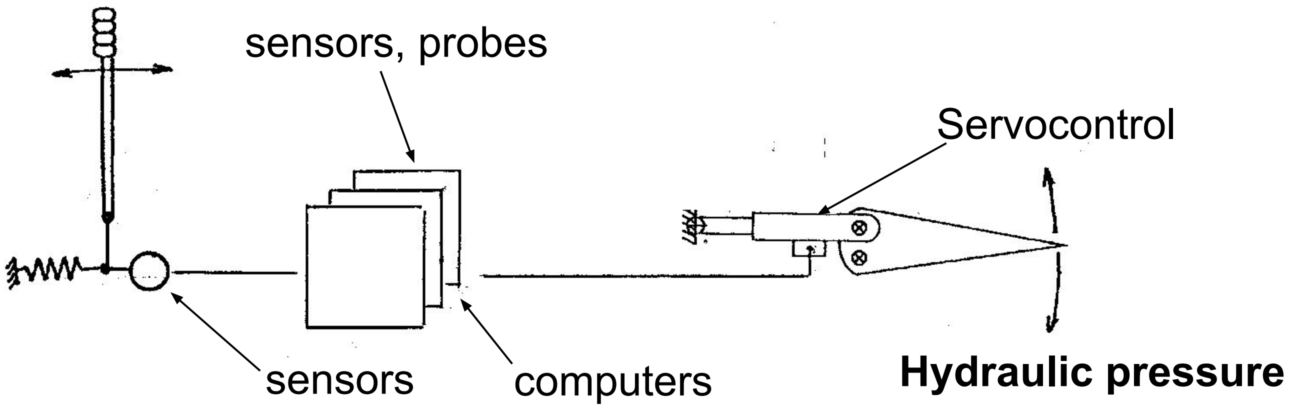
Critical points:

- Blocking of valve
  - Detection sensor
  - Overpressure valve
  - Return spring
- Force fighting
  - Break of attachment
  - Adjustment problem
  - Spring rods which break
  - Synchronisation check
- Incorrect flight control loop gain

THE MUSCLES: ACTUATORS



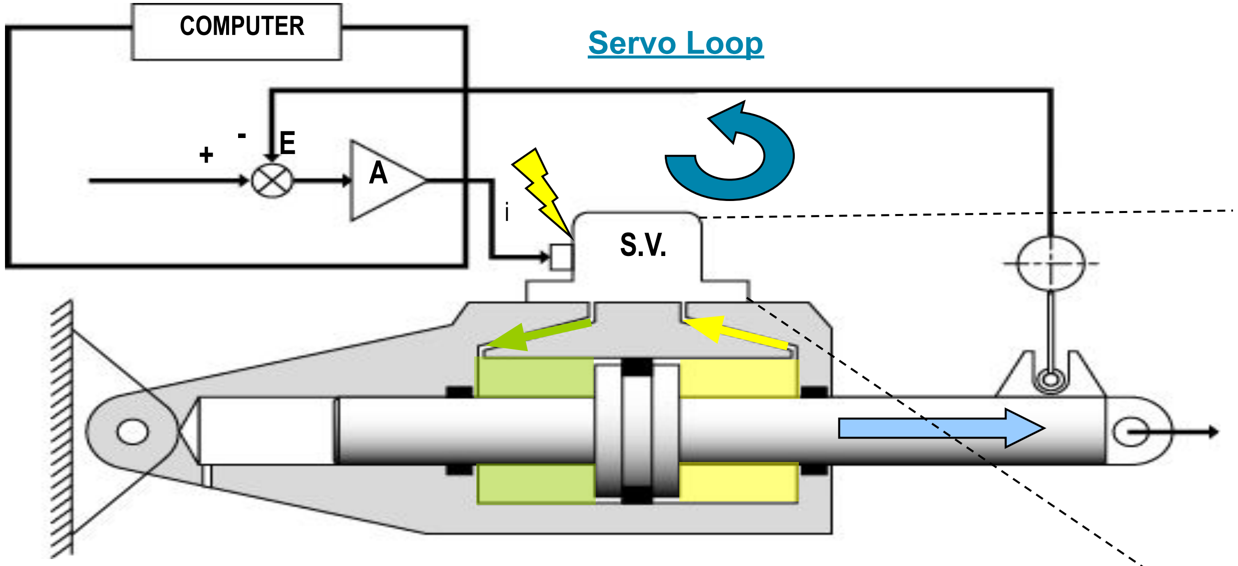
- FLY-BY-WIRE (FBW) SYSTEM
  - Pilot control speaks to a computer (through sensors), and this computers command the actuator (and associated surface) motion, taking into account several other parameters (aircraft attitudes, …)



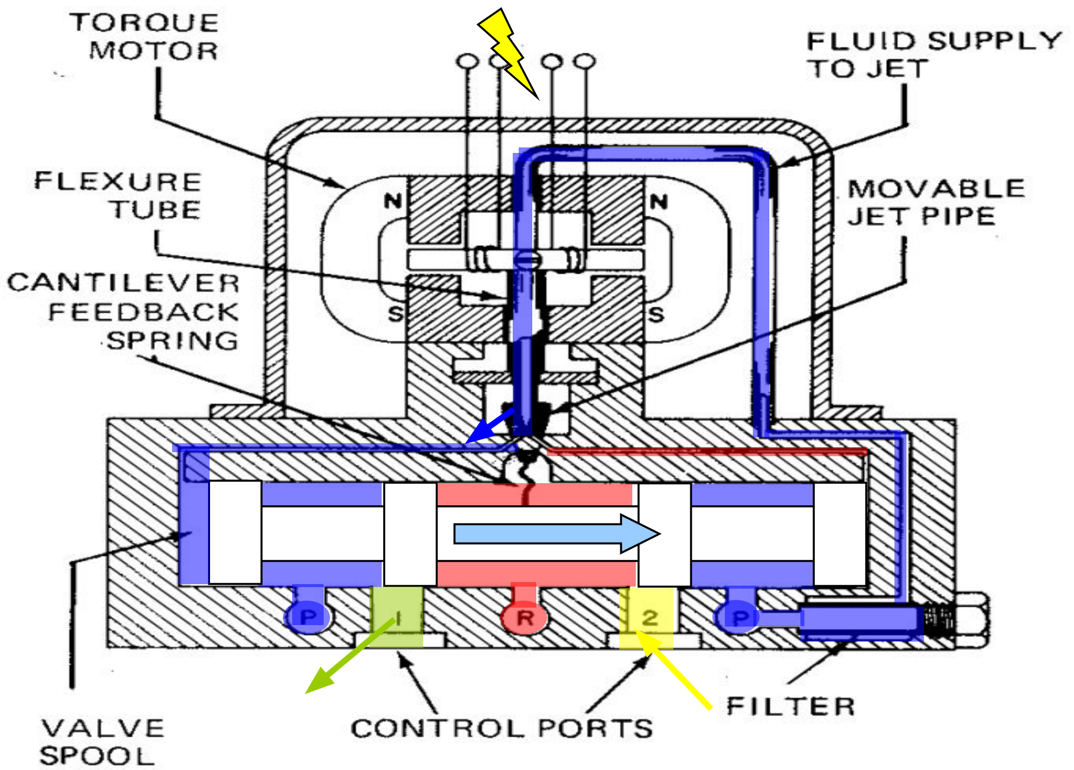
THE MUSCLES: ACTUATORS

- FLY-BY-WIRE (FBW) SYSTEM
  - Key element, the servovalve, part of the servoloop

Servo Loop



Servo Valve electro hydraulical



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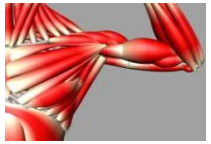
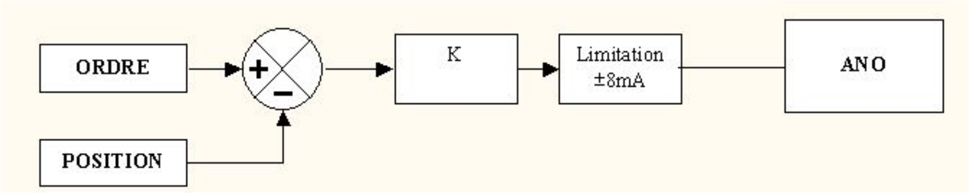


- FLY-BY-WIRE (FBW) SYSTEM

Servoloop characteristics:

- Ensures the control of the control surface at the position commanded by the laws.
- Computer receives the position of the control surface (or of the servocontrol rod) by means of transducers (inductance position sensor)
- Computer closed loop controls the current of the servovalve (ANO = analog output)



- Ensures the performances (bandwidth, accuracy) and the stability margins throughout the life of the aircraft
- During its adjustment, representativeness is vital to ensure performance and stability. For the computers, care must be taken with the asynchronisms and delays. For the actuators, the stiffness of the attachment is an essential parameter.
  - The loop is adjusted on dedicated benches with real actuators and real computers
  - The conformity check is done on real aircraft (real inertias, real stiffnesses)
- The position of the loop can be delocalised; up to the A400M, AIRBUS favoured centralisation, but the electronics are remote on the A350 with the advent of smart actuators …

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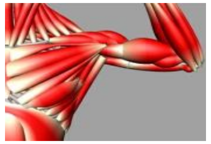
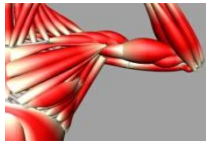
THE MUSCLES: ACTUATORS



- FLY-BY-WIRE (FBW) SYSTEM
  - Simple system: no more play, hysteresis, jamming, etc.
  - Caution: the loss of electrical power (supplying the computers) becomes as critical as the loss of hydraulic power
  - Caution: the wiring must be done with care (see Installation §)
  - The servovalve is current controlled (fast loop, less sensitive to electrical disturbances, etc.)
  - On the critical control surfaces, a servovalve slide valve position sensor is used (to detect runaway at the source)

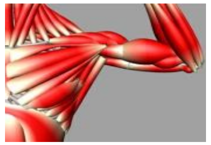
THE MUSCLES: ACTUATORS



- FLY-BY-WIRE (FBW) SYSTEM

Various servocontrol operating modes:

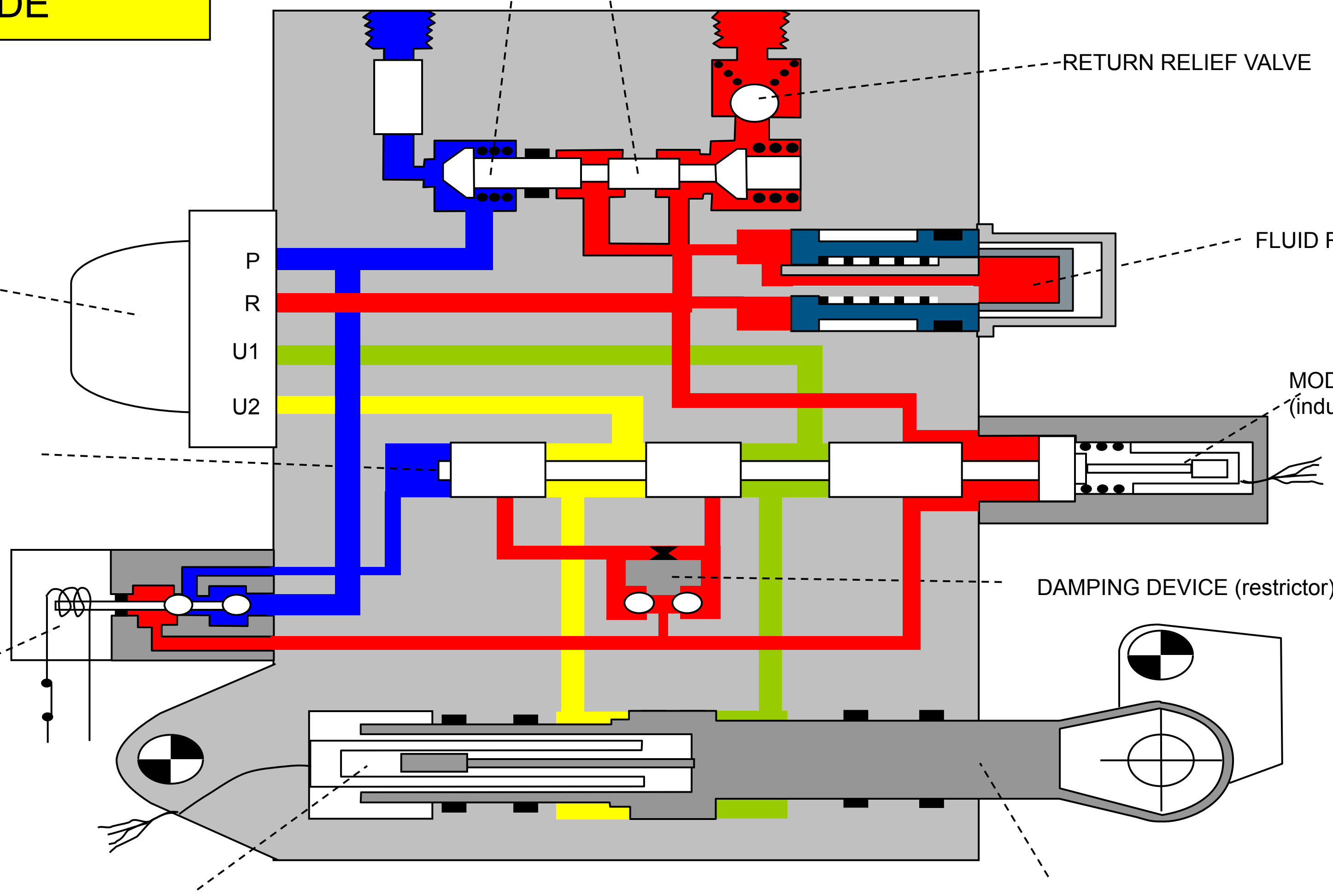
- Active:
  - Normal mode for a servocontrol per control surface which requires hydraulic power and the digital control of a computer.
  - In this mode, the servocontrol exerts a force which can be as high as a stall load.
- Damping (or stand-by):
  - Normal mode for the servocontrol in stand-by but degraded mode in case of loss of hydraulic power or control.
  - In this mode, the servocontrol performs the damping like a dash pot (the hydraulic flow passes from chamber to another via a restrictor).
- Depressurised:
  - Degraded mode in case of loss of connection to the hydraulic line.
  - In this mode, the servocontrol performs the damping and an accumulator compensates for the internal hydraulic losses (essentially related to thermal phenomena which cause the internal pressure to vary).
- Self-centred (only on SA and LR elevators and on A340-500/600 ailerons)
  - Highly degraded mode in case of simultaneous loss of control on two adjacent actuators, provided that the hydraulic power is available.
  - In this mode, the servocontrol places the control surface in neutral position. This mode is implemented on the axes where the positioning of a control surface at zero hinge moment would generate flight disturbances and significantly reduce the safety margins.



THE MUSCLES: ACTUATORS

- FLY-BY-WIRE (FBW) SYSTEM

ACTIVE MODE



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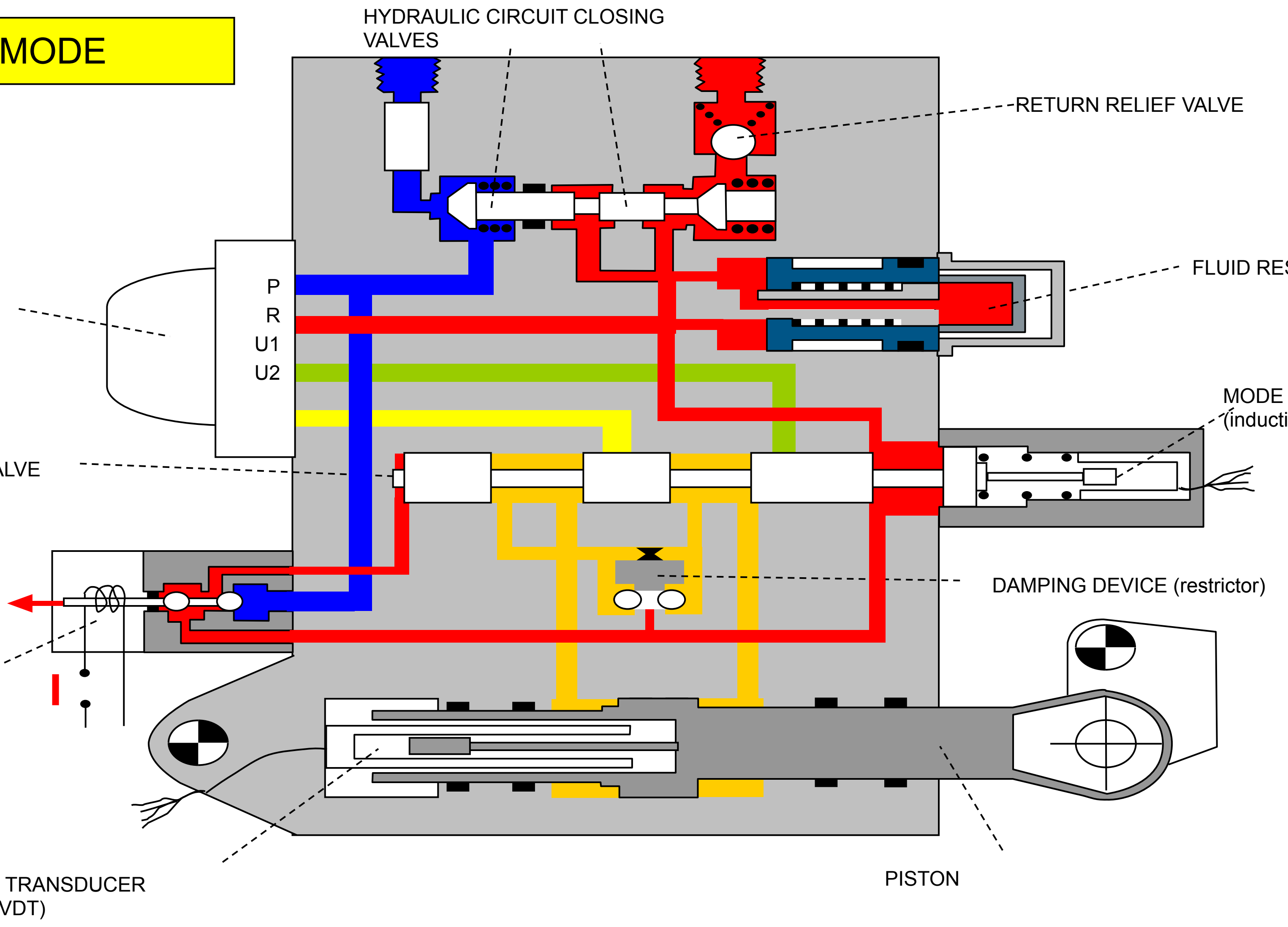
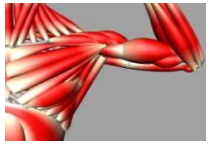
THE MUSCLES: ACTUATORS

- FLY-BY-WIRE (FBW) SYSTEM

DAMPING MODE

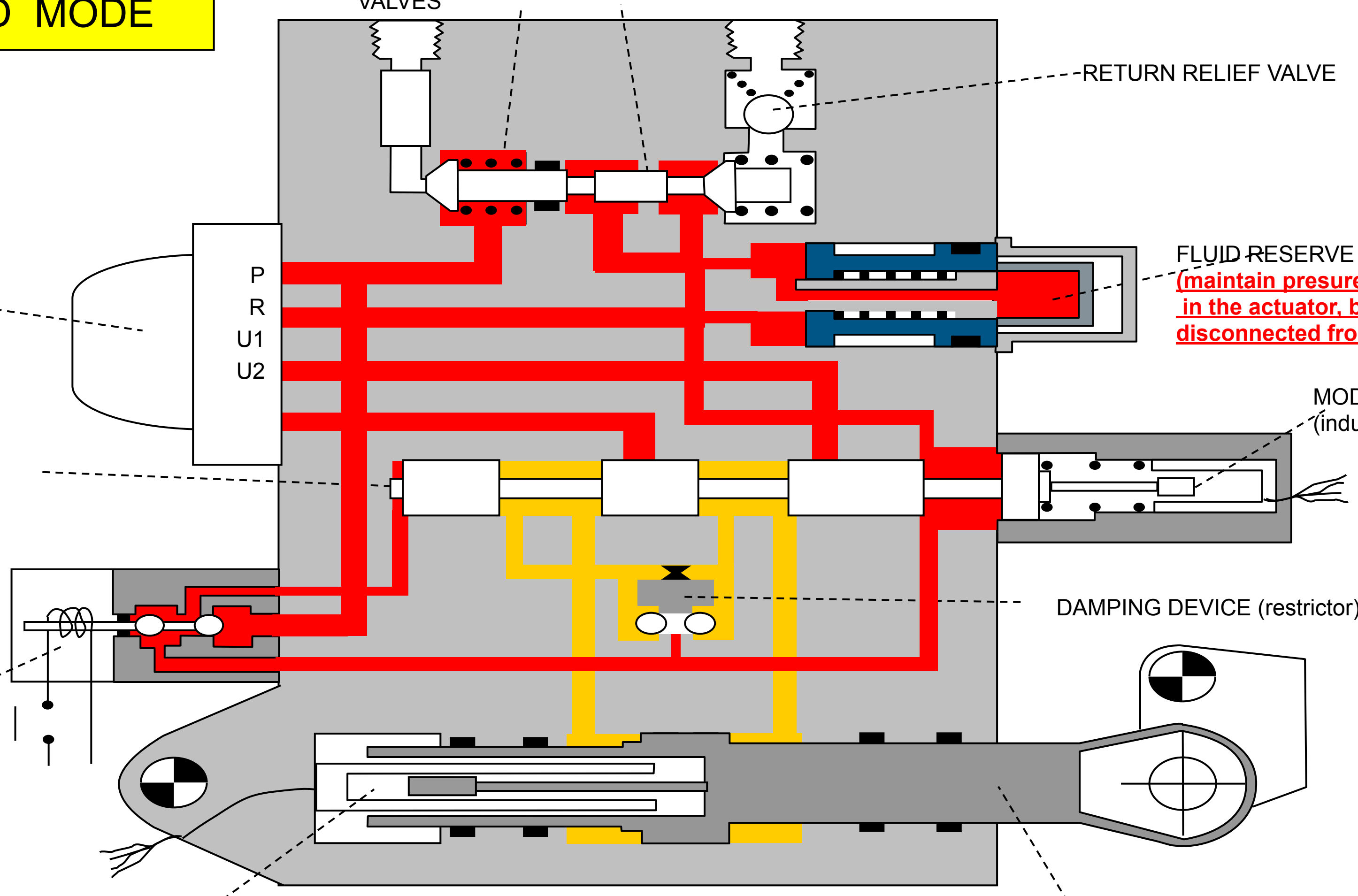




THE MUSCLES: ACTUATORS

- FLY-BY-WIRE (FBW) SYSTEM

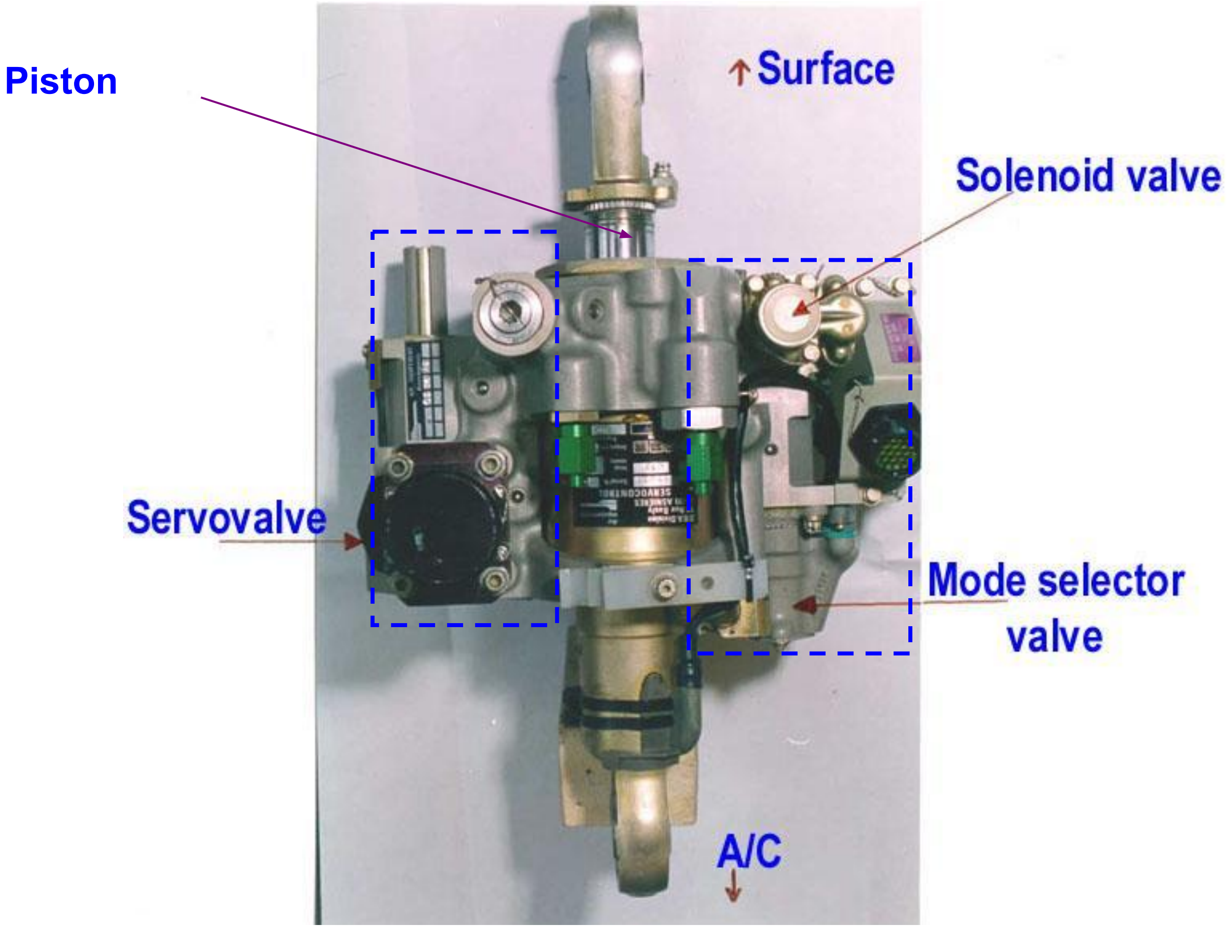
DEPRESSURIZED MODE

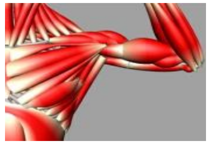


THE MUSCLES: ACTUATORS

- SYSTEME « FLY BY WIRE »

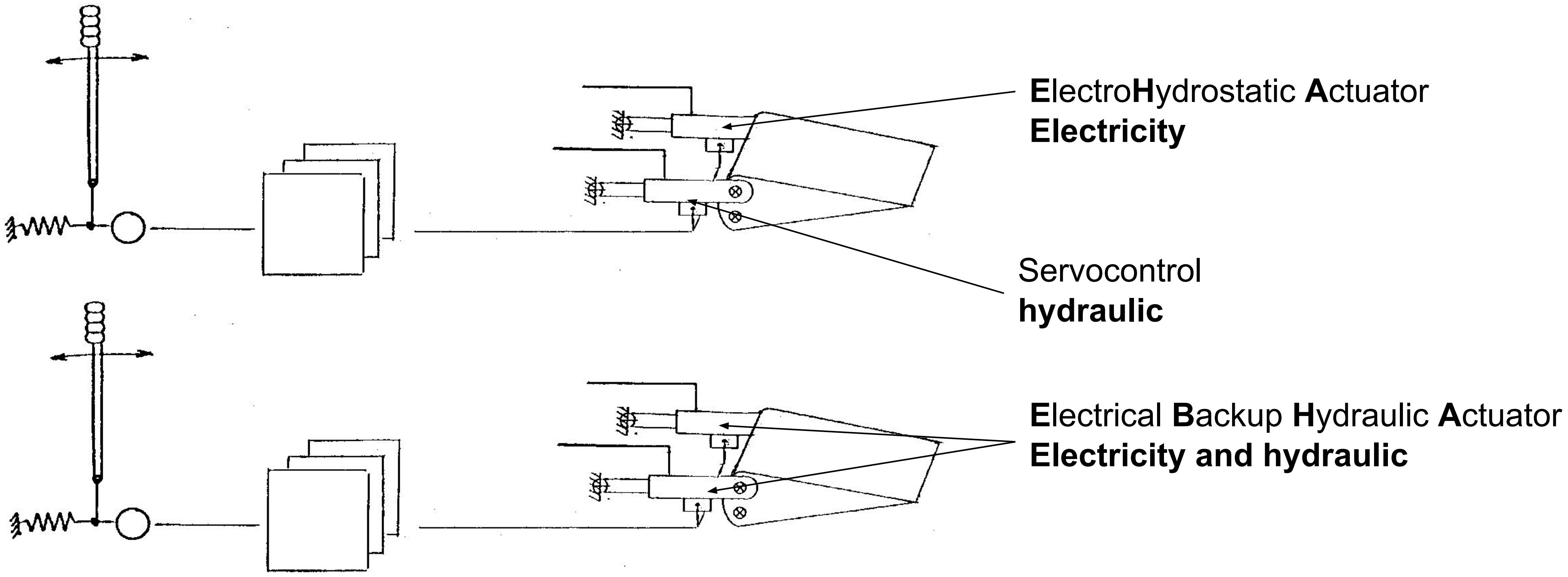
  Ex: Aileron A320





THE MUSCLES: ACTUATORS

- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM
  - The stand-by servocontrol can be replaced by an EHA which generates its hydraulic power autonomously thanks to an electric motor
  - The active servocontrols can be replaced by EBHAs which nominally draw their power from the hydraulic circuit but which, like EHAs, have motors capable of generating their own hydraulic powers



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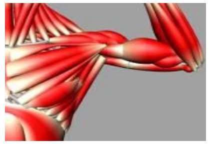
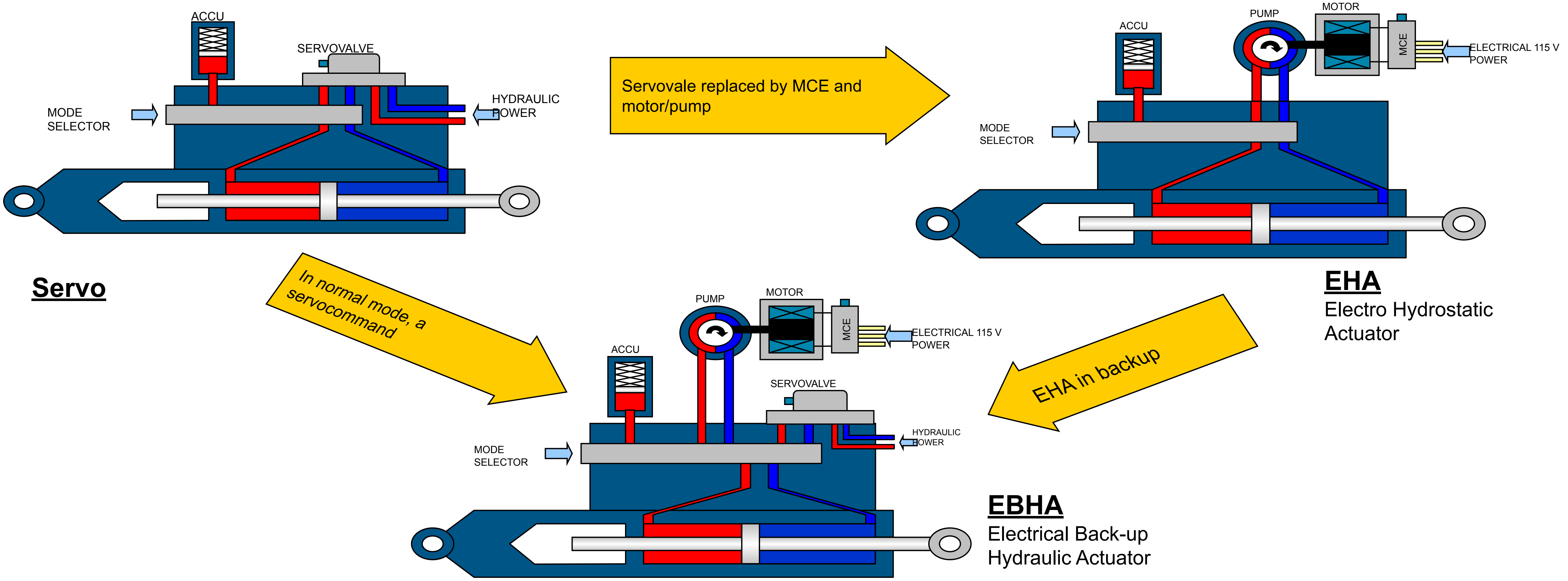


THE MUSCLES: ACTUATORS

- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM

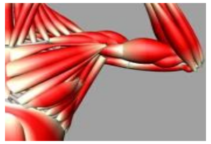


Servo

EHA
Electro Hydrostatic Actuator

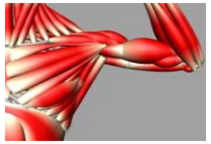
EBHA
Electrical Back-up Hydraulic Actuator

THE MUSCLES: ACTUATORS



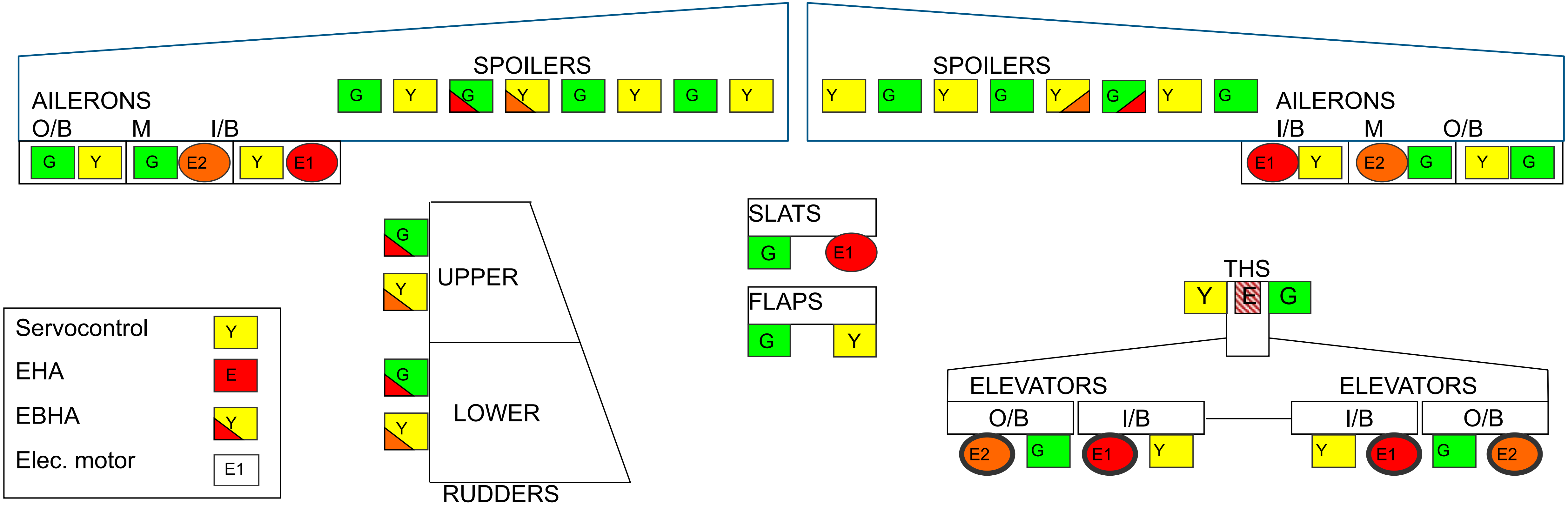
- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM
  - Advantages:
    - One step more towards the all-electric aircraft (hydraulics is not ideal for maintenance, it is cumbersome, etc.)
    - Dissimilar power sources, that is better availability and level of safety increased still further
    - Obvious weight savings at aircraft scale as the deletion of a hydraulic circuit easily compensates for the extra weight of the actuators and the electrical circuit
    - Segregations easier to do as the electrical installation is much easier than the hydraulic installation
  - The idea may appear to be simplistic but required 20 years of research and development at AIRBUS and could only come into being with the advent of very powerful motors.

THE MUSCLES: ACTUATORS



- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM

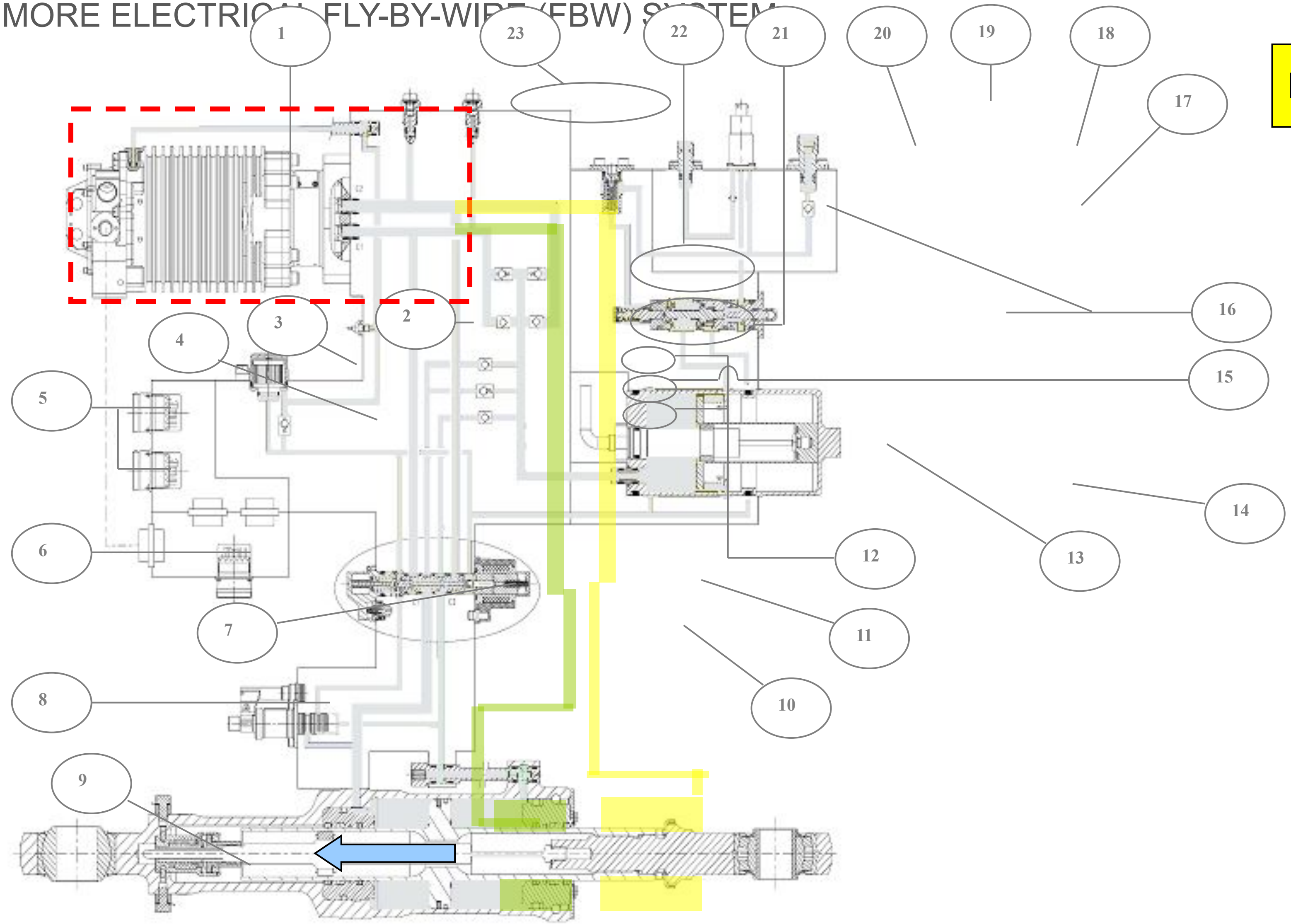
Ex: A380, first to get electric



Electrically Powered Actuators in stand-by positions

THE MUSCLES: ACTUATORS

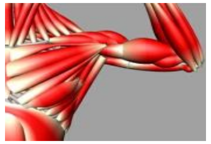
- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM



Electrical Active Mode

1-Motor Pump Assembly
2-Temperature Sensor
3-Filter Case Drain
4-Relief Valve
5-Electrical Connector
6-Motor Control Electronics (MCE)
7-Mode Selector Valve transducer
8-Differential Pressure Transducer
9-Piston Rod Position Transducer
10-Mode Selector Valve
11-Linear Solenoid
12-Ram Anti-cavitation Valves
13-Level Transducer
14-Accumulator
15-Thermal Relief Valve
16-Shut-off Accumulator Filling Valve
17-Check Valve
18-Return Port
19-Solenoid Valve
20-Pressure Port
21-Pump Anti-cavitation Valves
22-Pump Relief Valves
23-Filling Valve

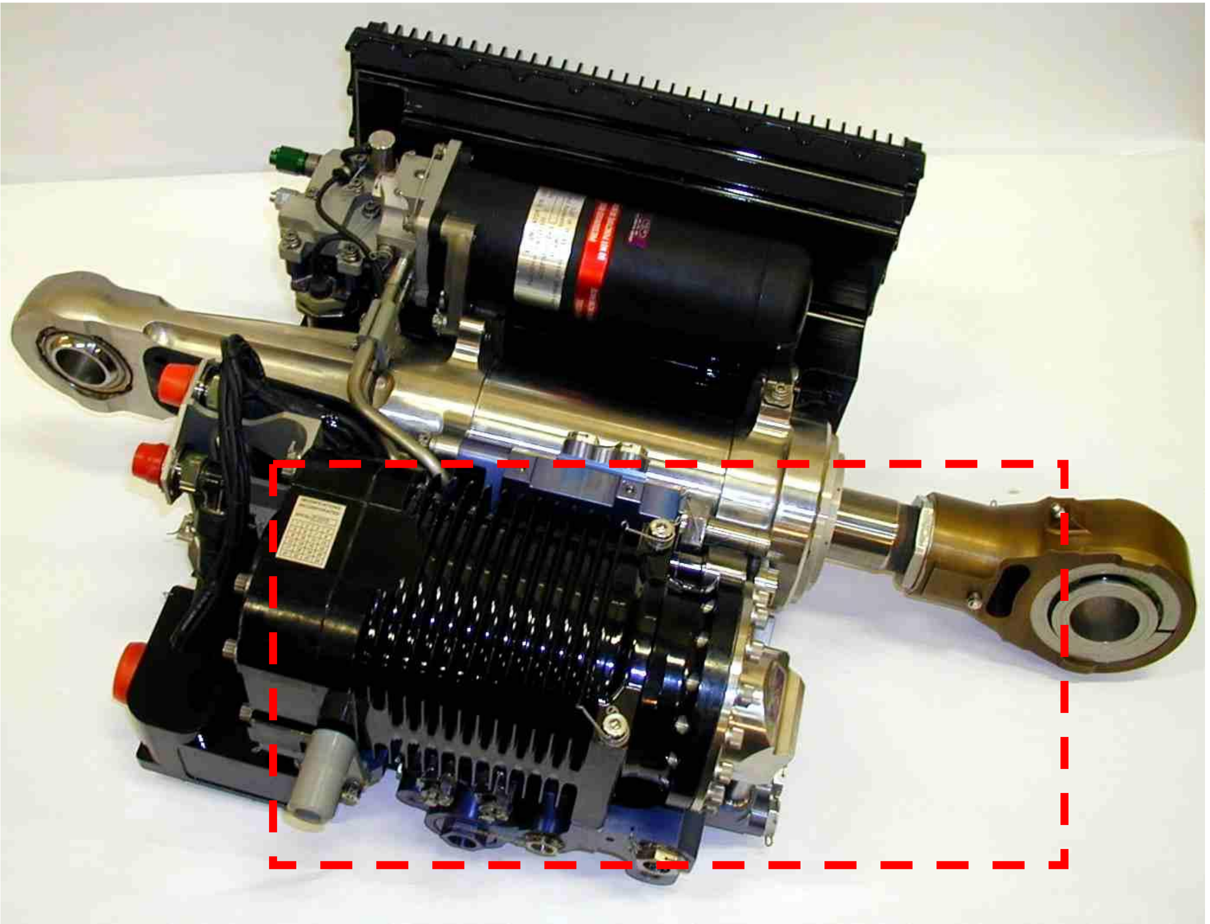
AIRBUS



THE MUSCLES: ACTUATORS

- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM

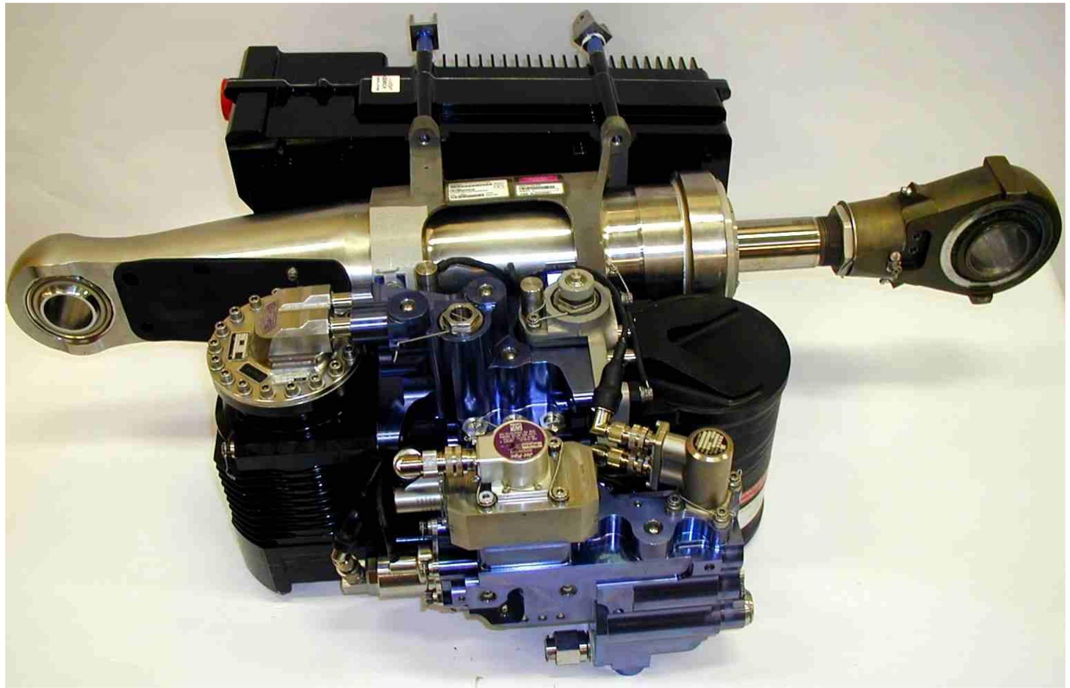
EHA aileron A380

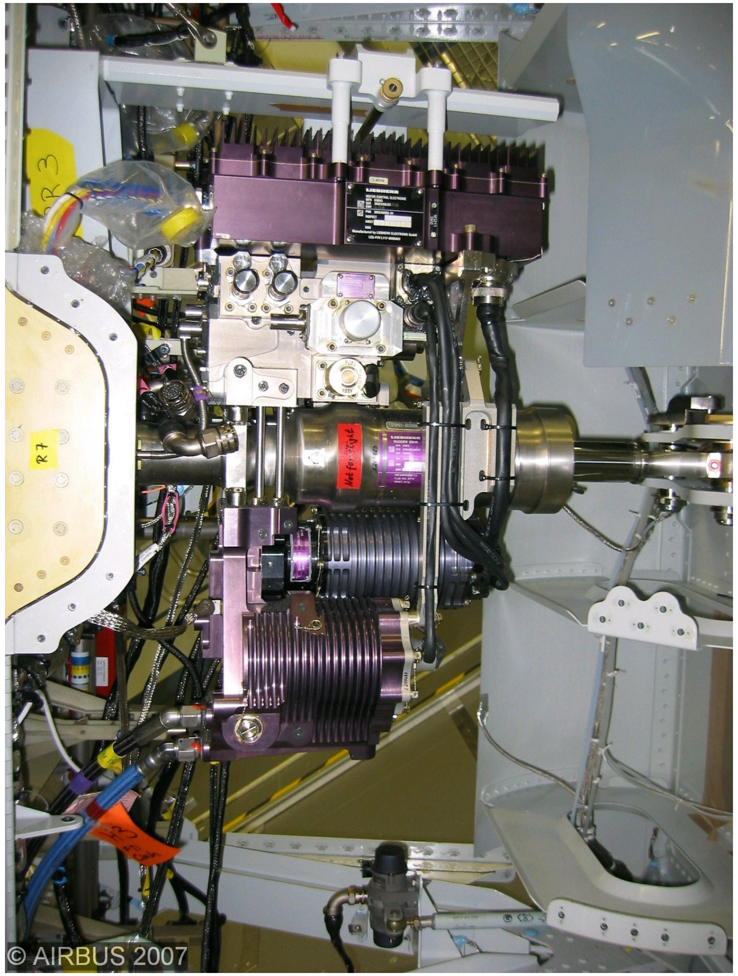


THE MUSCLES: ACTUATORS

- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM

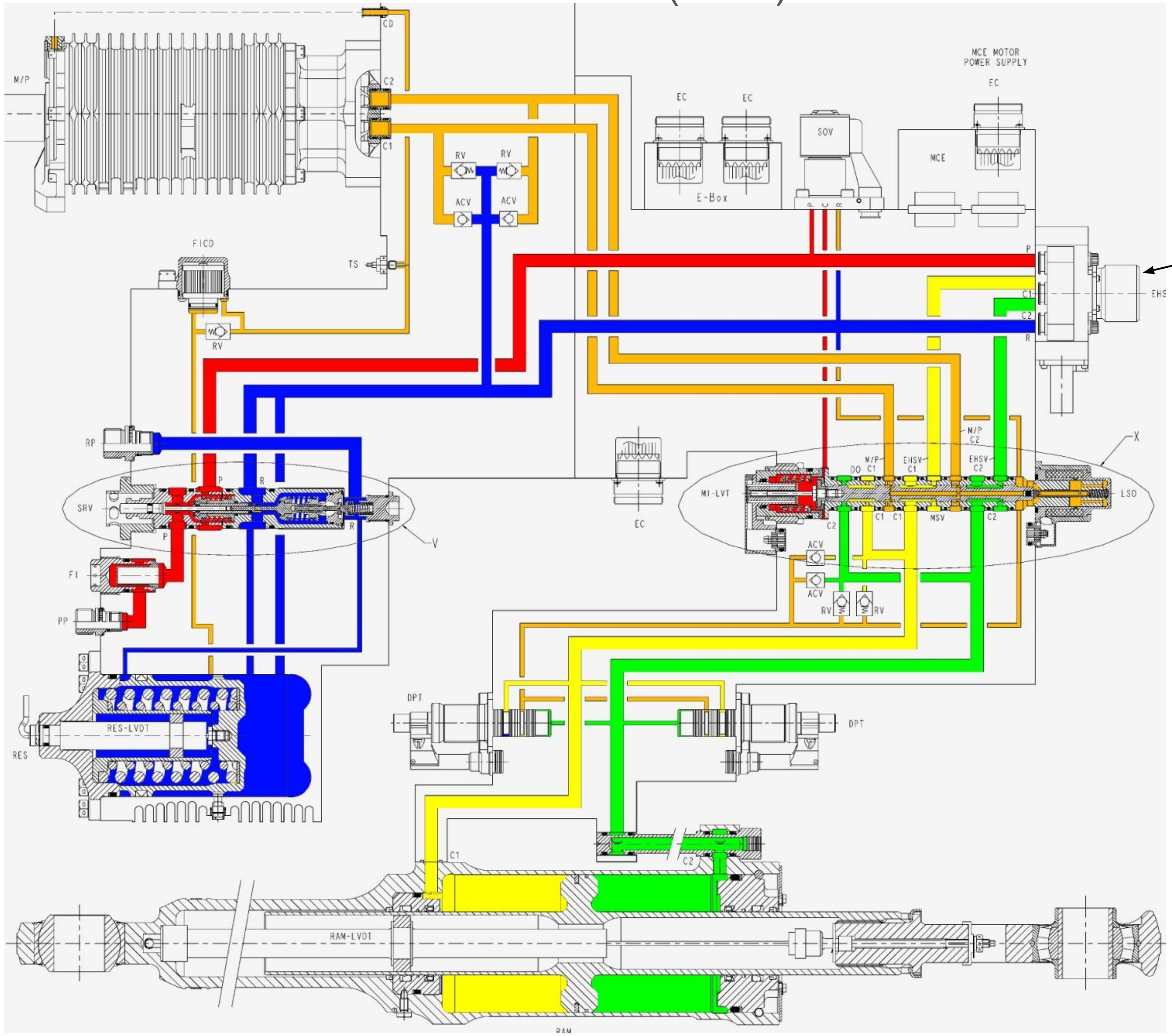
EBHA A380 and A400M rudder actuator

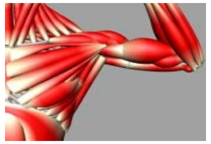




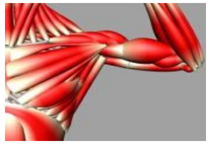
THE MUSCLES: ACTUATORS

- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM





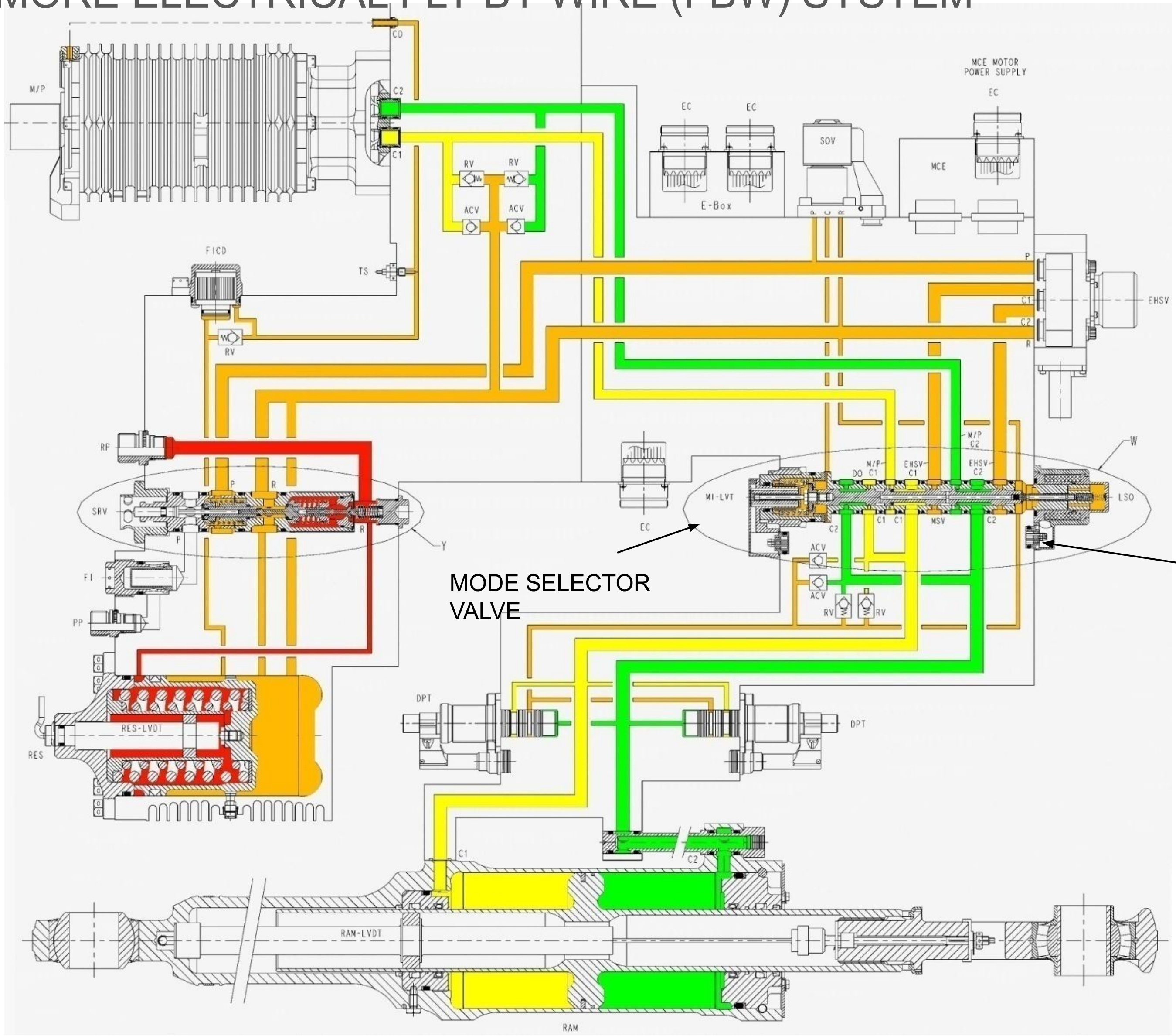
AIRBUS



THE MUSCLES: ACTUATORS

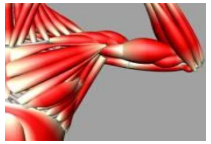
- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM

ELECTRICAL ACTIVE MODE



MODE SELECTOR

AIRBUS



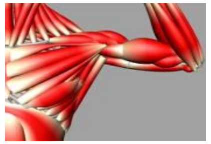
THE MUSCLES: ACTUATORS

- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM

EHA intrinsic issues:

- **heavy** (dedicated tools required for maintenance)
- **too big** (difficult to install)
- **it's hot** (and close to carbon and fuel, it is not a good idea)

THE MUSCLES: ACTUATORS



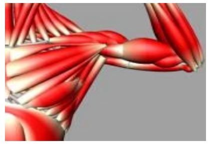
- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM

The other characteristics of the EHAs:

- The lives of pumps and motors are short (small equipment which rotate quickly) hence use as backup only
- The evacuation of the heat during operation is a real headache
- The power electronics, near to fine control electronics, requires many precautions to avoid propagating disturbances
- A real headache for the FAR88 demonstration (explosion close to the tanks)
- Long start-up time at low temperatures (fluid not very fluid)
- Taking into account of the EHAs sometimes difficult by electrical generation and, especially, for the sizing of the RAT
- Internal leaks require topping up (manual or automatic) or a sufficient large reserve of fluid

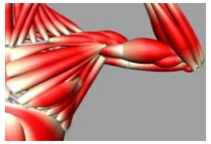
AIRBUS

THE MUSCLES: ACTUATORS

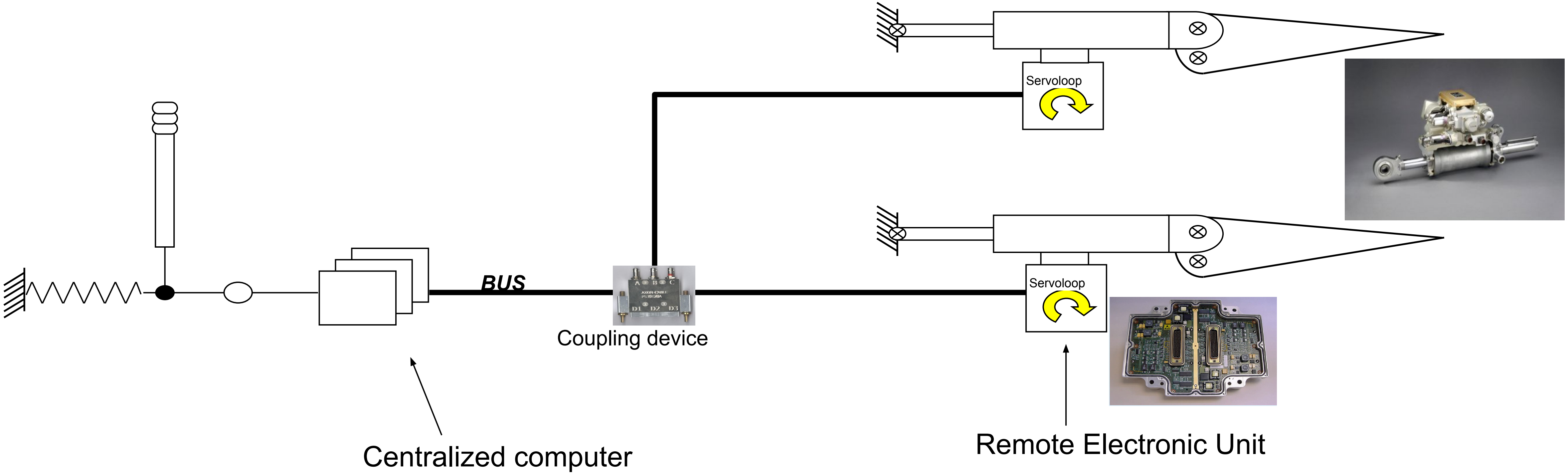


- MORE ELECTRICAL FLY-BY-WIRE (FBW) SYSTEM
  - The same problems as on the EHA are found on the EBHA except for the filling and cold start.
  - We use the EBHA:
    - Alone if the control surface is not critical (spoilers)
    - In duo to simplify an architecture (3 hydraulic servocontrols become 2 EBHAs)

THE MUSCLES: ACTUATORS

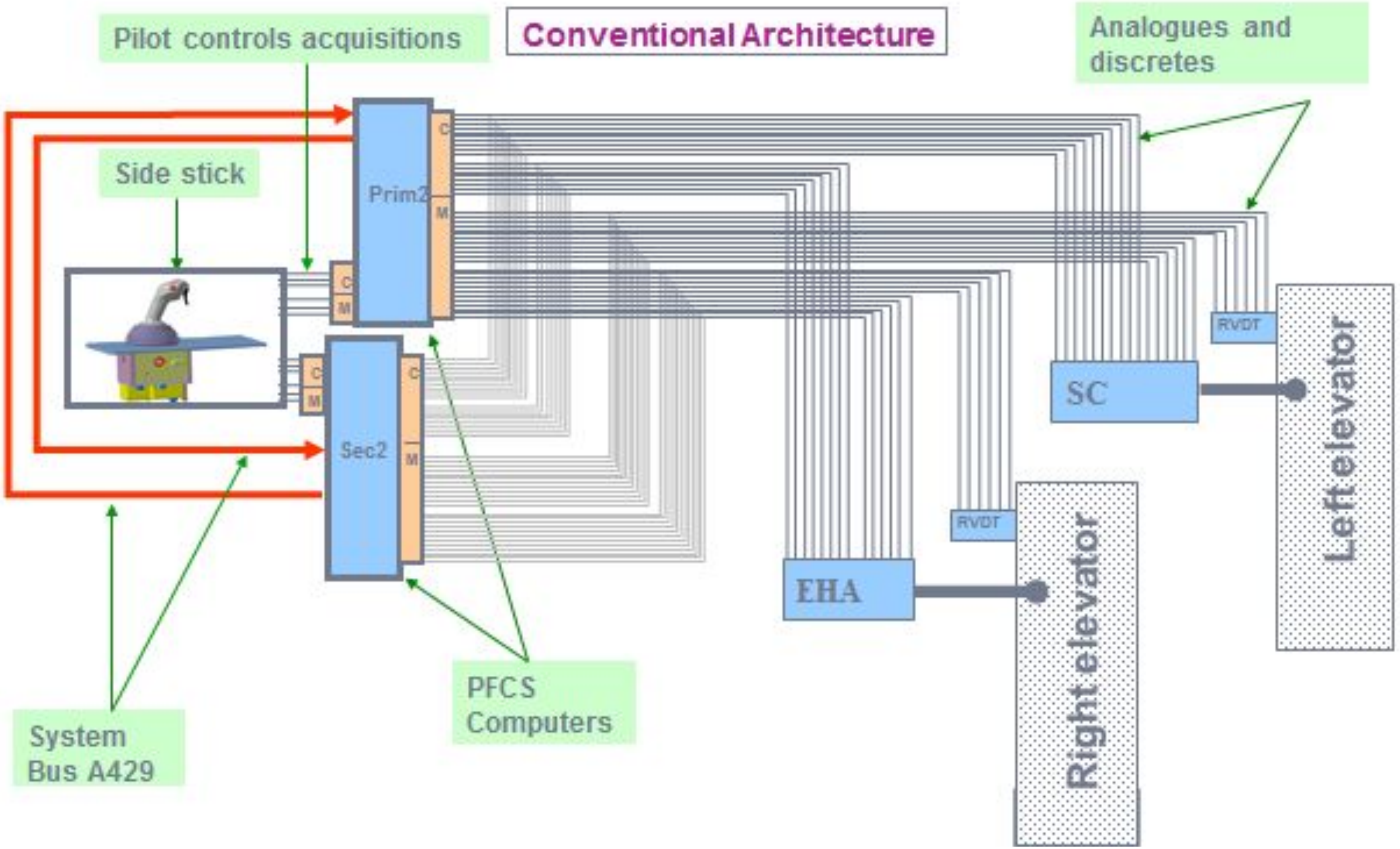


- MORE REMOTE FLY-BY-WIRE (FBW) SYSTEM
  - Some piece of the command of the servo control is transferred from centralized computer to remote electronic devices



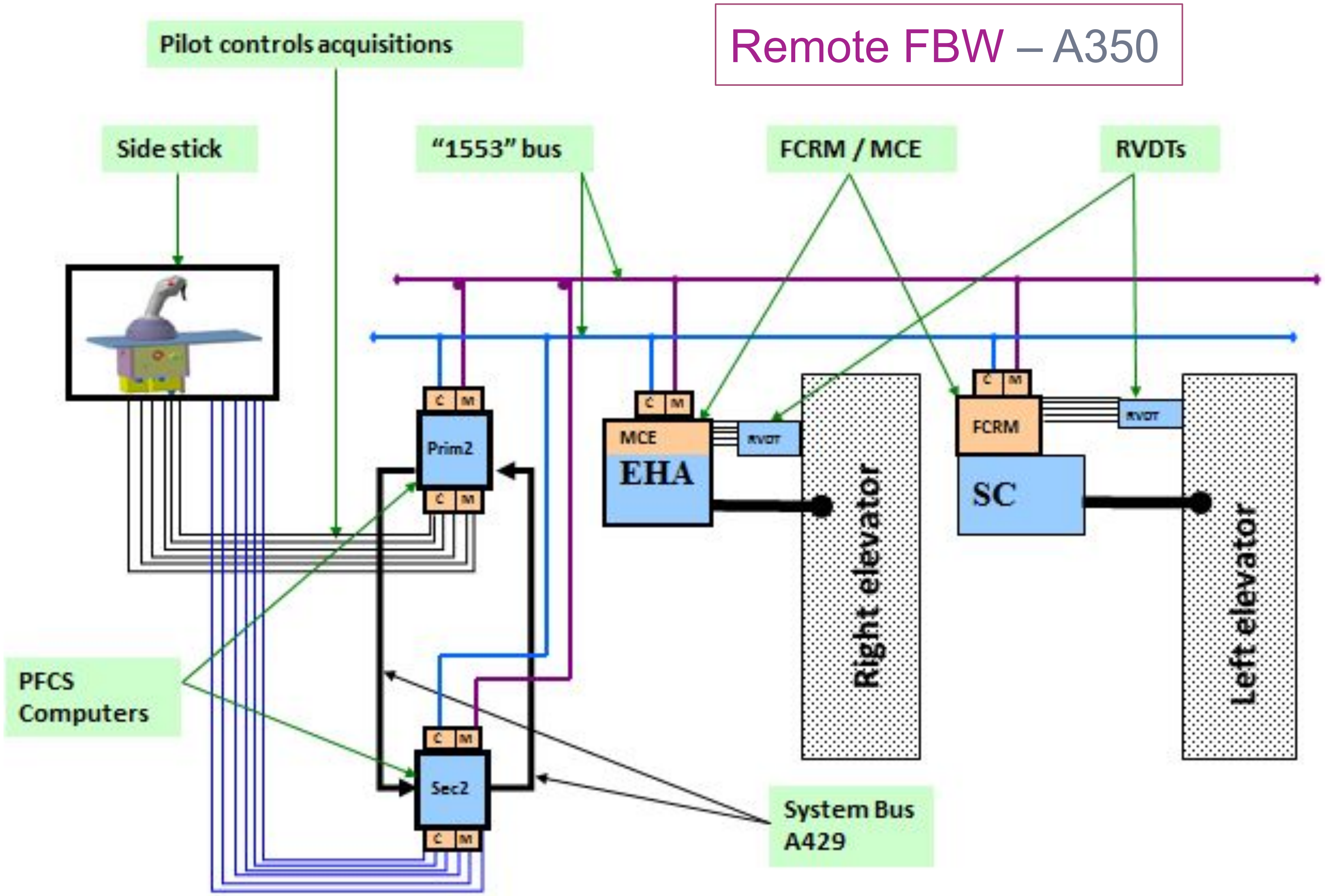
THE MUSCLES: ACTUATORS

- MORE REMOTE FLY-BY-WIRE (FBW) SYSTEM

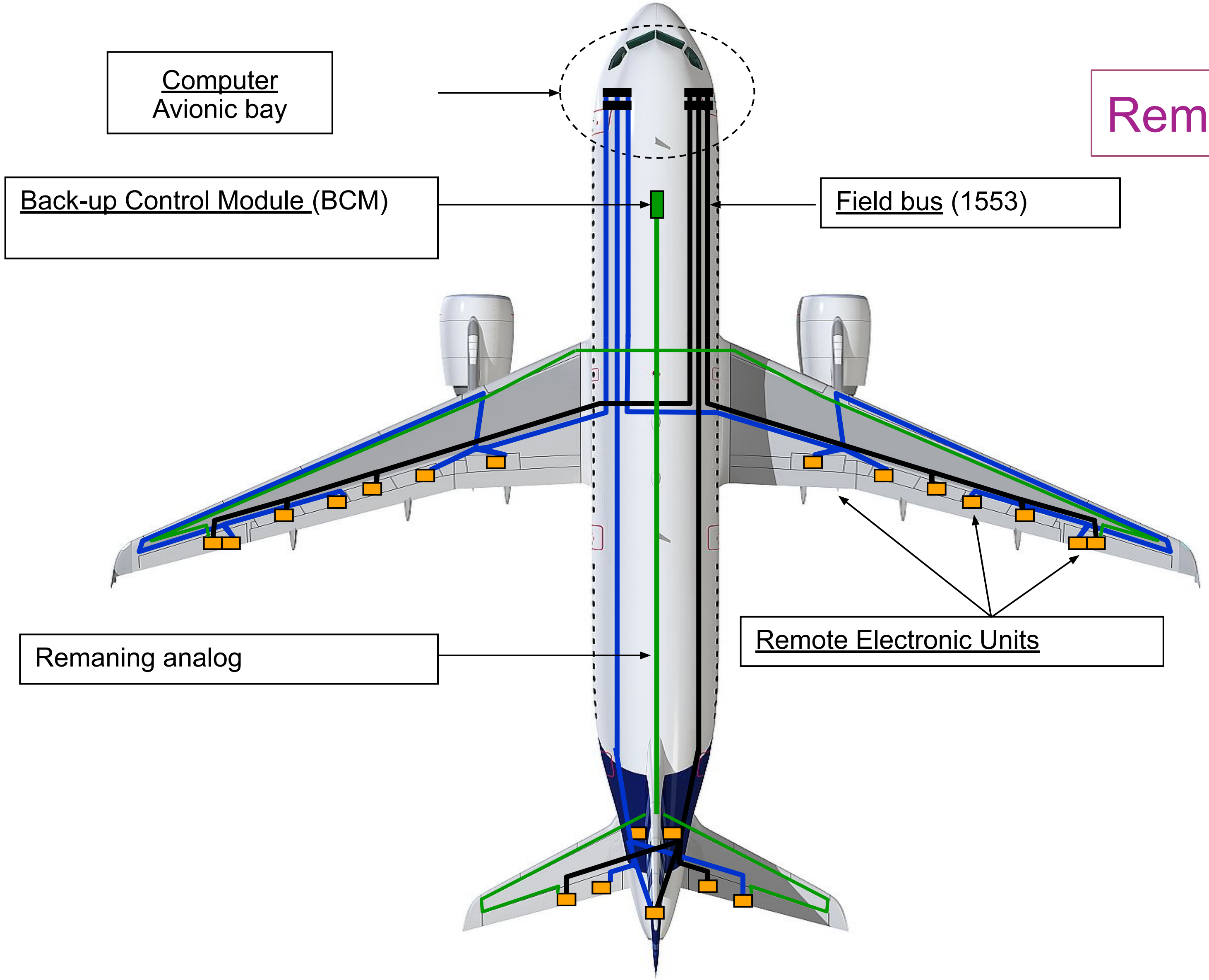


THE MUSCLES: ACTUATORS

- MORE REMOTE FLY-BY-WIRE (FBW) SYSTEM



THE MUSCLES: ACTUATORS

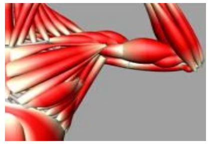


Remote FBW – A350

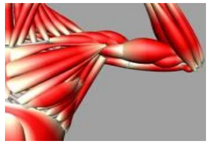
System 1
System 2
BCM

- 2 independent systems with digital buses
- 1 analogue back-up

THE MUSCLES: ACTUATORS

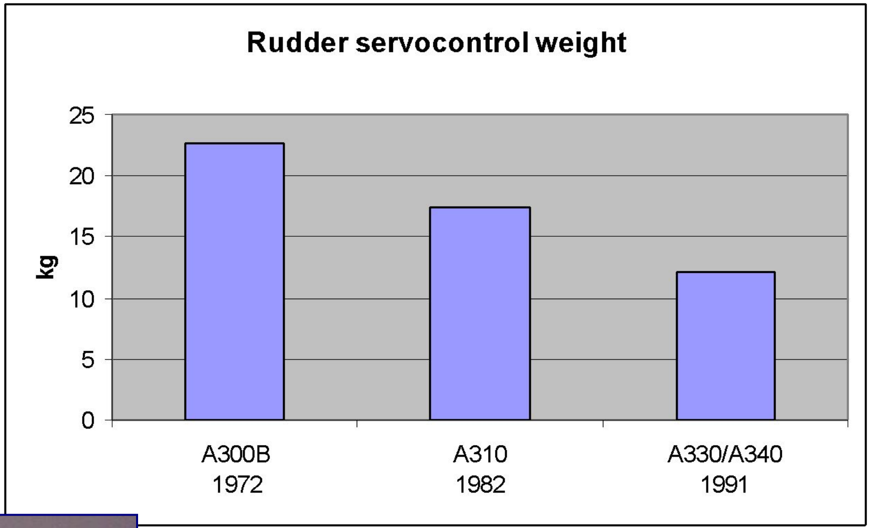


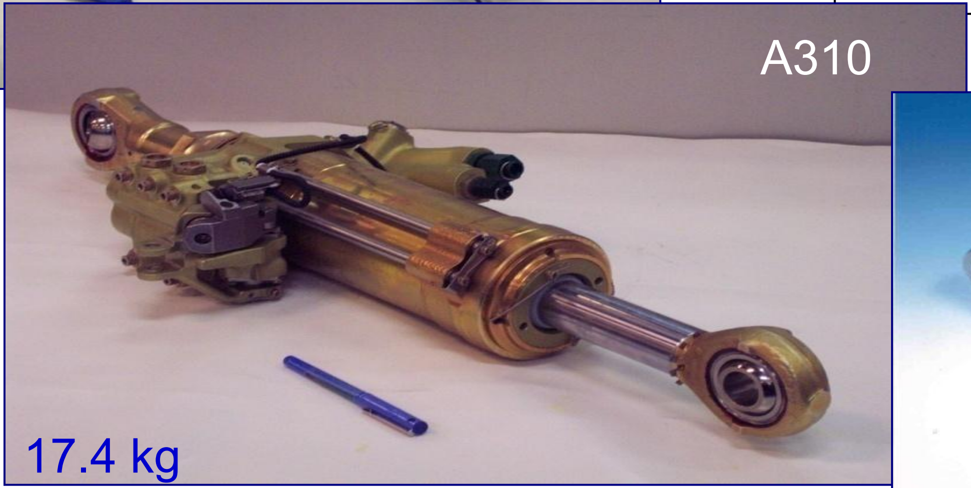
- MORE REMOTE FLY-BY-WIRE (FBW) SYSTEM
  - Advantages:
    - Robustness to electromagnetic aggressions thanks to military standard buses. The need for robustness arose especially with composite aircraft.
    - Additional weight savings by reduction in wiring, lightning protections (fuses) in the centralised computers, etc.
  - Risks
    - Longer REU software fine tuning cycles, lower reactivity.
    - Electronic control module near from hostile environment instead of avionic bay

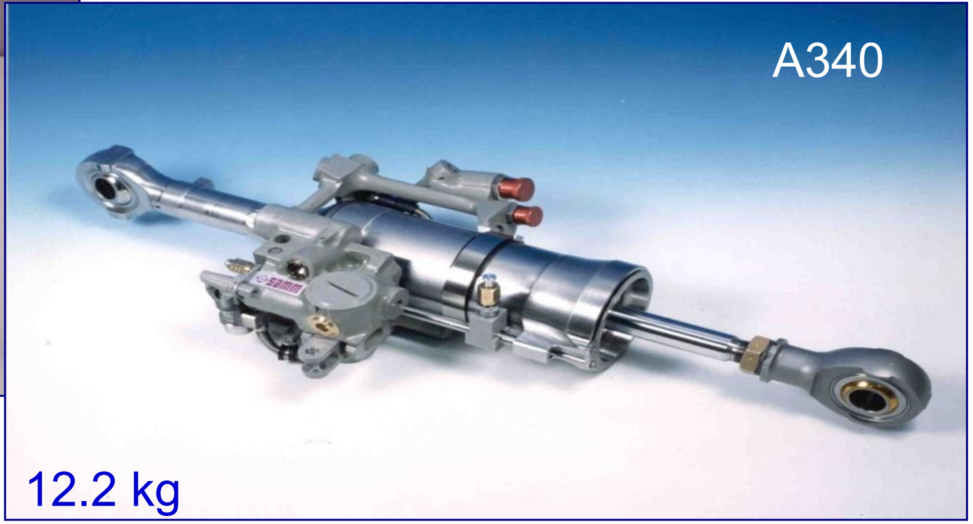


THE MUSCLES: ACTUATORS

- LIGHTER AND LIGHTER

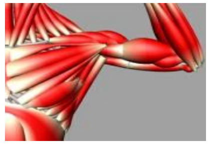






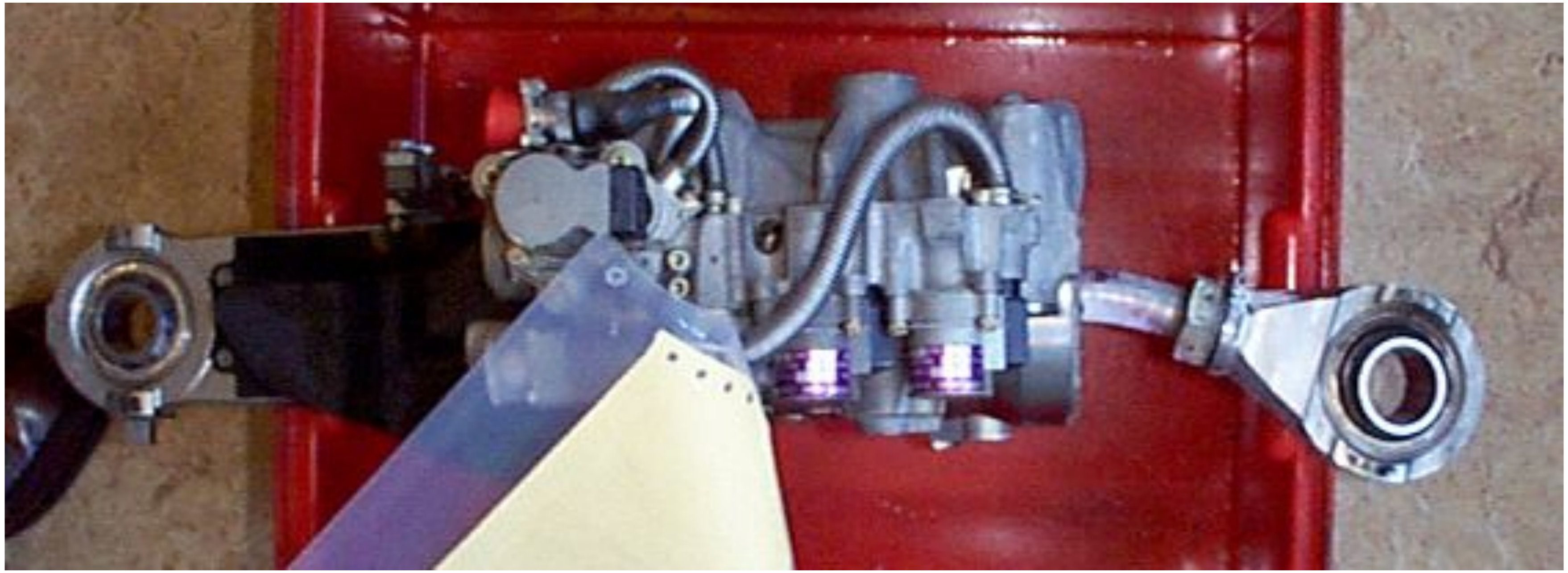
3 servocommands with identical features (interchangeable)

THE MUSCLES: ACTUATORS

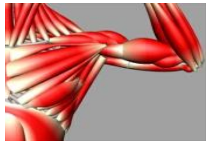


- LIGHTER AND LIGHTER

But we can reach the limits…



THE MUSCLES: ACTUATORS

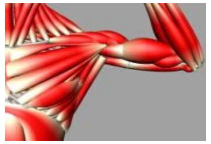


- TRIMMABLE HORIZONTAL STABILISER ACTUATOR

- Specificity: slow movement and enormous forces (57,000 daN on A380)
- Two hydraulic motors (and since the A380, an electrical backup) combined with a clutch, a worm screw and a no back system
- Sizing:
  - Motor performance: with forces on the control surface for manoeuvres at +/- 0.3 g around balance position
  - Static: that which the structure can support (the THS will break before the actuator...)
  - Fatigue: estimation of cycles depends on loading which depends on the activity of the elevators
  - Endurance: estimation of cycles depends on flight control law
- Fine tuning is very difficult (many iterations) as the fatigue and endurance cycles are difficult to anticipate (sensitivity to modifications in flight control laws and centre of lift position which substantially change during design)

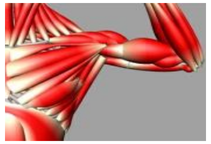
AIRBUS

THE MUSCLES: ACTUATORS



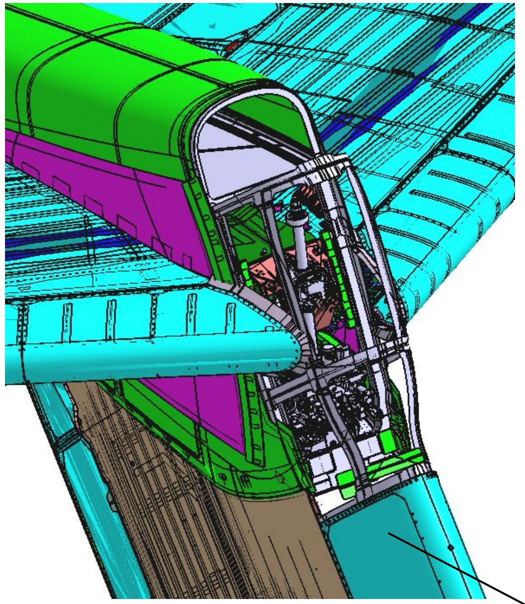
- <u>T</u>RIMMABLE <u>H</u>ORIZONTAL <u>S</u>TABILISER <u>A</u>CTUATOR
  - Runaway of THS to stop is highly CATastrophic
  - Requires a dual load path (attachment point redundancy)
  - No back required as the worm screw is reversible
  - The main problems with THSAs:
    - ***DEM**** in failed status on LR (smart actuator)
    - Cracking of screws
    - Choice of ball materials (steel or ceramic?)
    - Loss of balls
    - Fine tuning of the dual load path

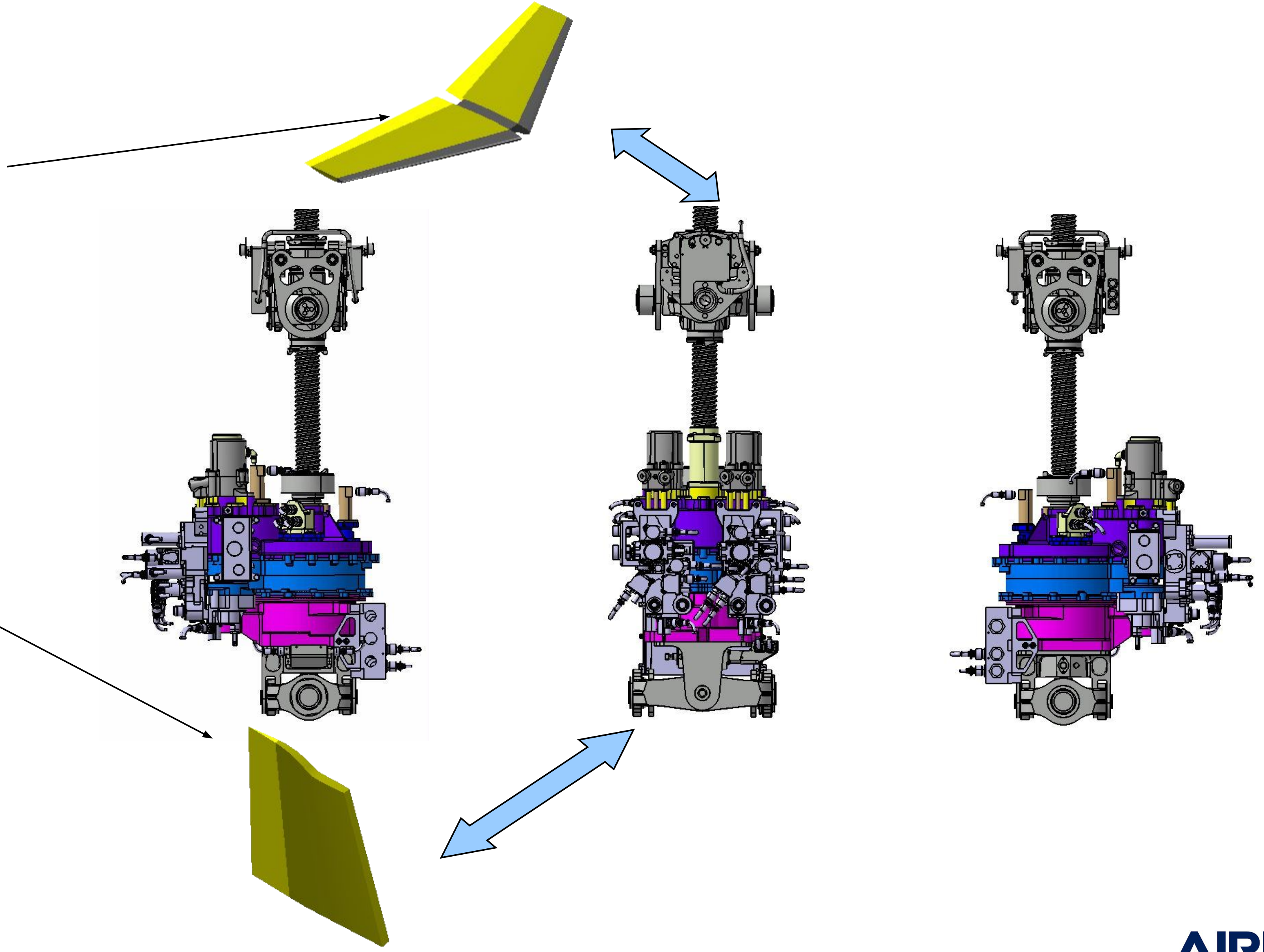
DEM* ***Digital Electronic Module***



THE MUSCLES: ACTUATORS

- THSA A400M

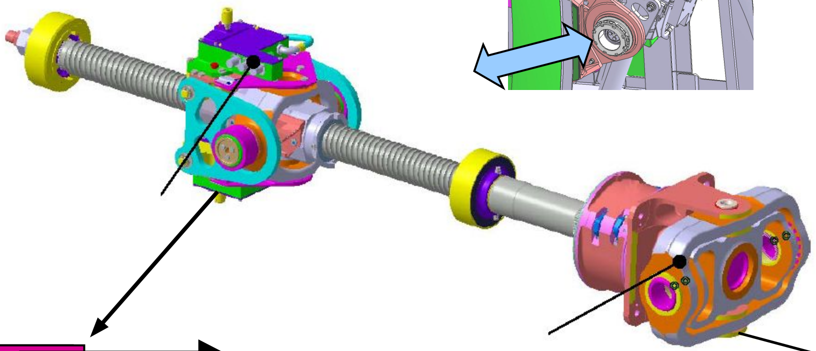


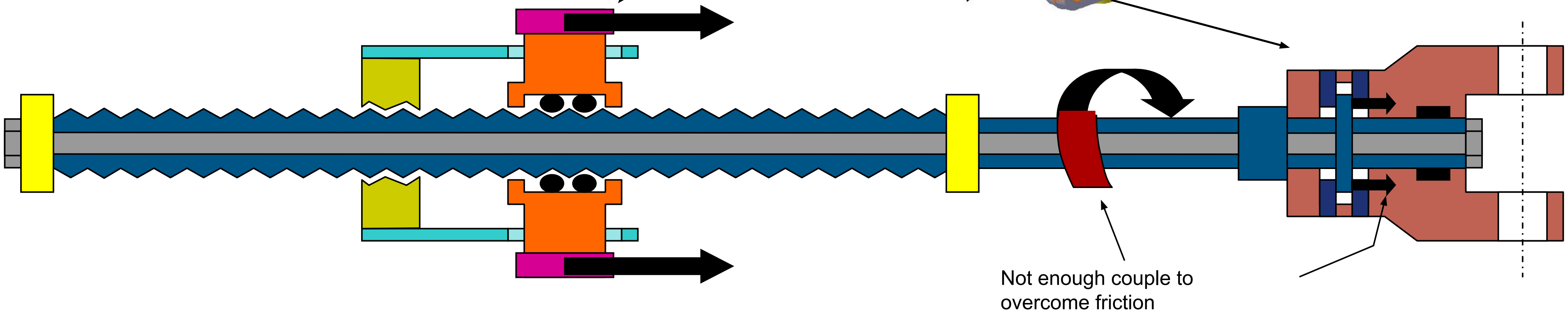


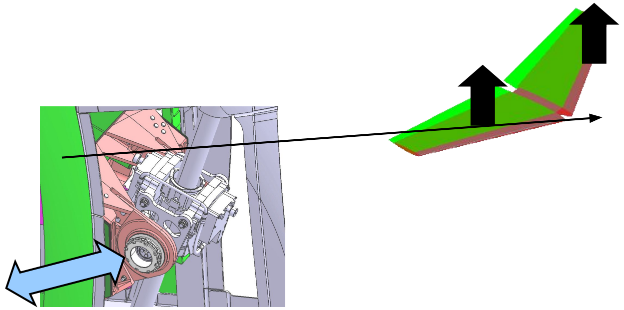
THE MUSCLES: ACTUATORS

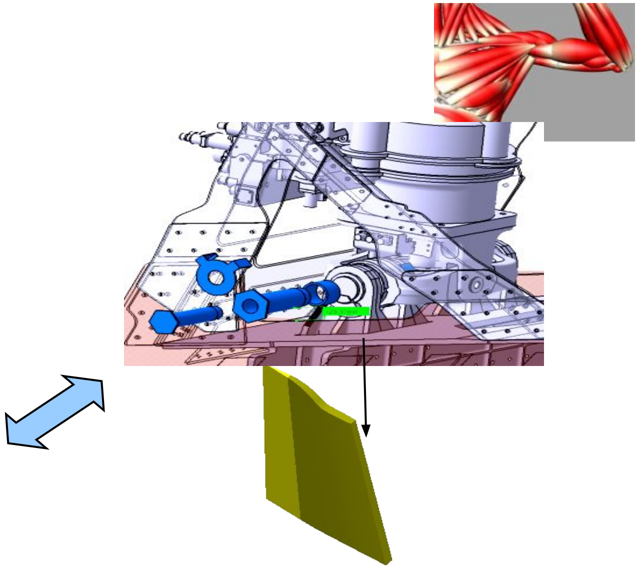
- Screw principle

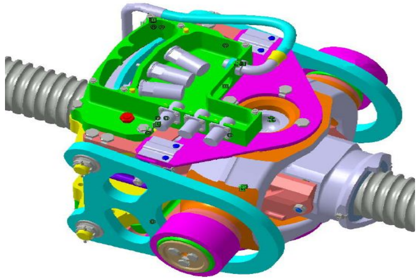
et noback

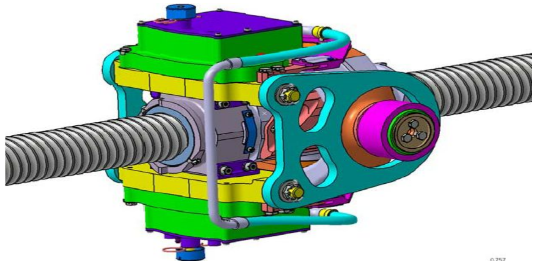


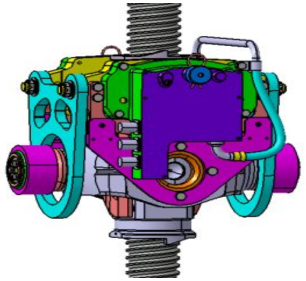


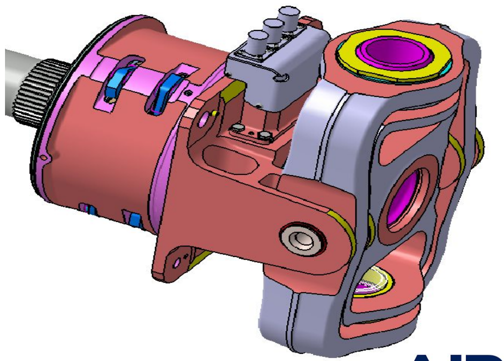




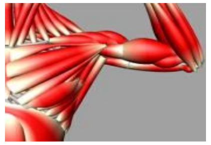




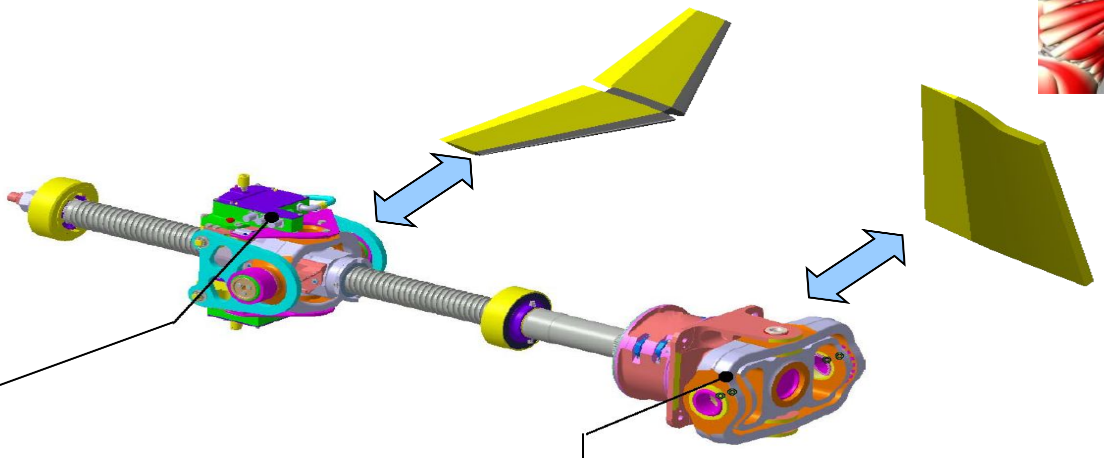


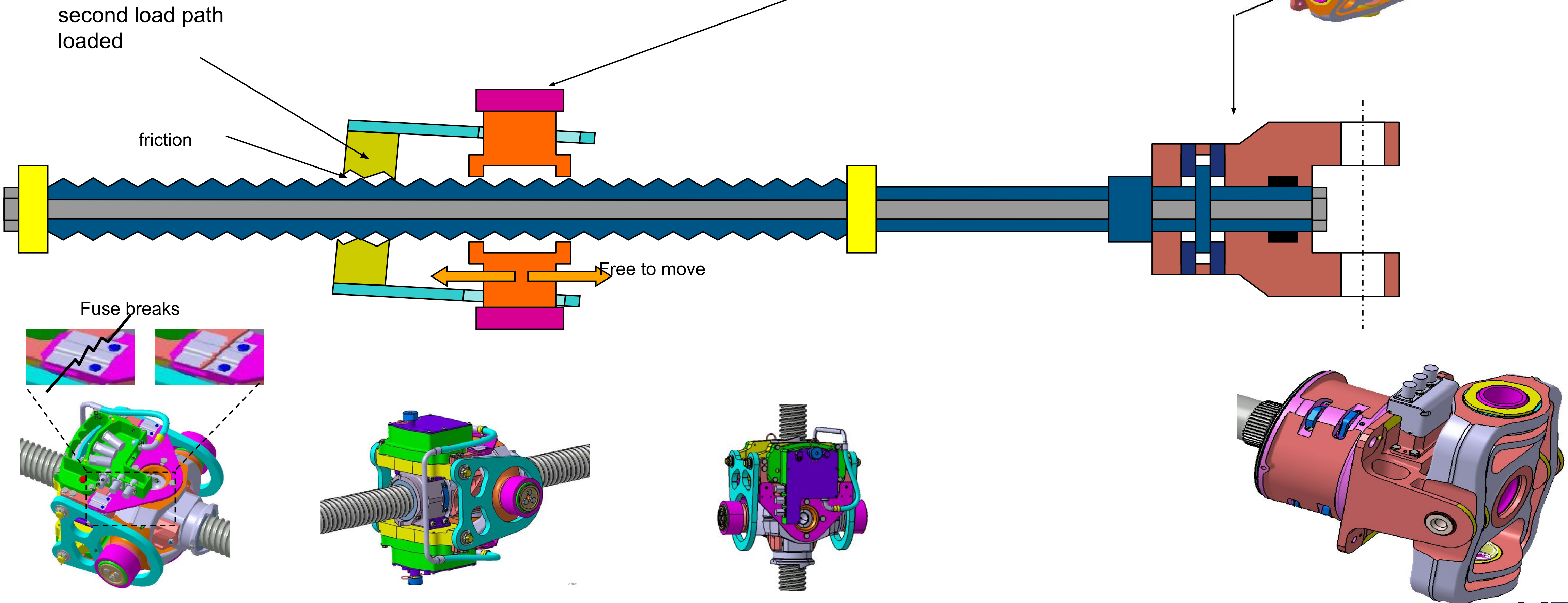


THE MUSCLES: ACTUATORS



- Dual Load Path

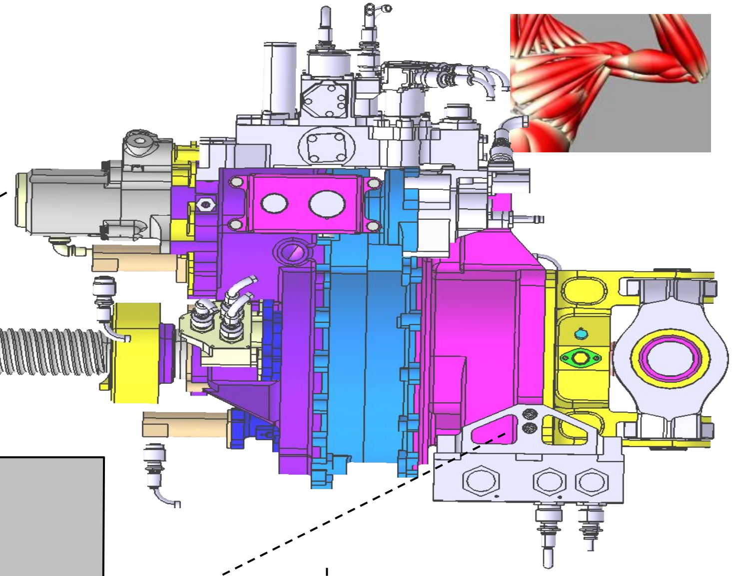


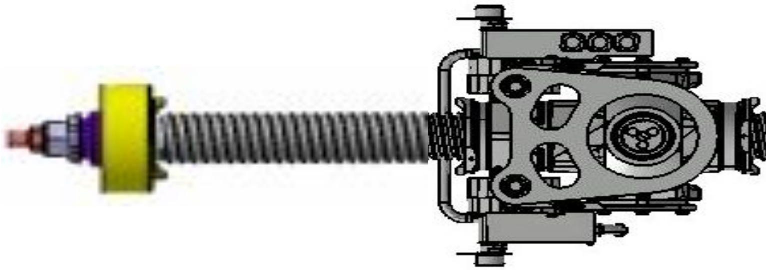


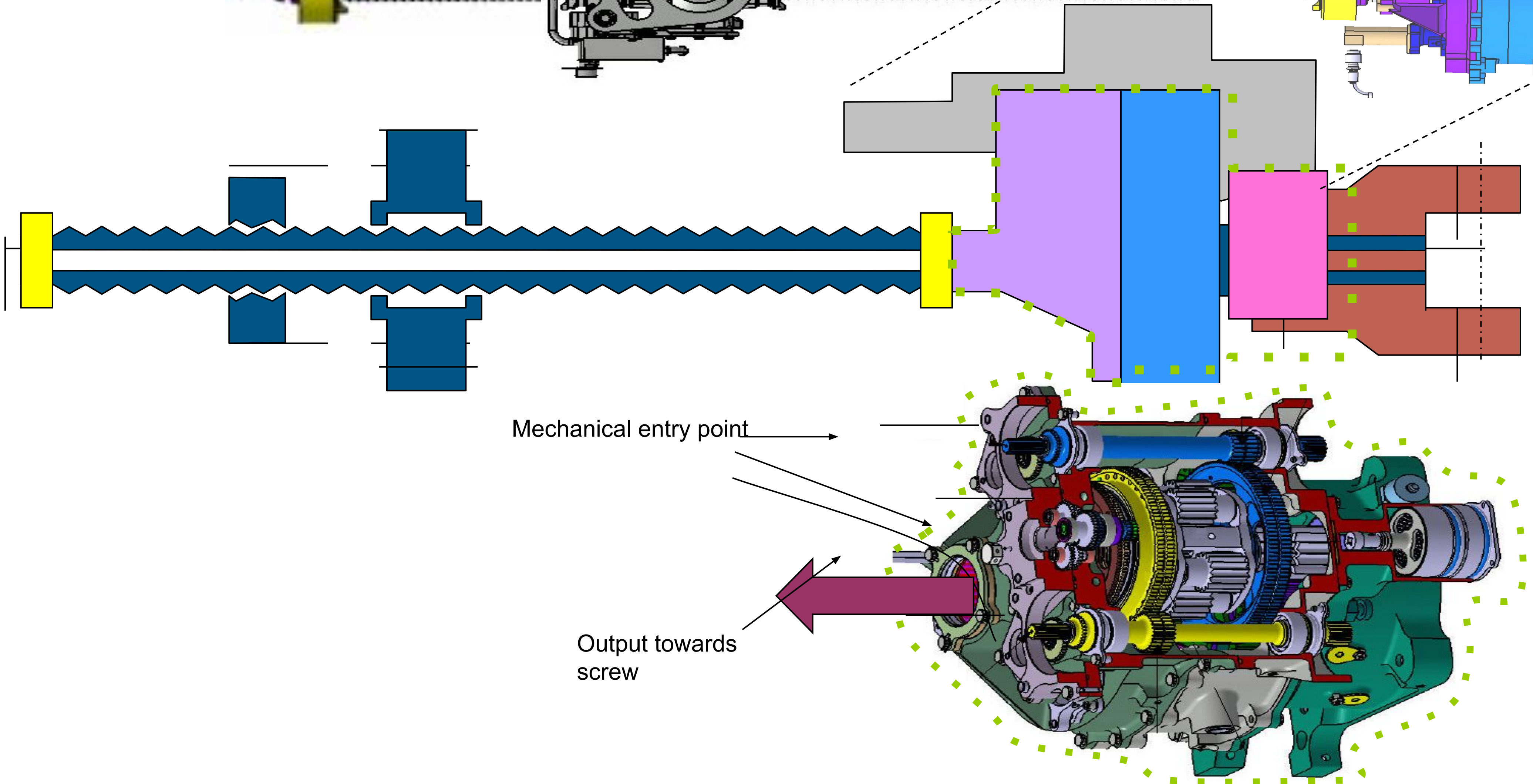
AIRBUS

THE MUSCLES: ACTUATORS

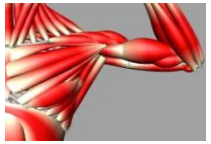
- With gearbox





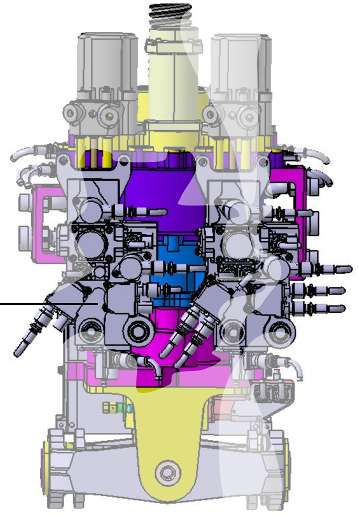


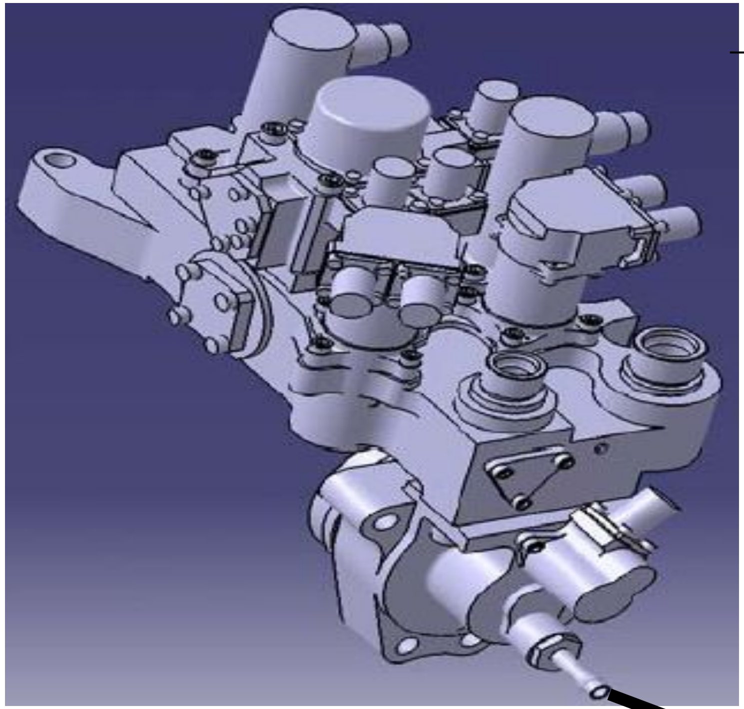
BLUE HYDRAULIC
GEARBOX

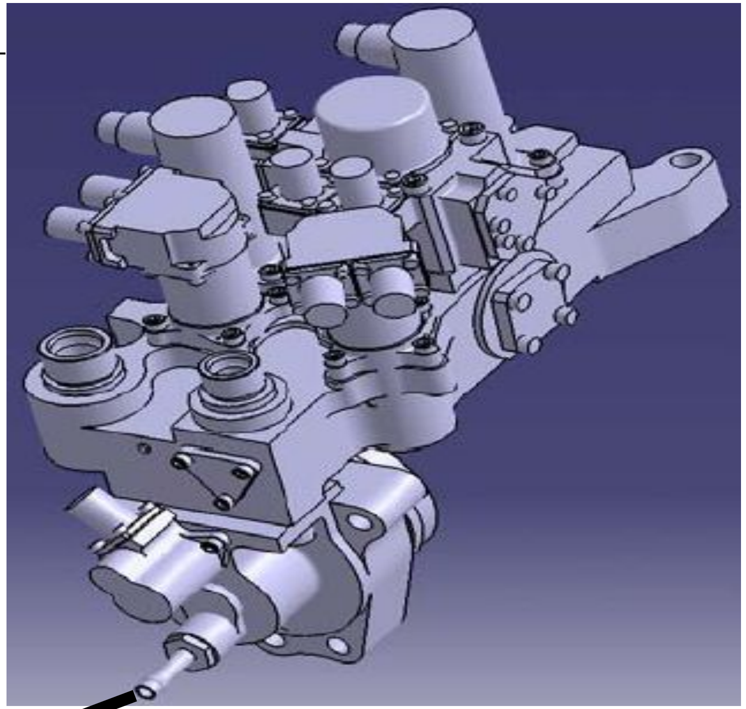


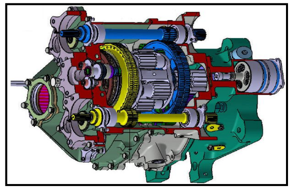
THE MUSCLES: ACTUATORS

- Actuator principle



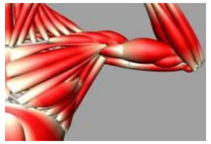




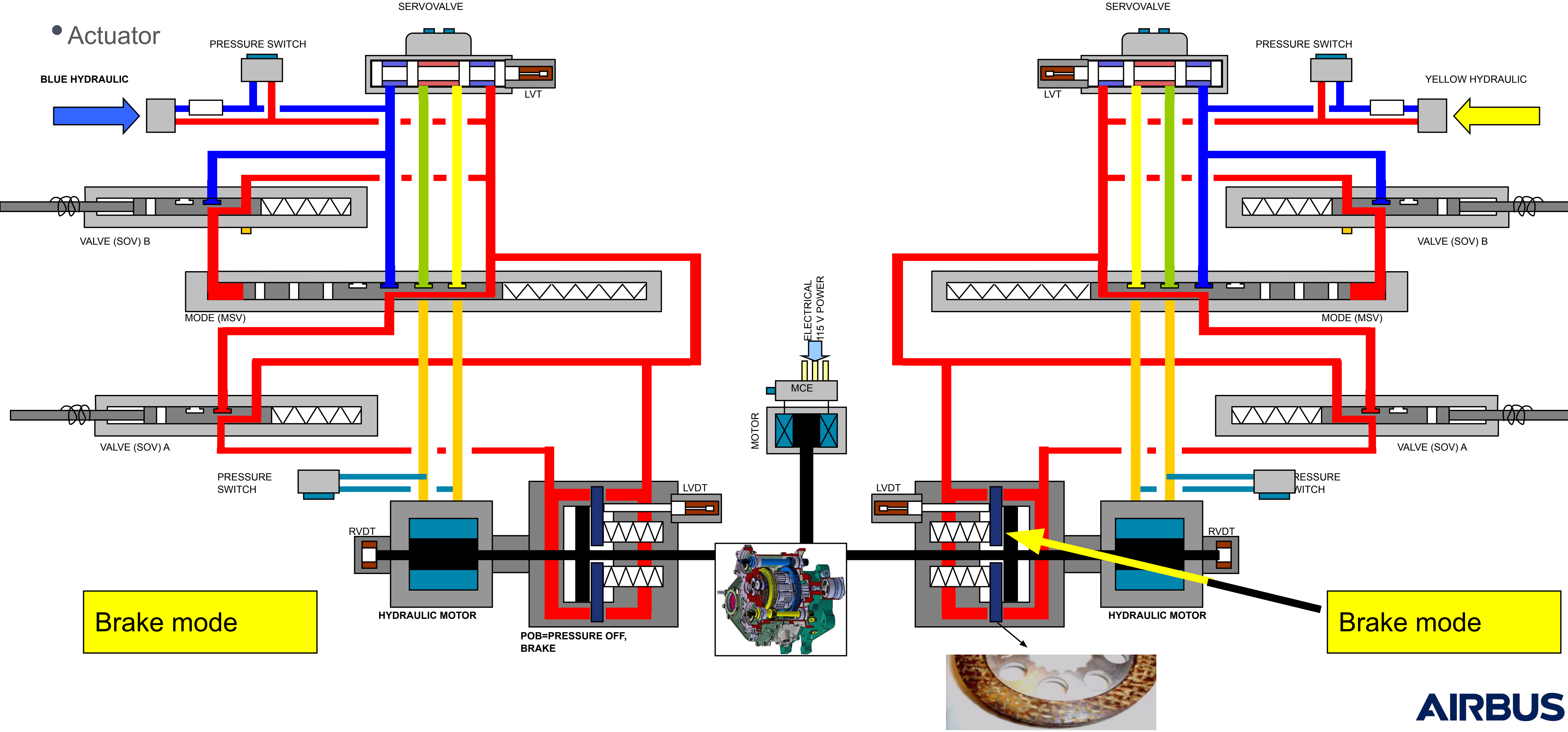


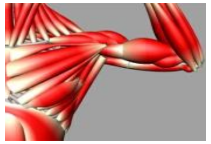
AIRBUS

THE MUSCLES: ACTUATORS



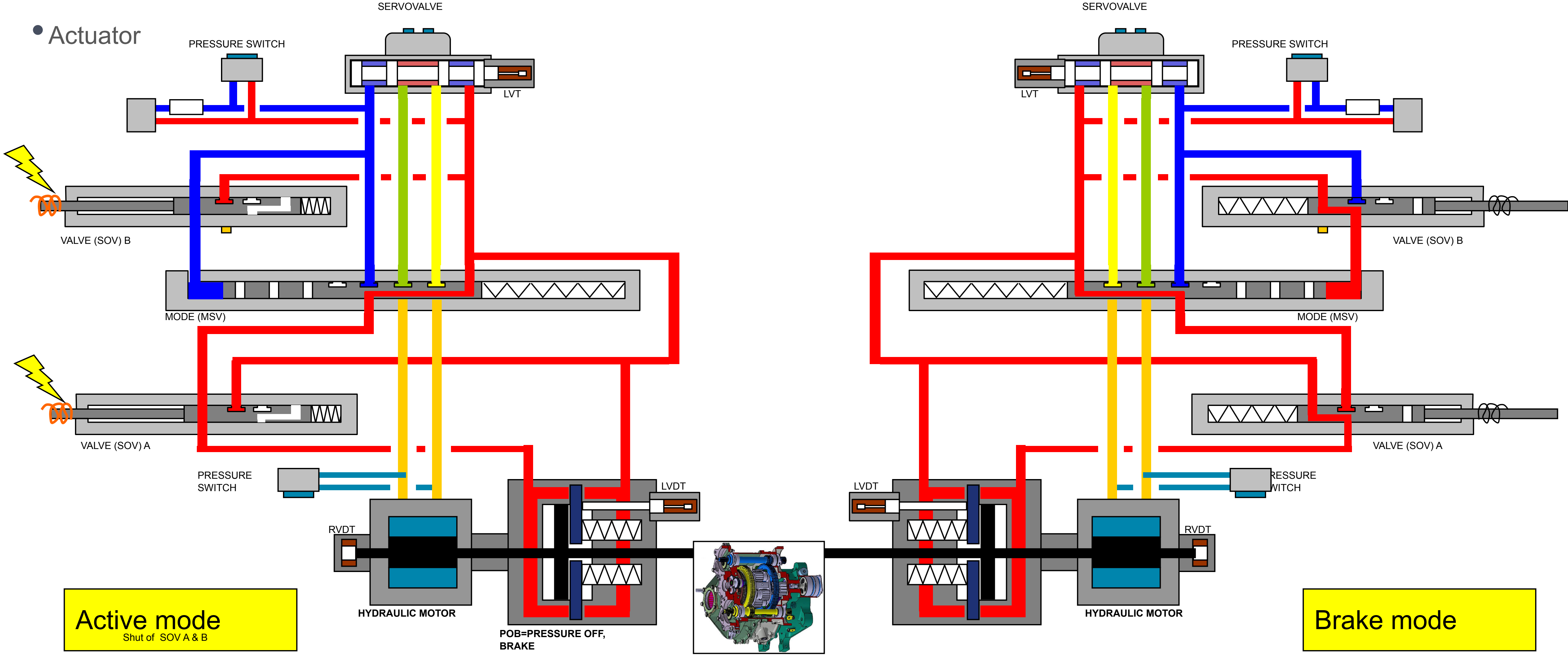
- Actuator





THE MUSCLES: ACTUATORS

- Actuator



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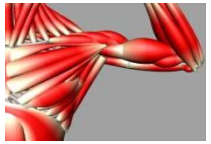
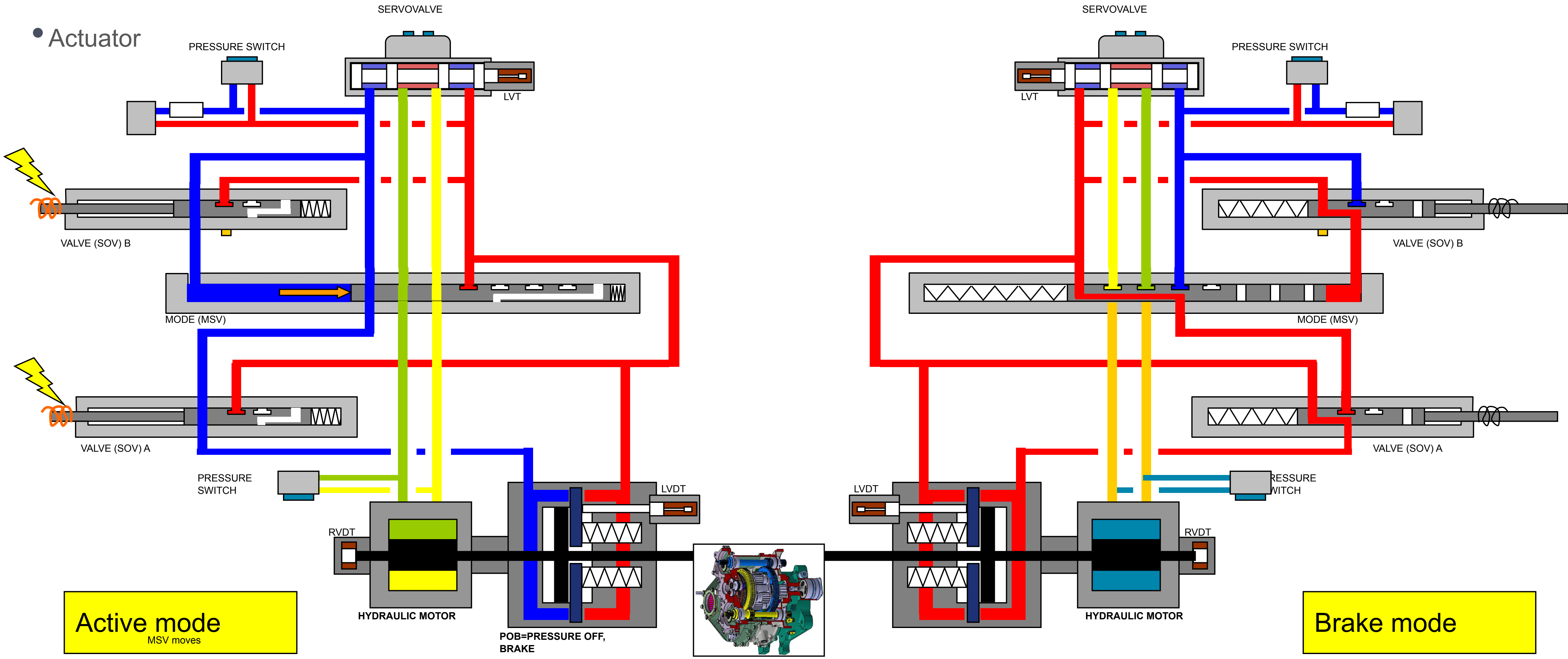


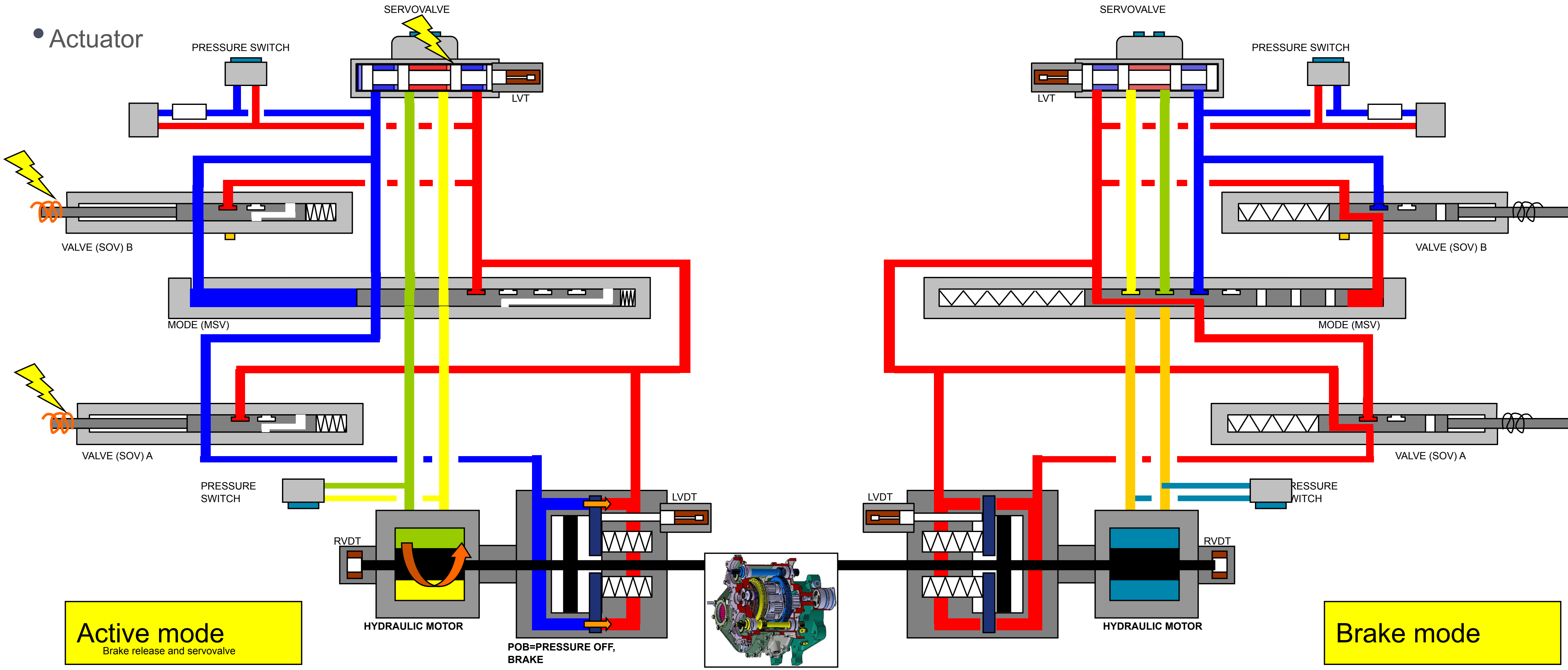
- Actuator



AIRBUS

THE MUSCLES: ACTUATORS

- Actuator



THE BLOOD: POWER SOURCES

- Actuators consume the major part of the energy used in the flight controls:
  - 120 kW on A320 and 500 kW on A380
  - Computers only 100 W per unit (on average)

- Up to now, the energy was mainly supplied by the hydraulic system but electricity will soon be here with the EHAs and the EBHAs

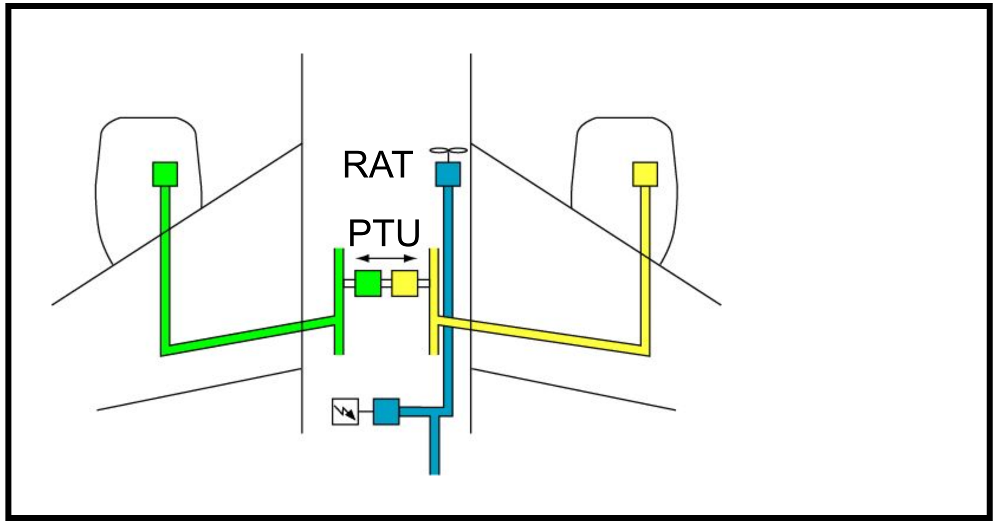
- The flight controls are the main customer of the hydraulic system and are beginning to weigh on the electrical power budgets

- As the flight controls do not mess about with safety, it is normal that they influence the power architectural choices

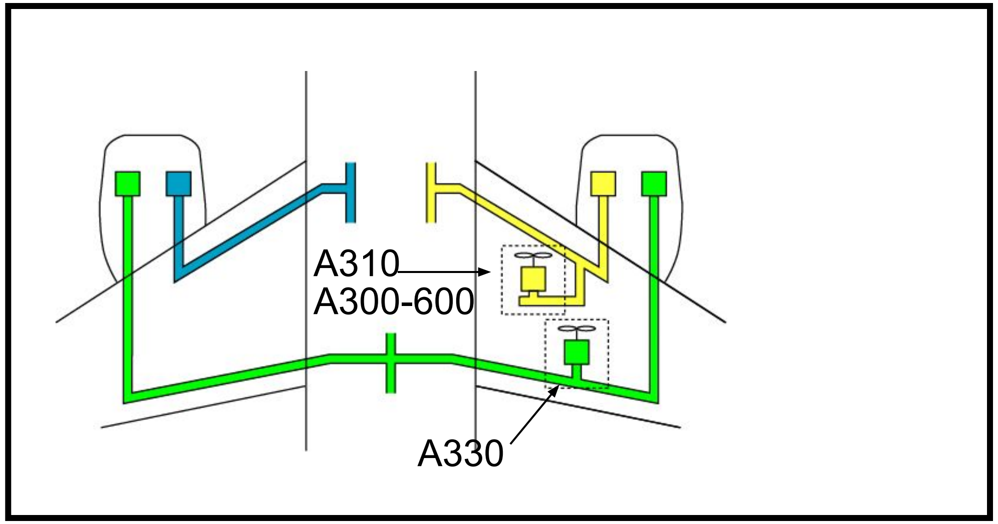
THE BLOOD: POWER SOURCES

- 3-HYDRAULIC SYSTEM ARCHITECTURES

  - To meet the safety constraints, 3 independent circuits are required
  - For a two-engined aircraft:
    - One circuit per engine and the third one on electric pump (A320)
    - One circuit per engine and the third one on two engines (A300 and A330)
    - In case of dual engine failure, a circuit pressurised by a RAT
    - On the A320, a PTU ensures the pressure of a circuit after the failure of an engine (to control the landing gears)



A320



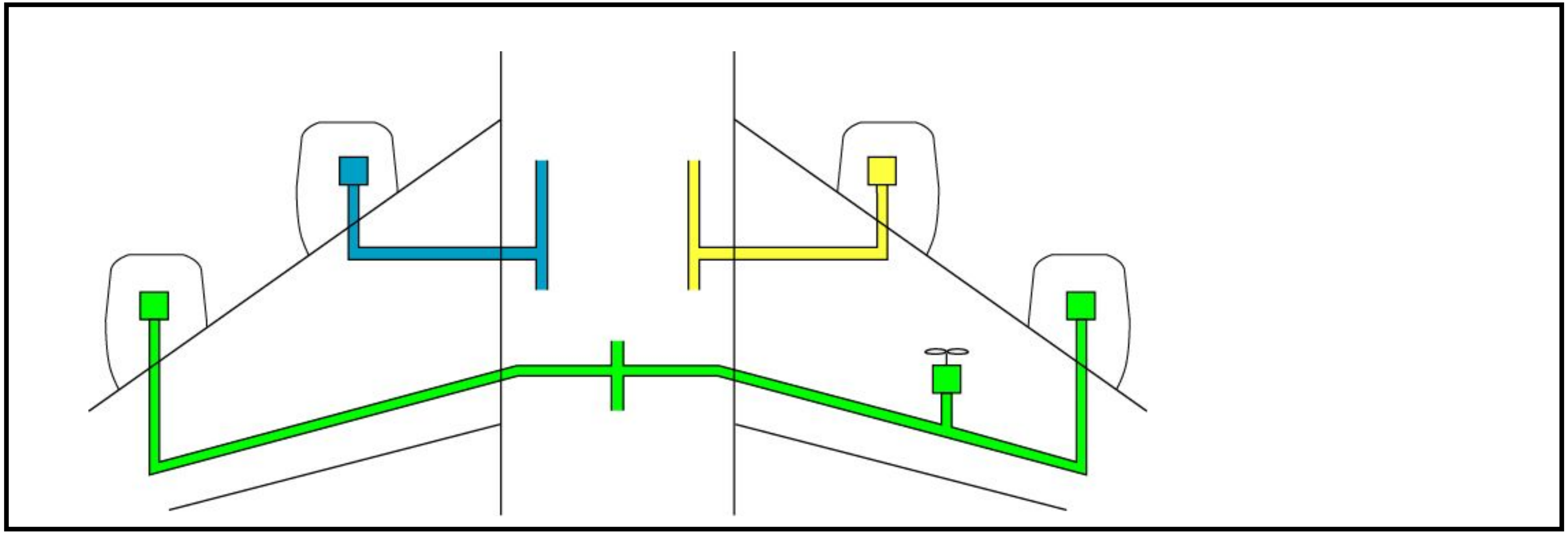
A310-A300-600 / A330

PTU* ***Power Transfer Unit***
RAT* ***Ram Air Turbine***

THE BLOOD: POWER SOURCES

- 3-HYDRAULIC SYSTEM ARCHITECTURES

  - For a four-engine aircraft:
    - One circuit per inboard engine
    - The third one on the two remaining engines

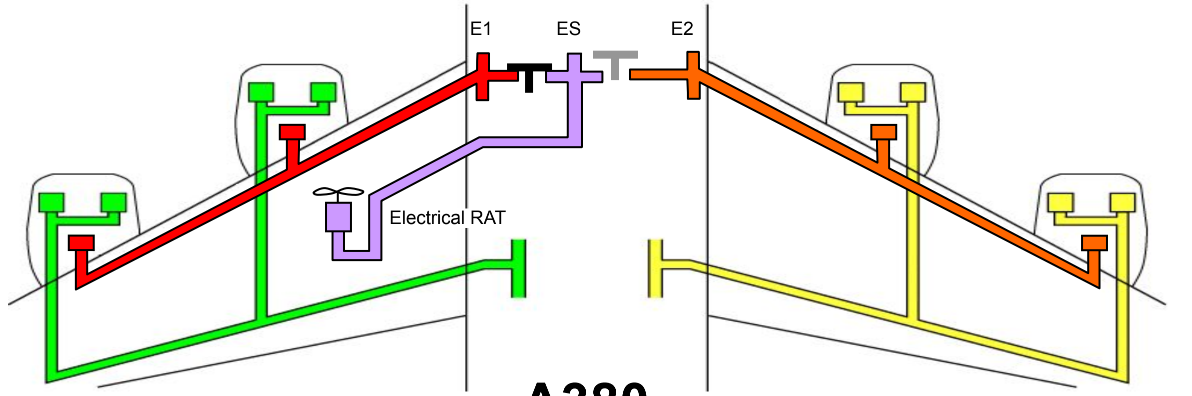


A340

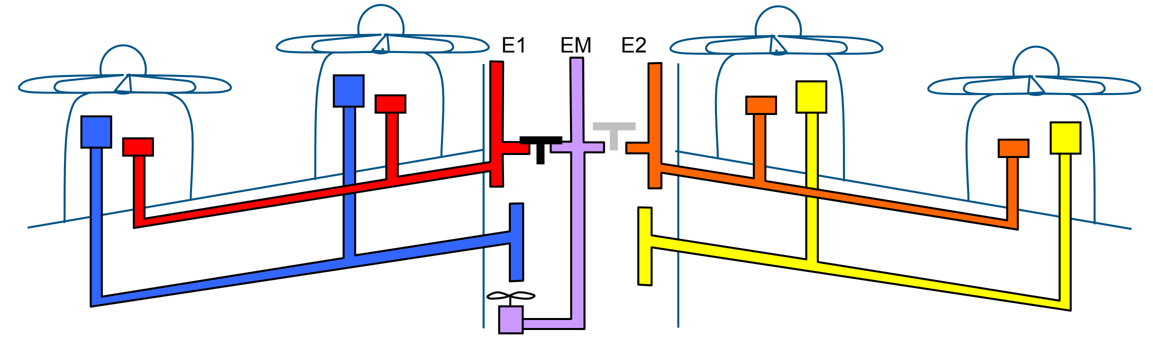
THE BLOOD: POWER SOURCES

- HYBRID HYDRAULIC/ELECTRICAL ARCHITECTURES

    - 2 hydraulic systems are sufficient as, in case of dual failure, there are the EHAs and EBHAs
    - One electrical RAT is sufficient
    - Even if a single electrical circuit is sufficient, as the aircraft proposes 2, we profit from this (it is free!) to segregate. Hence the name 2H/2E



A380



A400M

THE BLOOD: POWER SOURCES

- EVEN LESS HYDRAULICS?

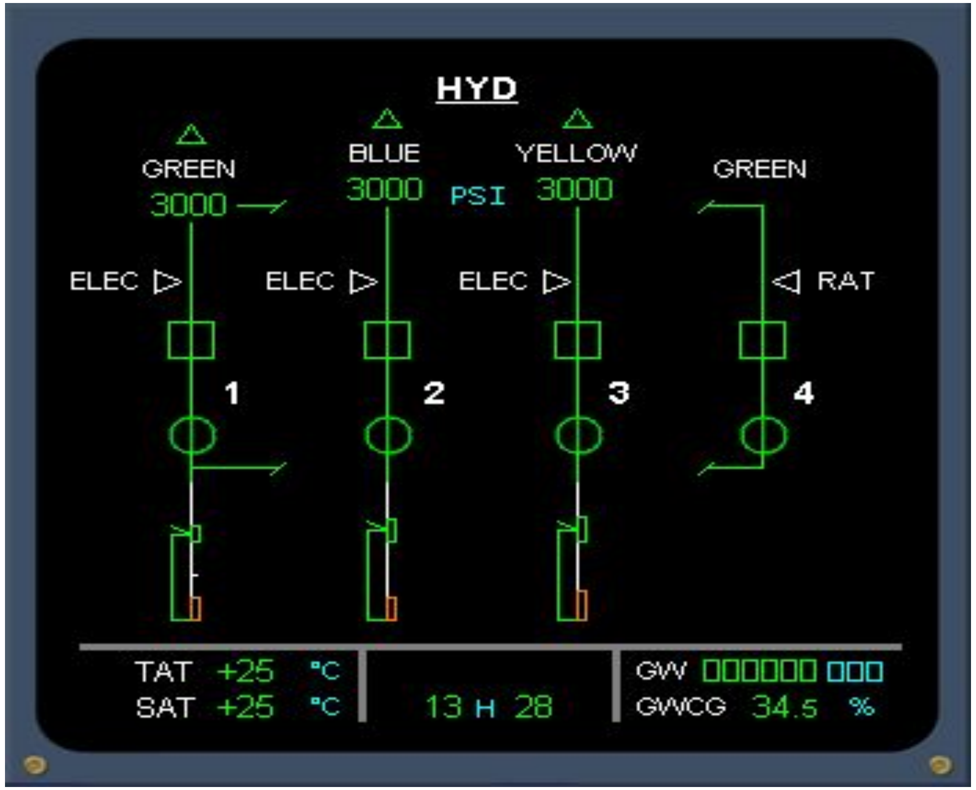
  - The tendency is towards all-electric
  - With 2H/2E, the EHAs and EBHAs ensure the backup. With 1H/2E, they must be used in the nominal manner
  - For the moment, we do not have sufficient feedback to make the step and we think that it would be preferable to pass onto another actuator technology

  - For the change to an all-electric aircraft to be profitable, all the systems must be electrical. This is not a foregone conclusion for the landing gears

THE BLOOD: POWER SOURCES

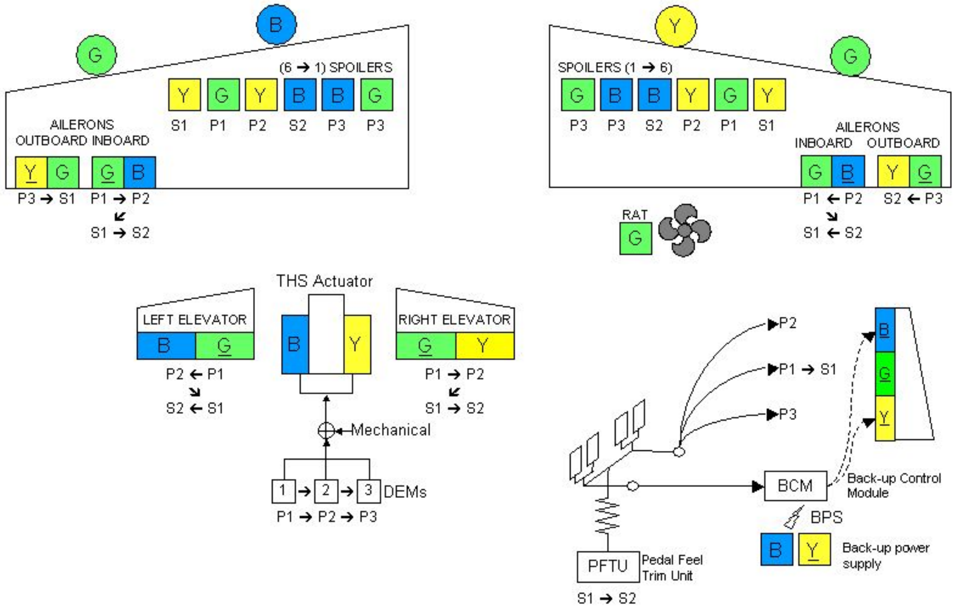
- HYDRAULICAL ARCHITECTURE (cockpit)

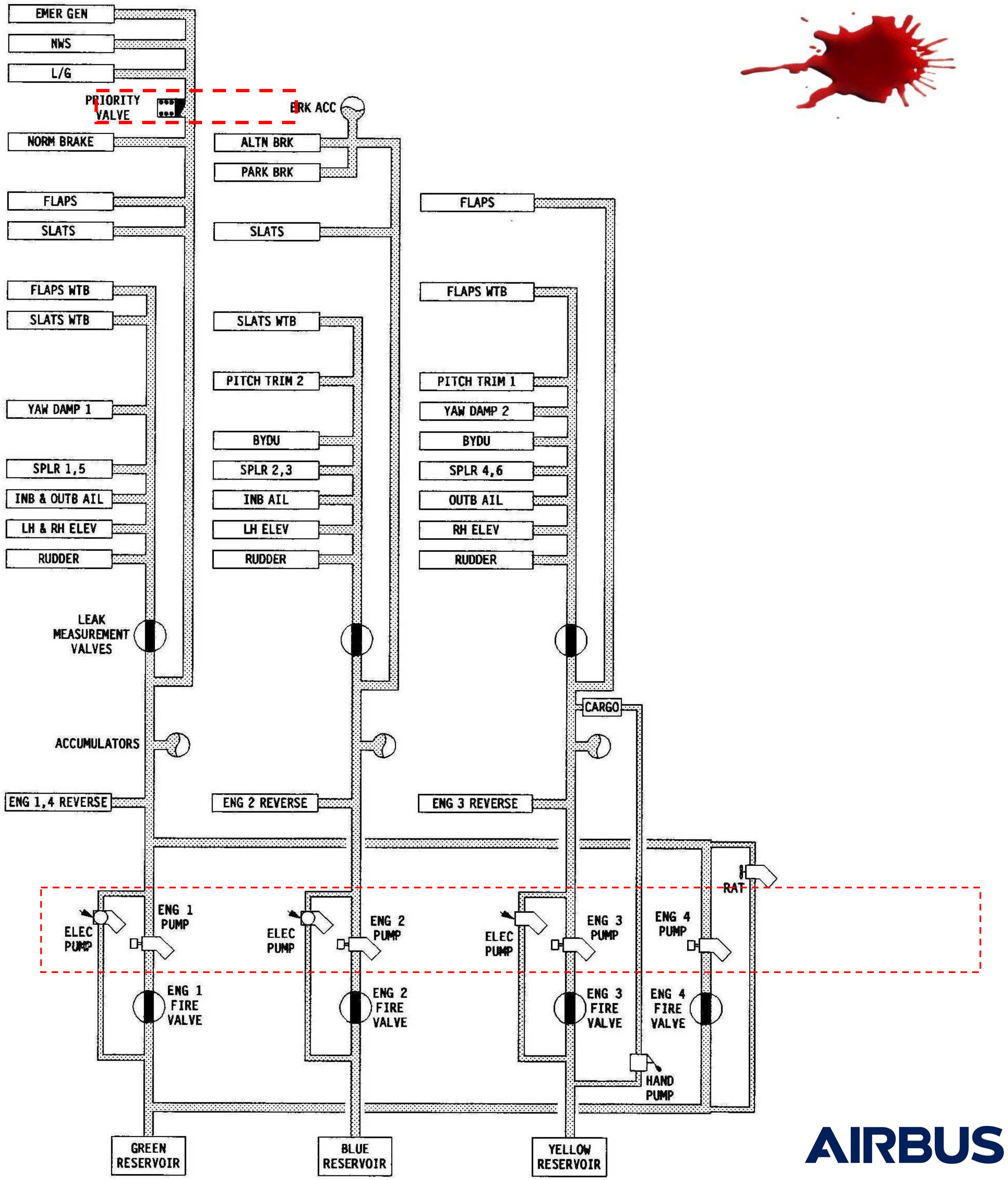
Ex A340



THE BLOOD: POWER SOURCES

- HYDRAULICAL ARCHITECTURE
  Ex A340

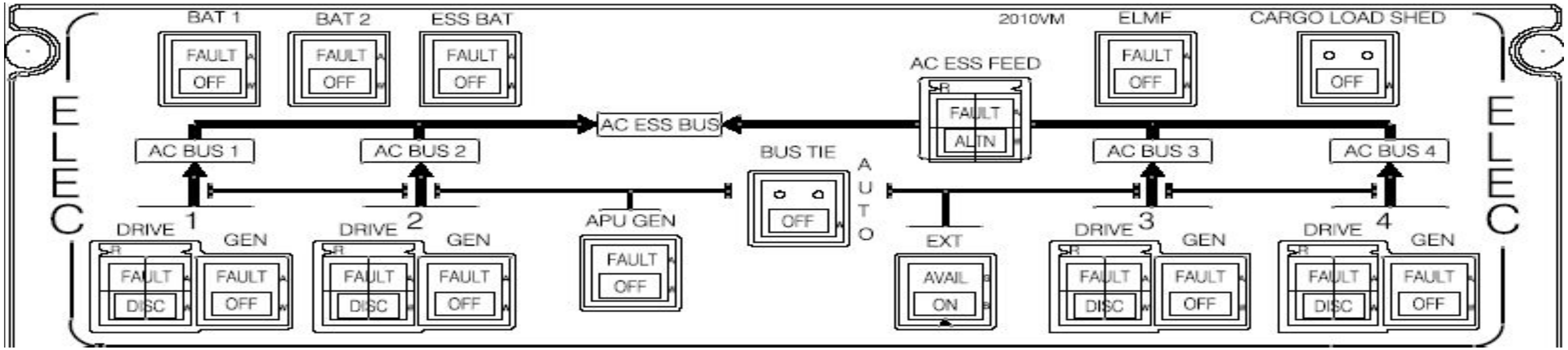


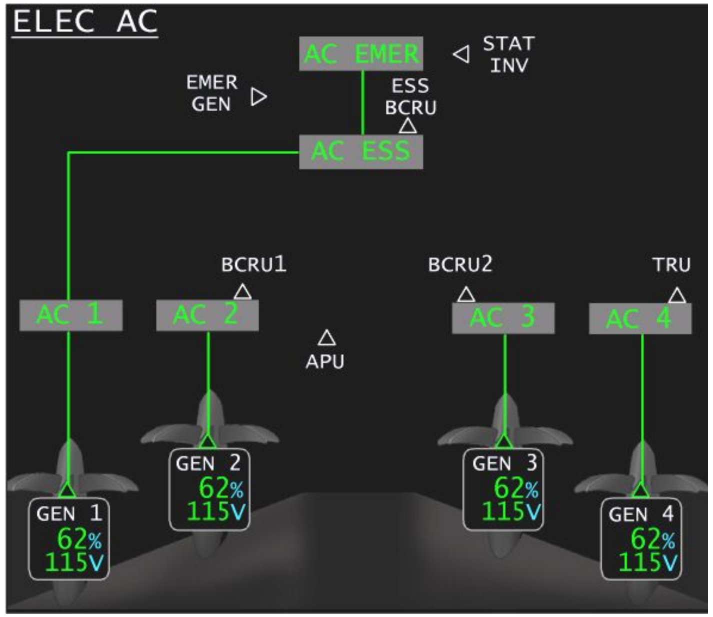


THE BLOOD: POWER SOURCES

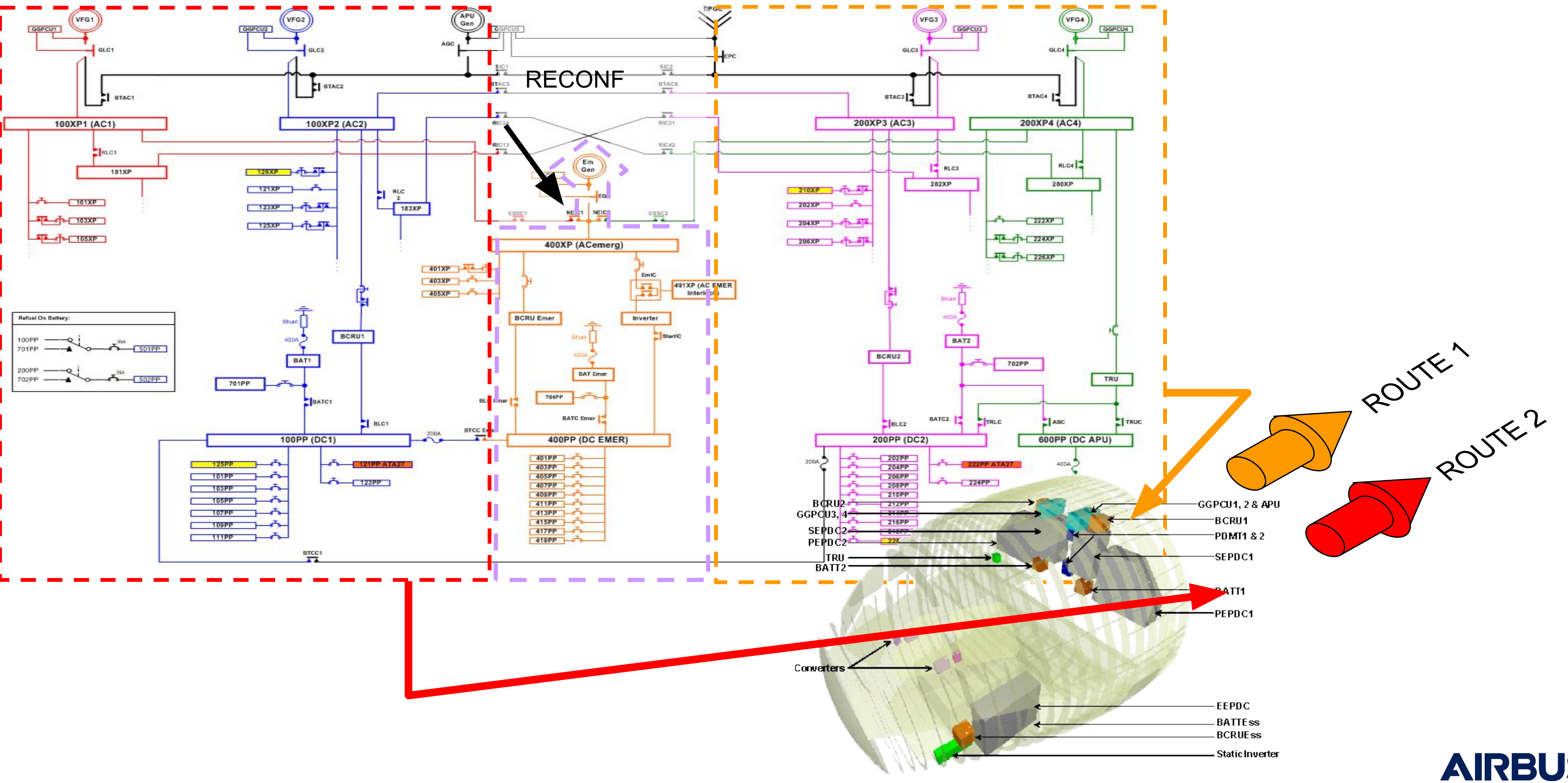
- ELECTRICAL ARCHITECTURE

  Ex A400M





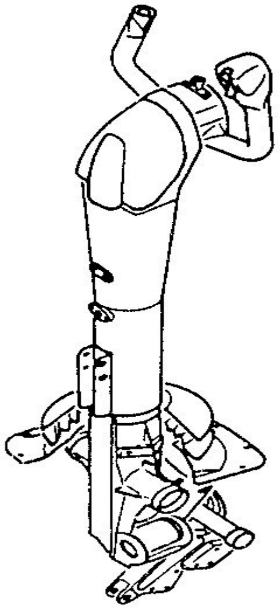
THE BLOOD: POWER SOURCES

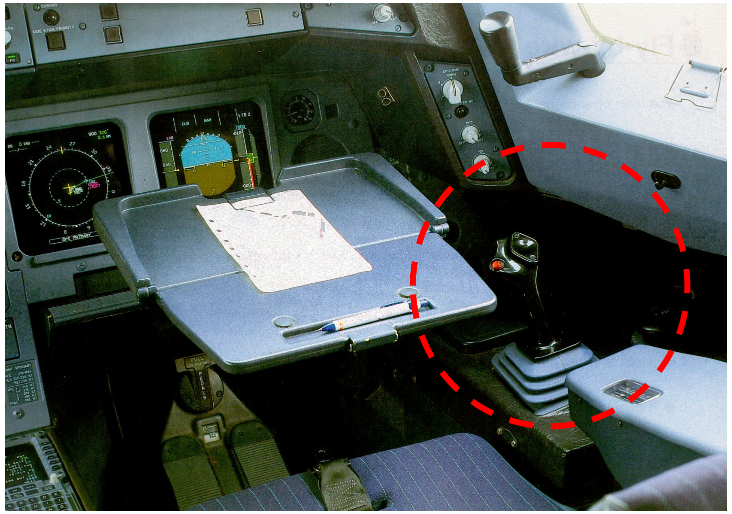


AIRBUS

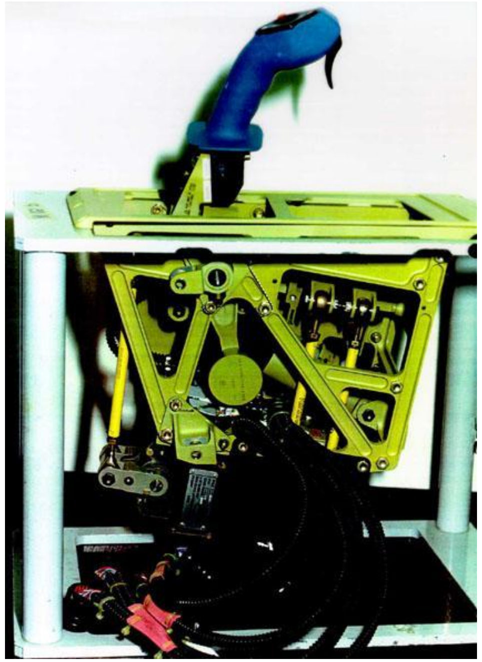
THE SENSES: FLIGHT CONTROL COMPONENTS

- SIDESTICKS





Wide view and a tablet



The iceberg …

A400M HOTAS sidestick (Hand On Throttle And Sidestick)

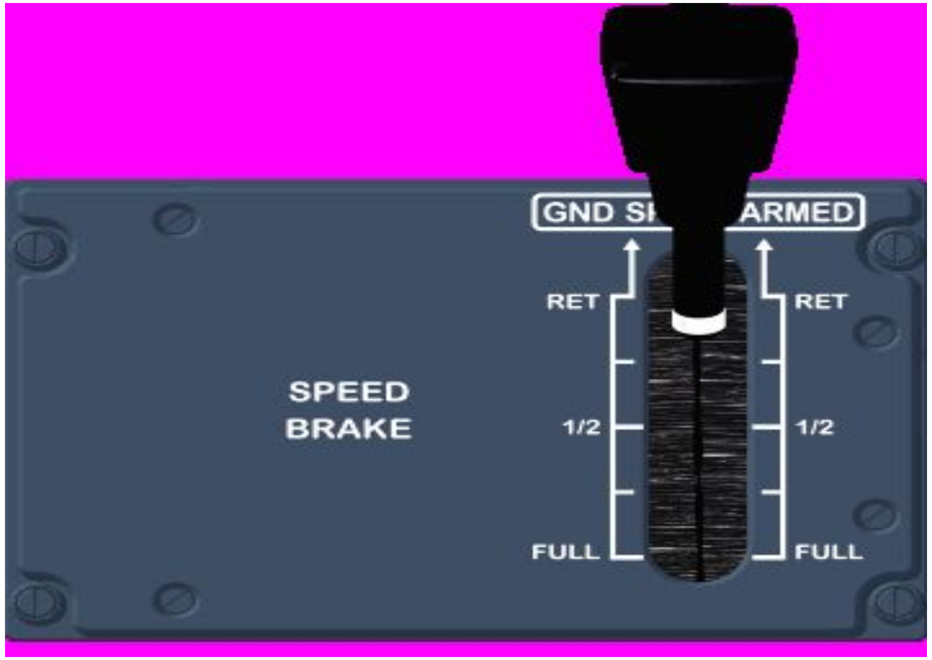
THE SENSES: FLIGHT CONTROL COMPONENTS

- THE SIDESTICKS
  - The sidesticks are the logical conclusion of the fly-by-wire controls whereas the traditional control columns find their utility for hydro mechanical controls where the force to be delivered by the pilot is high.
  - Thanks to the sidesticks, the design is much simpler both mechanically (frictions, hysteresis, etc.) or in terms of safety analysis (no common mode as no coupling, etc.). Note that many APC problems were encountered on the 777 (cf. videos) simply with the mechanics of its control columns.
  - The main disadvantage is the absence of mechanical feedback on the First Officer’s actions. However:
    - the dual input is not a standard procedure (civil aircraft),
    - returns are available to avoid confusion (buzzer, audio and visual),
    - powered sticks have been studied but the game is not worth the candle.

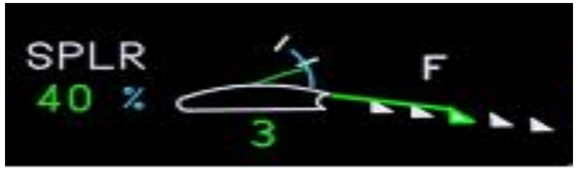
THE SENSES: FLIGHT CONTROL COMPONENTS

- AIRBRAKES

Civil like



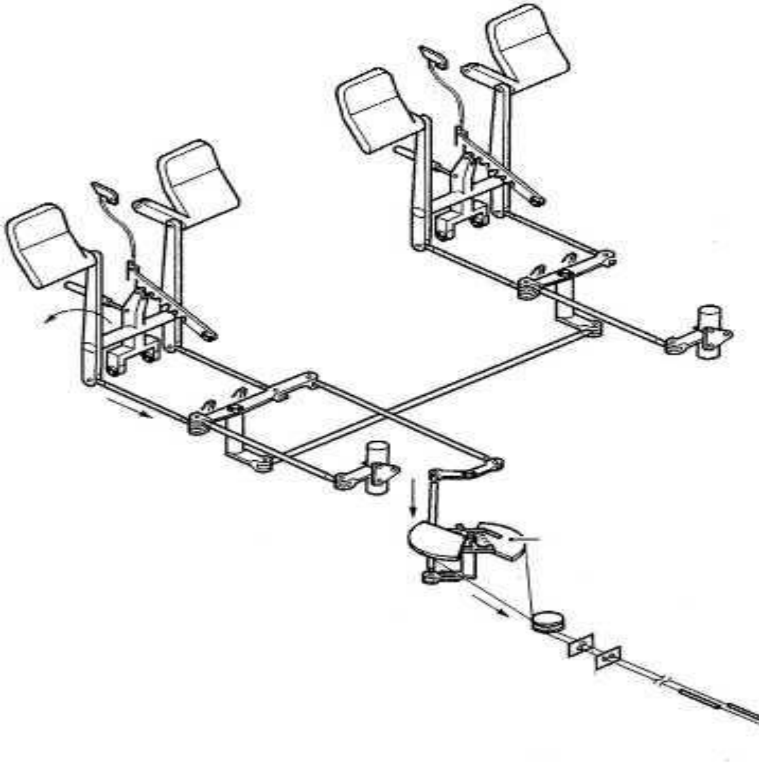
Military Like

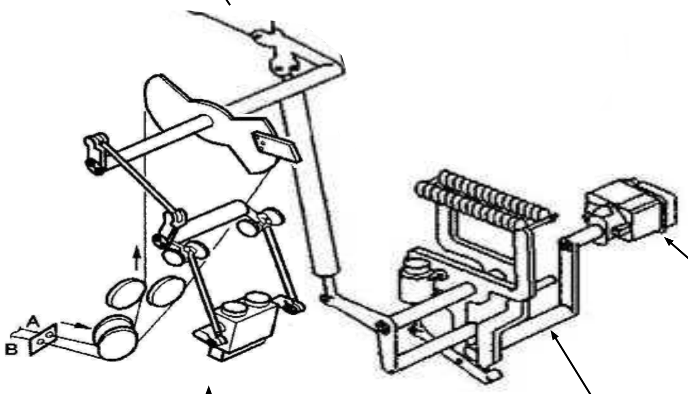


THE SENSES: FLIGHT CONTROL COMPONENTS

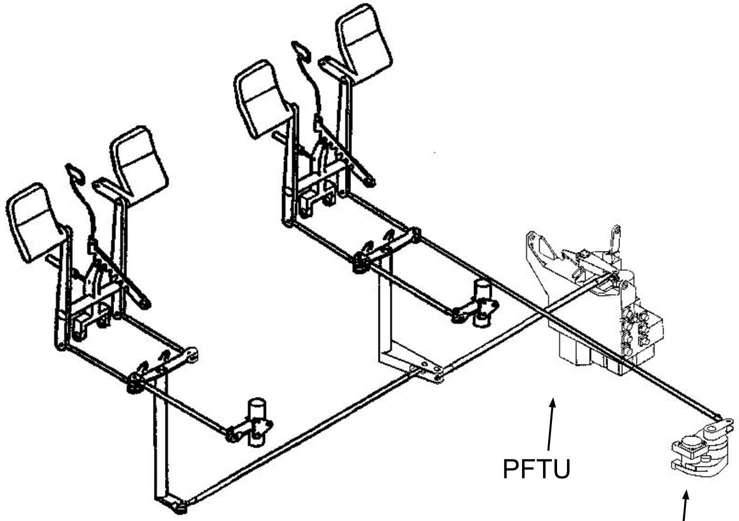
- PEDALS

With mechanical yaw axis





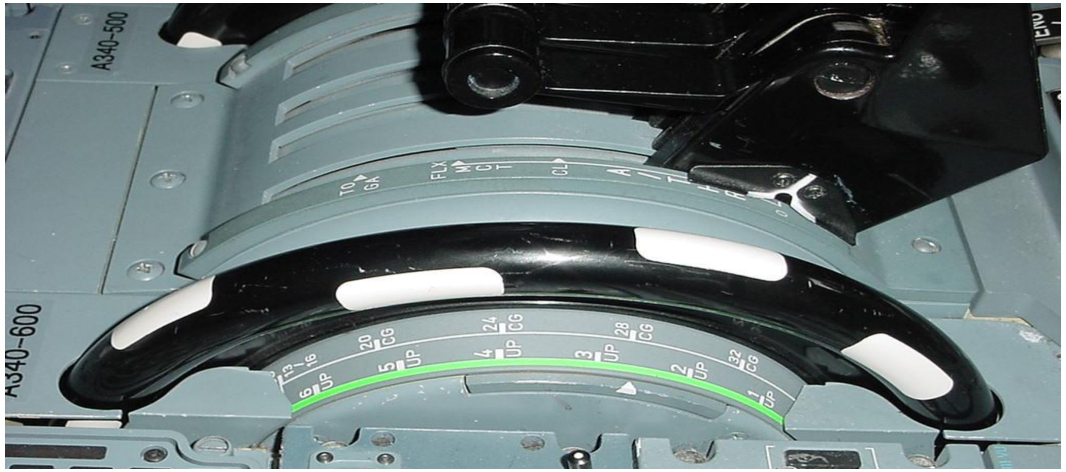
With electrical yaw axis

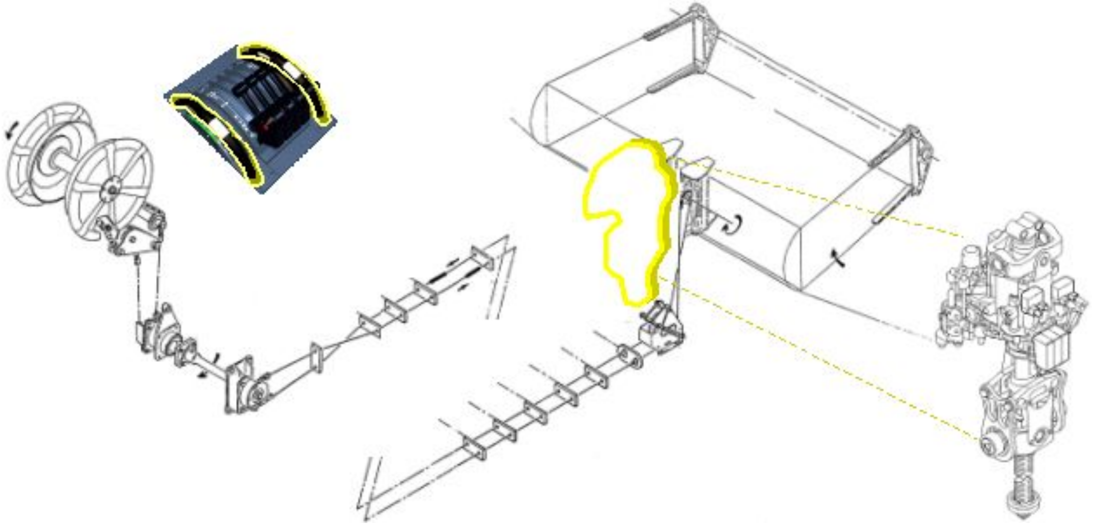


THE SENSES: FLIGHT CONTROL COMPONENTS

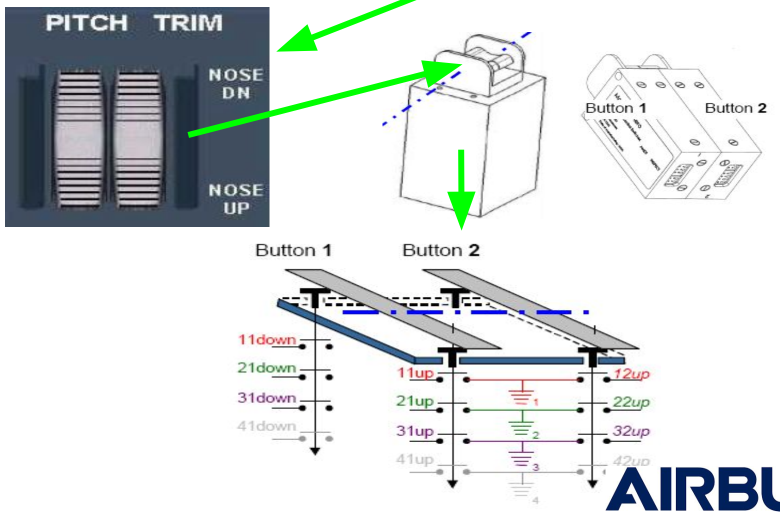
- PITCH TRIMS

With cable towards THS

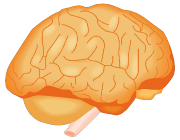




With THS electrical signalling



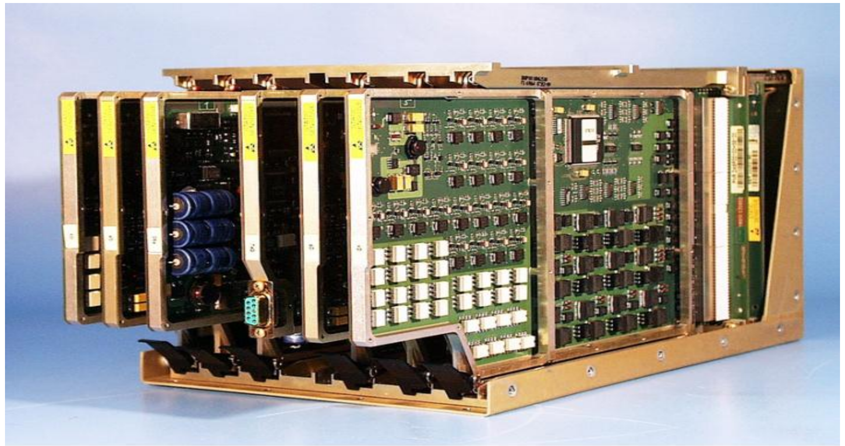
THE BRAIN: COMPUTERS WHICH CONTROL



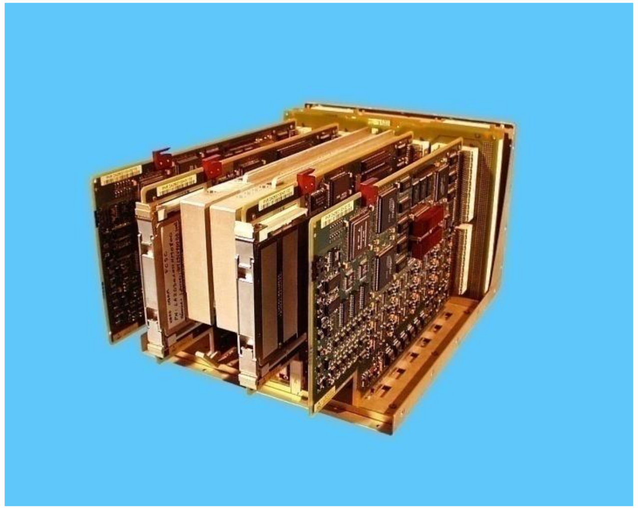
HIGH-TECH ELECTRONICS, HOSTILE ENVIRONMENT

- High-tech electronics, conventional for aeronautics:
  - Standard proven components (A320 with 68000, A340 with 386 then 486, A400M with G3-PPC755, USB hubs between boards)
  - Obsolescence management increasingly difficult (delicate choice of components, storage, etc.)
  - Massive use of ASICs
  - Maximum manufacturing quality (now 100% AIRBUS for better control)
  - Specific flight controls interfaces (ANI, ANO, etc.)
  - Downloadable software
  - Self-correcting RAMs
  - Strict management of dissemblance (to avoid the very feared common mode)

- Hostile environment:
  - High mechanical strength (vibration, especially windmilling, etc.)
  - Heat resistance (loss of ventilation, etc.).
  - SEU resistance (cosmic neutrons)
  - Lightning resistance (WF4 and WF5A)

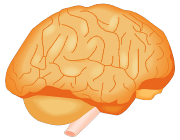


A380 BOITIER FCGU

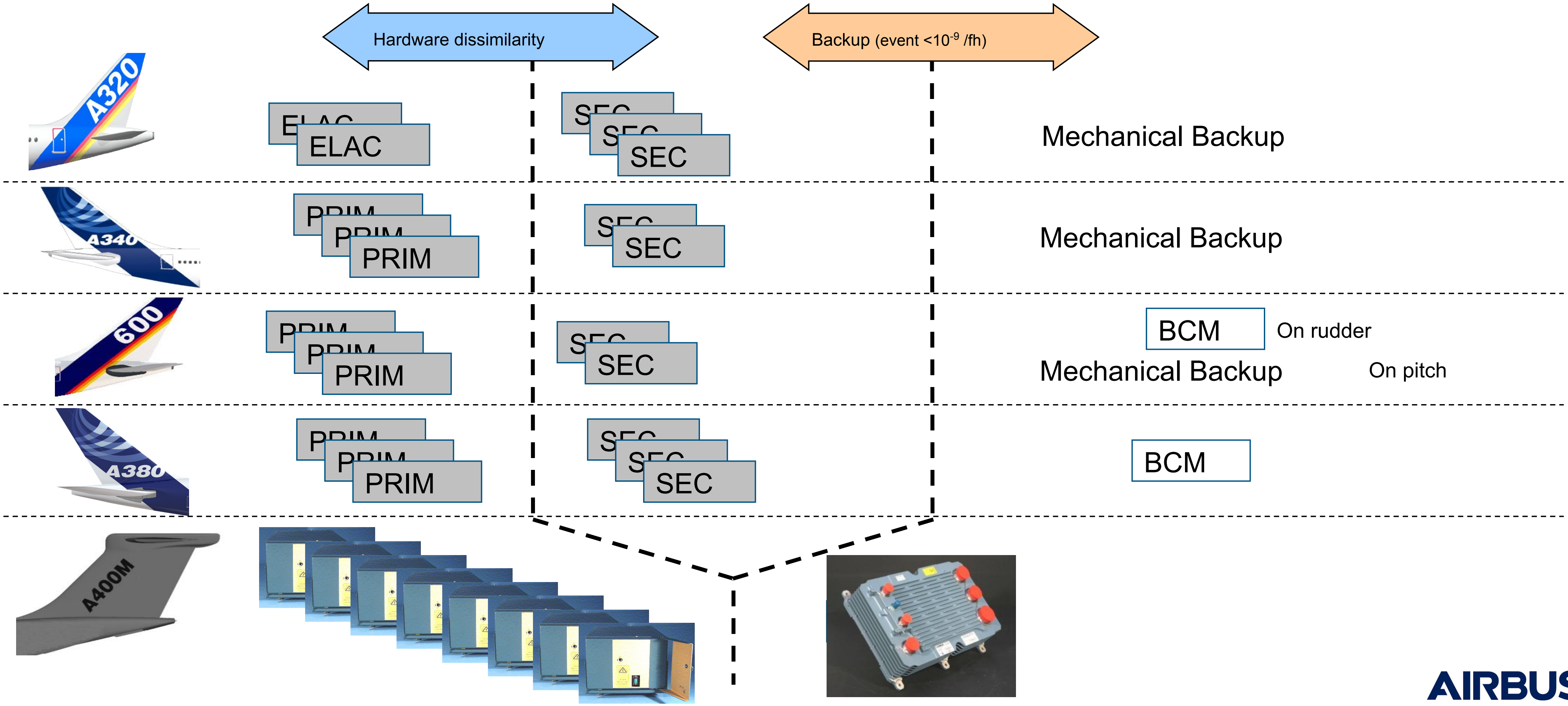


A340-600 SEC

THE BRAIN: COMPUTERS WHICH CONTROL



- DISSIMILARITY & REDUNDANCY



AIRBUS

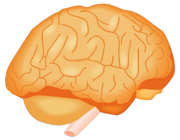
THE BRAIN: COMPUTERS WHICH CONTROL

redundancy

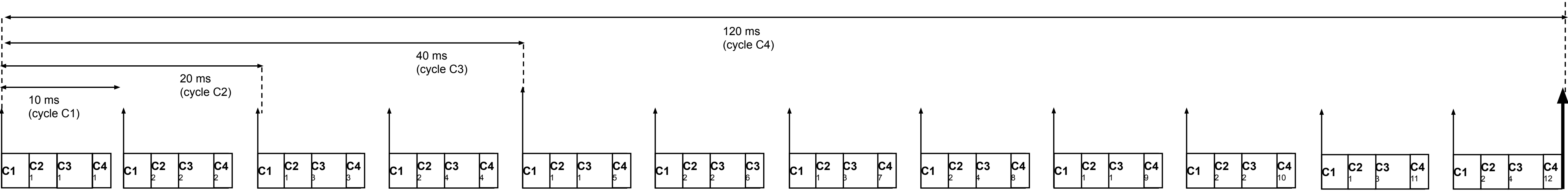
dissimilarity

AIRBUS

THE BRAIN: COMPUTERS WHICH CONTROL

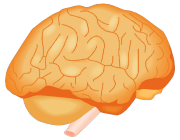


- TIME MANAGEMENT
  - For the flight controls, the software must be sequenced in a deterministic manner (we cannot expect to wait for Windows when the stability of a servoloop is in question)
  - There are 4 cyclic tasks with different periods (10, 20, 40 and 120 ms)

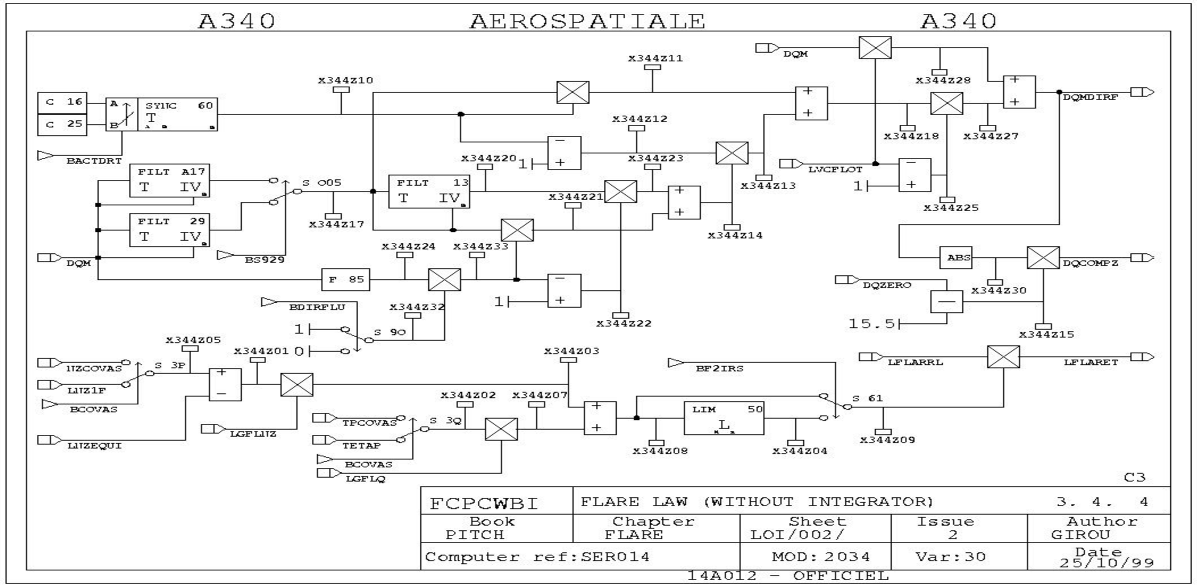


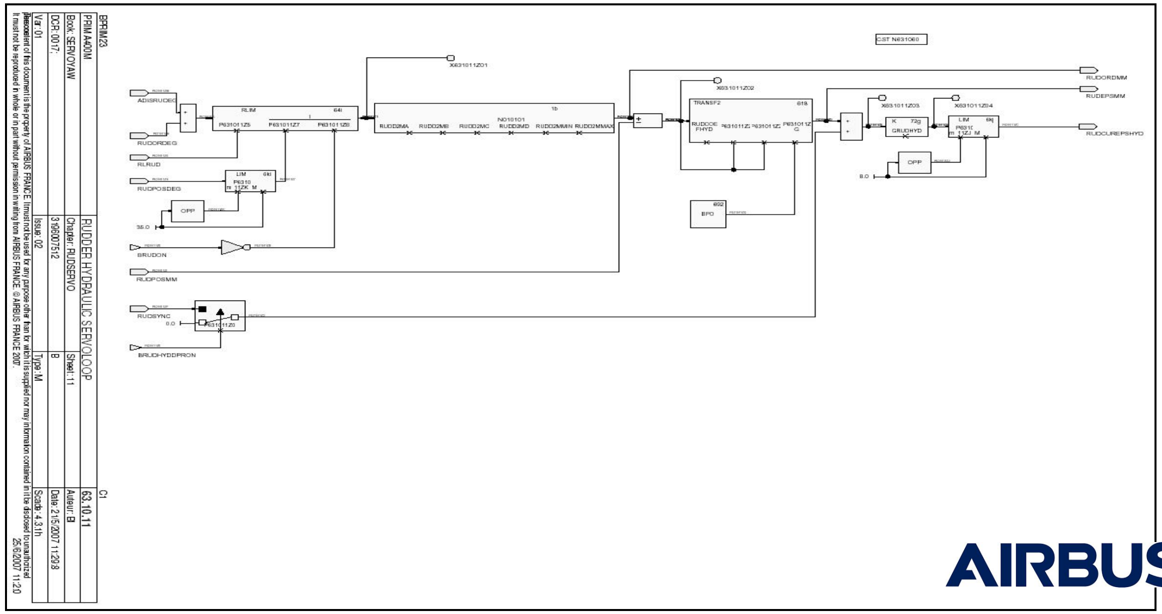
  - We must guarantee that there is no CPU overflow. For this, we calculate the WCET (Worst Case Estimated Time), that is the worst CPU overload configuration
  - For the functions with high time constraints (when stability is in question for example), we specify the location and the order of the processes within cyclic subtasks (which is the same as inhibiting the automatic sequencer)

THE BRAIN: COMPUTERS WHICH CONTROL



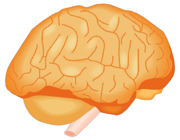
- SAO, SCADE AND AUTOMATIC CODING
  - The flight control engineer specifies the functions in a simple graphic language (of Simulink type) which can be either SAO (cf. below) or SCADE
  - The equipment manufacturer (AIRBUS...) uses this language to automatically code the contents of the computers
  - The coding chain is certified
  - The reactivity is phenomenal (under high pressure, a change can reach the aircraft in 24 hours where other systems are limited to several months)





AIRBUS

THE BRAIN: COMPUTERS WHICH CONTROL

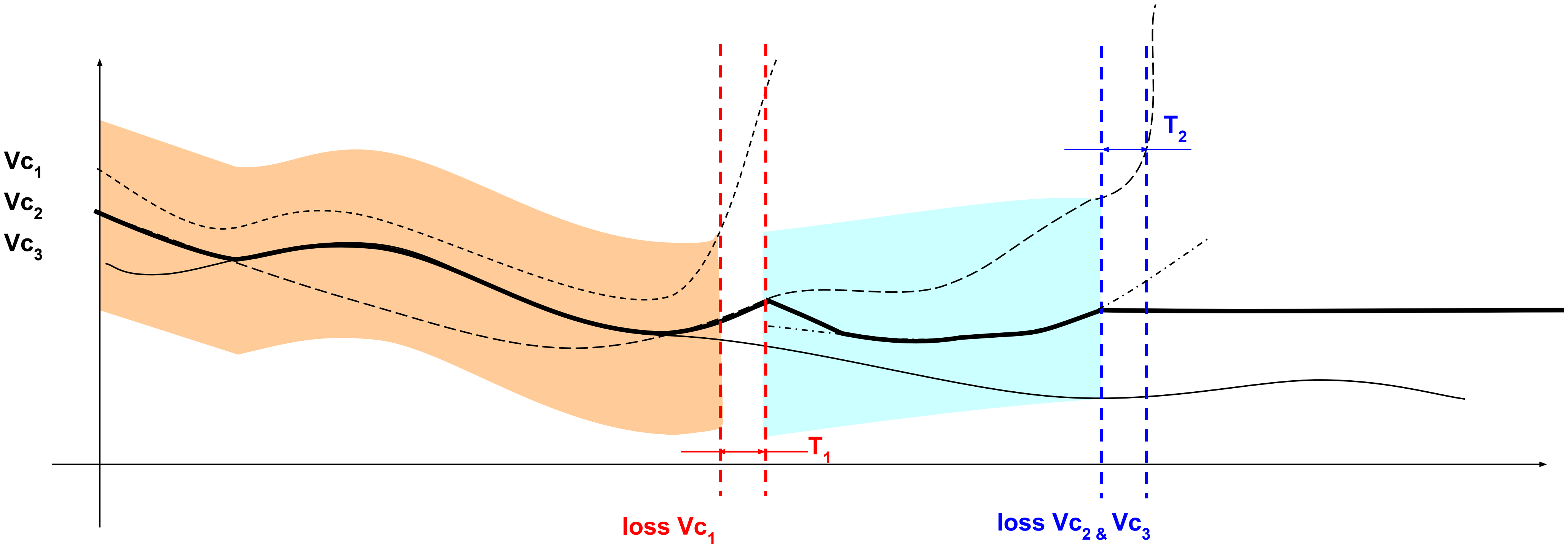


- ROLE OF COMPUTERS
  - Host the laws
  - Manage the multi-computer aspect
  - Control the aircraft control surfaces
  - Monitor, monitor and remonitor all inputs and outputs and monitor themselves:
    - Triplex
    - COM/MON
    - Etc.
  - Implement automatic controls to lighten the pilot’s workload such as, for example, reconfiguration logics (degraded laws or flight phases)

THE BRAIN: COMPUTERS WHICH CONTROL

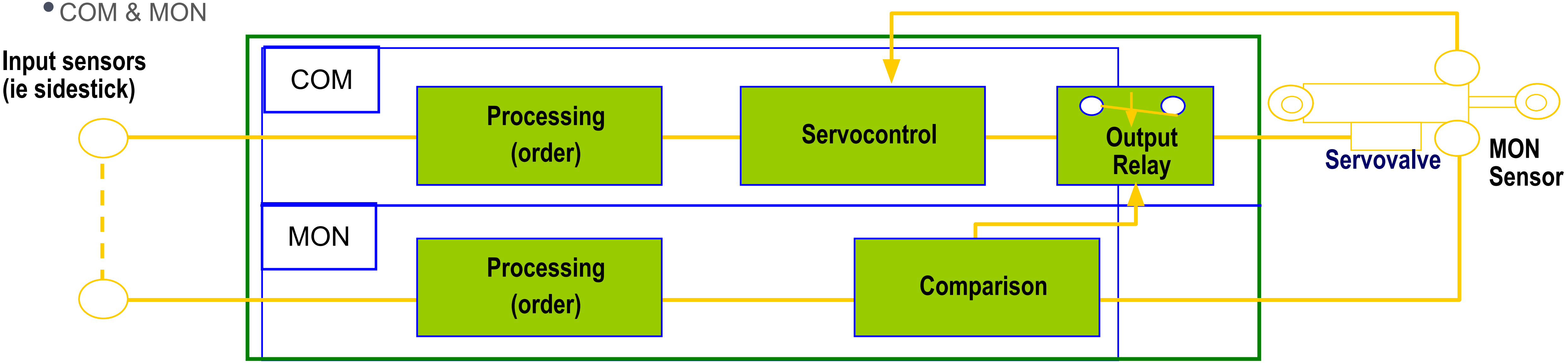
- TRIPLEX

With such a monitoring based on 3 sources, it is extremely improbable to use an erroneous value in the computers



THE BRAIN: COMPUTERS WHICH CONTROL

- COM & MON



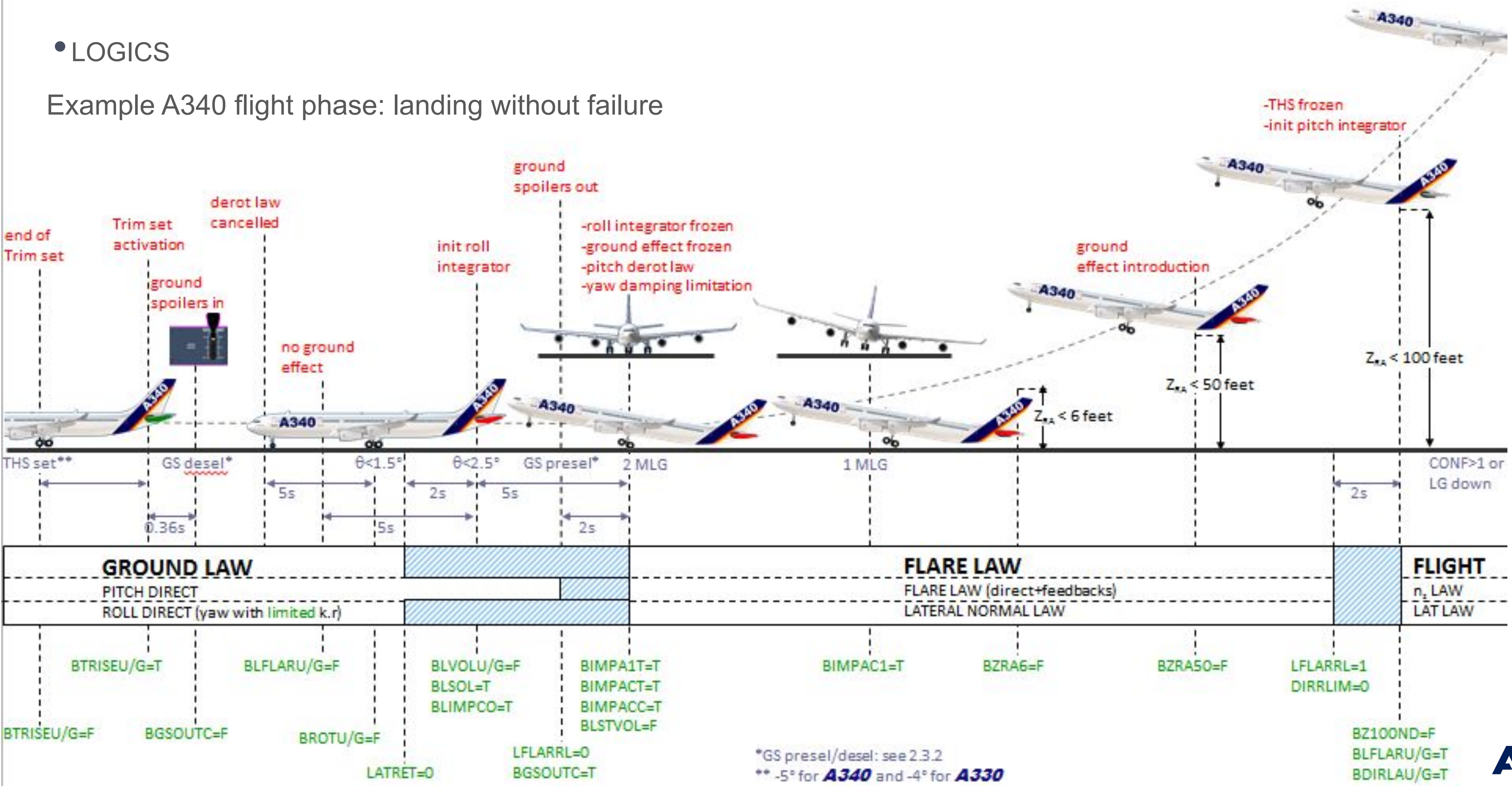
– Failures that lead to a discrepancy greater than a threshold, confirmed for a while, are passivated

– Once passivated, function is either lost, or reconfigured on another resource

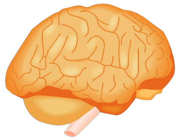
THE BRAIN: COMPUTERS WHICH CONTROL

- LOGICS

Example A340 flight phase: landing without failure



AIRBUS



THE BRAIN: COMPUTERS WHICH CONTROL

- LOGICS

Example A340 laws reconfiguration

NORMAL LAWS

n_z law / Flare law
lateral normal law

High speed protection
AOA protection:
- α protection
- θ protection
- α floor
- low energy

Loss of:
- THS control (actuation/position)
or
- Slats or Flaps position
or
- 1 elevator
or
- PRIM and SEC rudder control (***ENHANCED***)
or
- Yaw damper actuators (***BASIC)***
or
- 1 ADR + estimated α monitor trigger

ALTERNATE 1

n_z law / Flare law
lateral normal law

VMO2 protection
Vc protection

Loss of of VS1G :
- weight
or
- Slats and Flaps position

ALTERNATE 1A

n_z law / Flare law
lateral normal law

VMO2 protection

Loss of:
- 2 IRS
or
- 2 ADR
or
- all spoilers
or
- all inner ailerons
or
- rate limiting on green surfaces
or
- pedal / rudder position

ALTERNATE 2

n_z law / Flare law
roll direct / yaw alternate law

VMO2 protection
Vc protection

loss of:
- 2 ADR
or
- VS1G
- weight
or
- Slats and Flaps position

ALTERNATE 2A

n_z law / Flare law
roll direct / yaw alternate law

VMO2 protection

loss of 3 ADR

ALTERNATE 2B

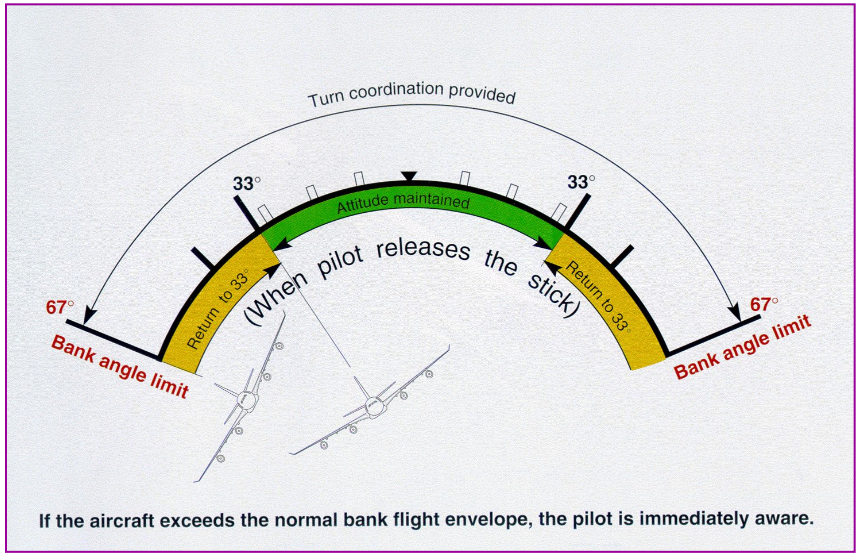
n_z law / Flare law
roll direct / yaw alternate law

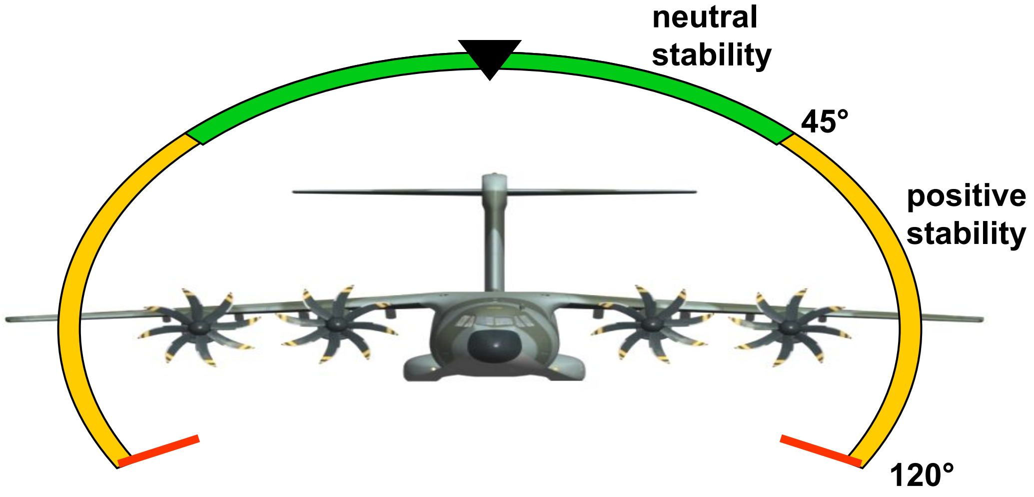
Loss of:
- 3 IRS
or
- 3 FCPC
or
- all elevators

DIRECT LAWS

pitch direct law
roll direct / yaw alternate law

THE BRAIN: COMPUTERS WHICH CONTROL





Agenda

- INTRODUCTION
- DESCRIPTION OF FLIGHT CONTROL SYSTEMS
  - THE MEMBERS: CONTROL SURFACES TO BE MOVED
  - THE MUSCLES: ACTUATORS
  - THE BLOOD: POWER SOURCES
  - THE SENSES: FLIGHT CONTROL COMPONENTS
  - THE BRAIN: COMPUTERS WHICH CONTROL
- AIRBUS FAMILY RANGE
- FLIGHT CONTROL ARCHITECTURE
  - ARCHITECTURE: A SYNOPTIC VIEW
  - PROBLEM OF AN FBW ARCHITECTURE
  - PROBABILITY against CLASSIFICATION (1309)
  - SPECIFIC RISKS
  - FLIGHT CONTROL INSTALLATION/SEGREGATION

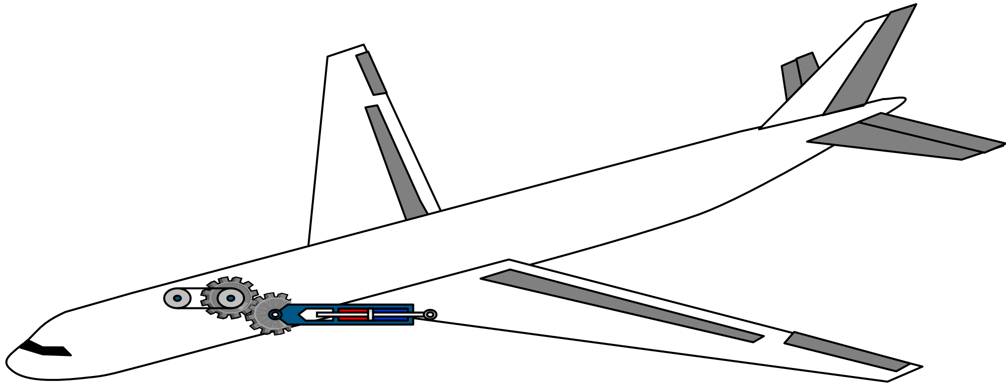
FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- WB FAMILY

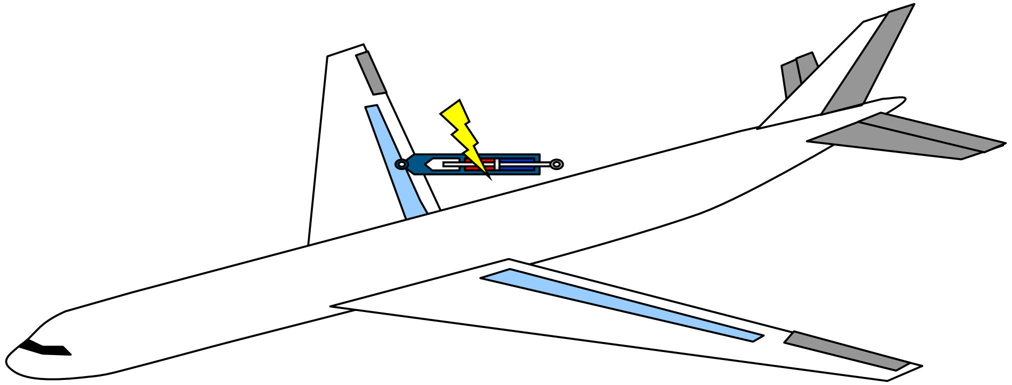
WB like Wide Body, that is to say a large fuselage.

Mechanical flight controls, except for spoiler A310.

A300
266 pax
7500 km



A310
220 pax
9600 km

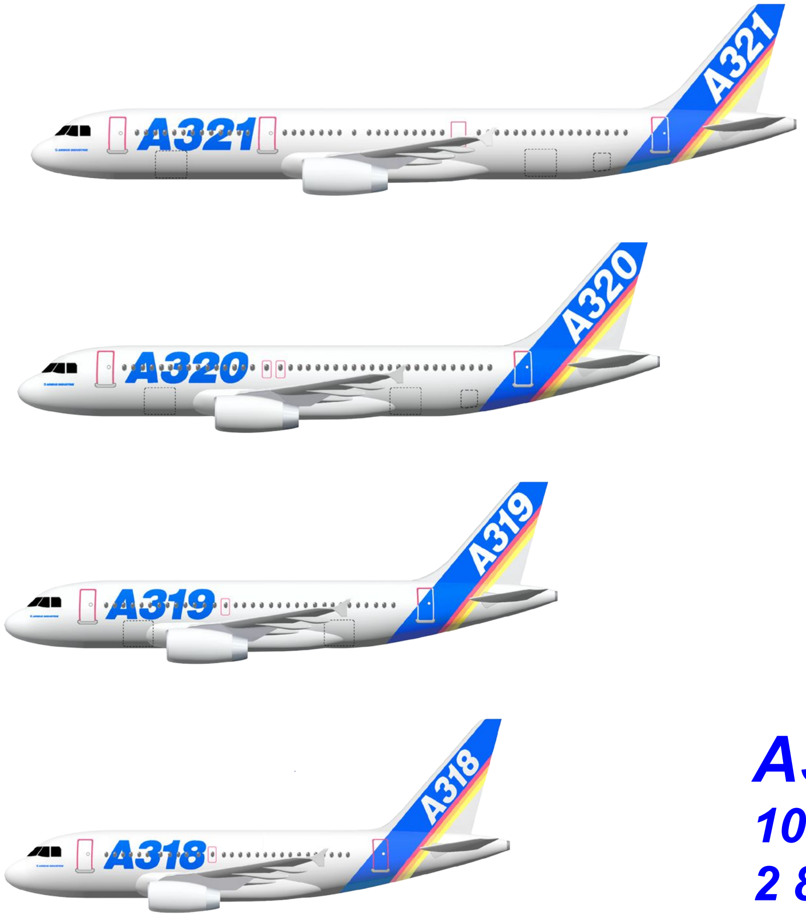


FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- SA FAMILY

SA like Single Aisle.

First fly by wire. Rudder and THS are still mechanical.



A321
185 pax
3 200 nm

A321 neo
185 pax
3 700 nm

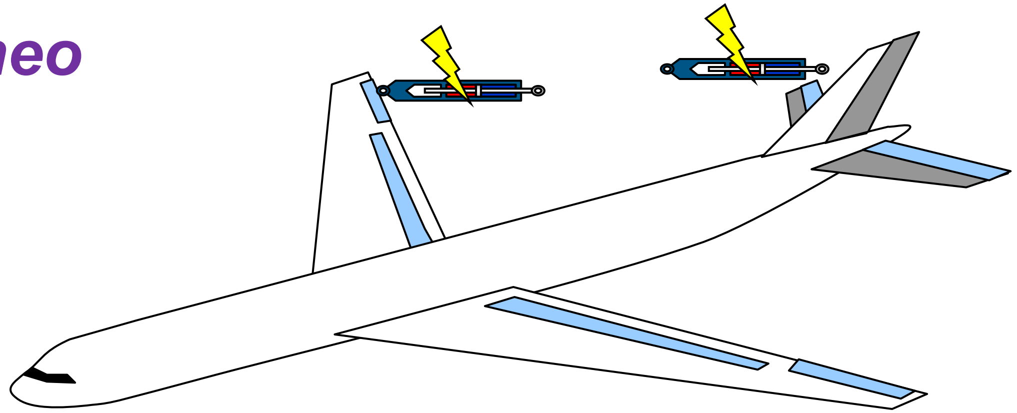
A320
150 pax
3 300 nm

A320 neo
150 pax
3 700 nm

A319
124 pax
3 700 nm

A319 neo
150 pax
4 200 nm

A318
107 pax
2 800 nm



AIRBUS

FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- LR FAMILY

LR like Long Range (WB that fly far).

« basics » or « enhanced », that is to say with or without electrical rudder.

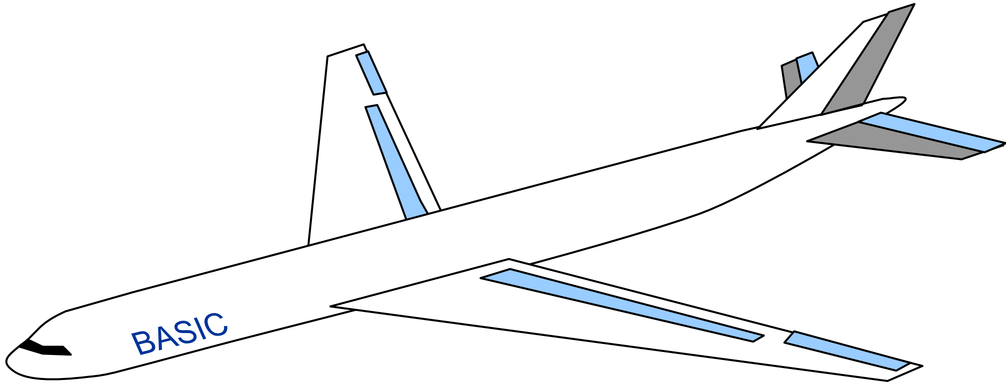
THS not yet mechanical.

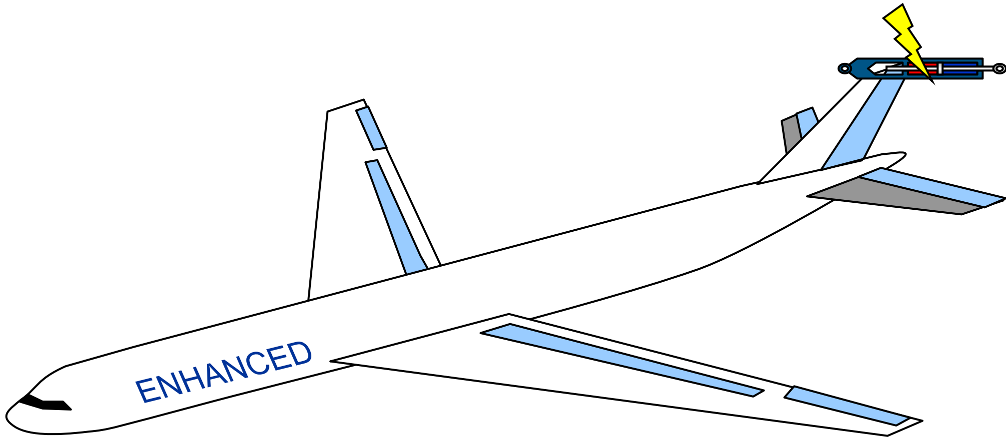
A340-200
250 pax
13 000 km

A340-300
278 pax
13 000 km

A330-300
278 pax
11 000 km

A330-200
246 pax
13 000 km





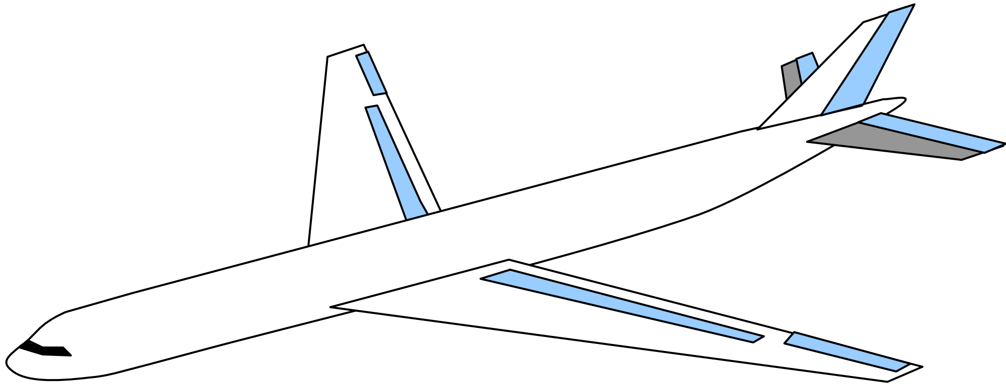
FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- THE « SMALL-LONG » OF LR FAMILY

  More range, more passenger, flight controls like LR enhanced

A340-600
380 pax
14 600 km

A340-500
313 pax
16 670 km



FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- THE NEW LR A350XWB FAMILY

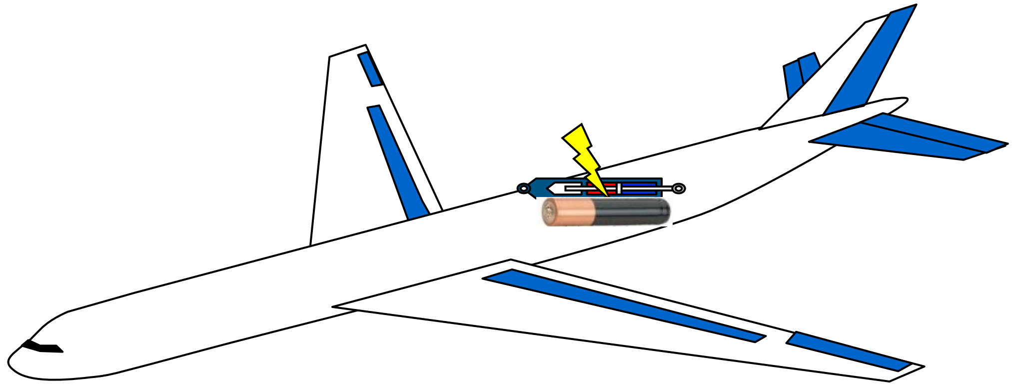
  More range, more passenger, flight controls like A380

  A350 is to A330 what A330 used to be to A300.

  Fully electrical, like A400M and A380, with remote control architecture

350 pax
15 600 km

314 pax
15 000 km



FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- XWB FAMILY (A350)

A highly innovative aircraft:

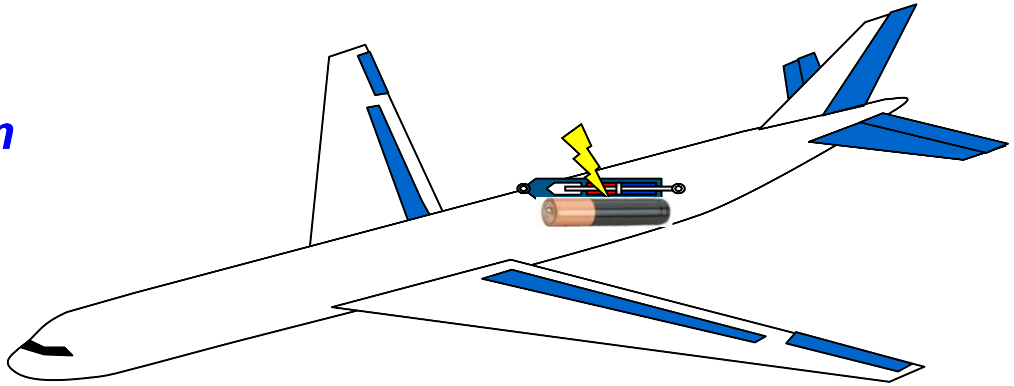
- 30 cm more for the fuselage and large windows
- Mach 0.85
- Carbon wings and fuselage, new sweep
- New engine
- New forward fuselage
- Innovative system architecture (remote electronics), but AIRBUS family concept
- Operating costs and performance rivalling the 787. But a difficult start

FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- A380 FAMILY

Fully electrical for command, and electrical power as backup

A380
525 pax
15 700 km

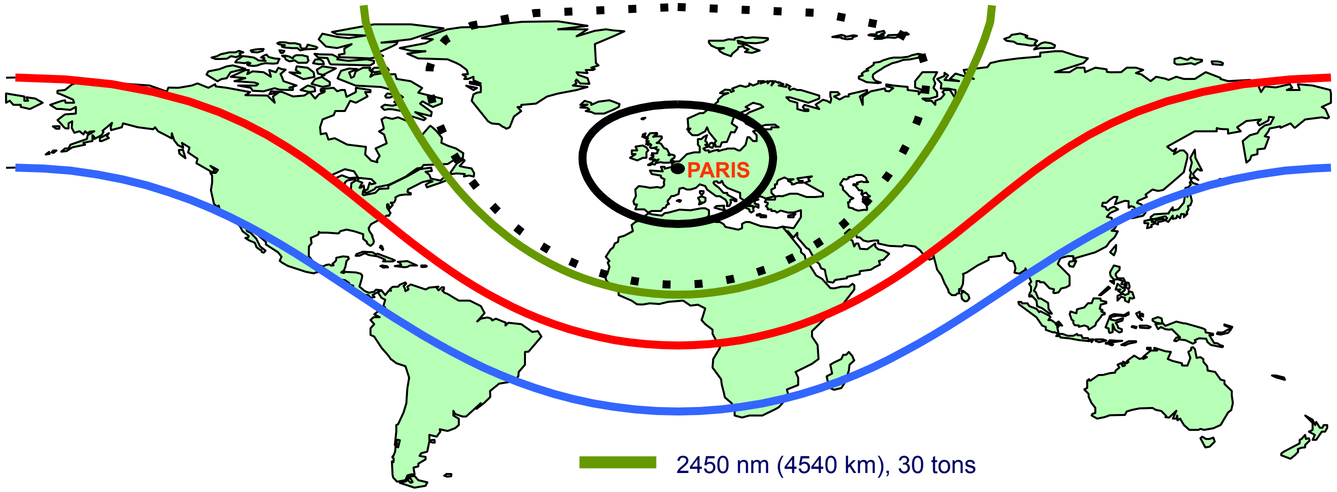


AIRBUS

FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

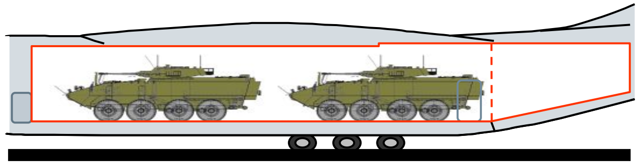
- A400M
  like A380

A400M
4500 km 30t
or
6500 km 20t

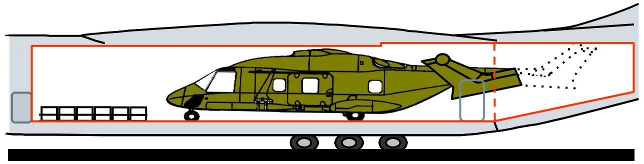


2450 nm (4540 km), 30 tons
3550 nm (6575 km), 20 tons
4900 nm (9075 km), ferry

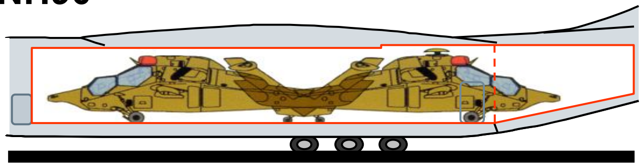
C-160 Transall — 1000 nm (1850 km), 16 tons
C-130H Hercules — 2240 nm (4150 km), 16 tons



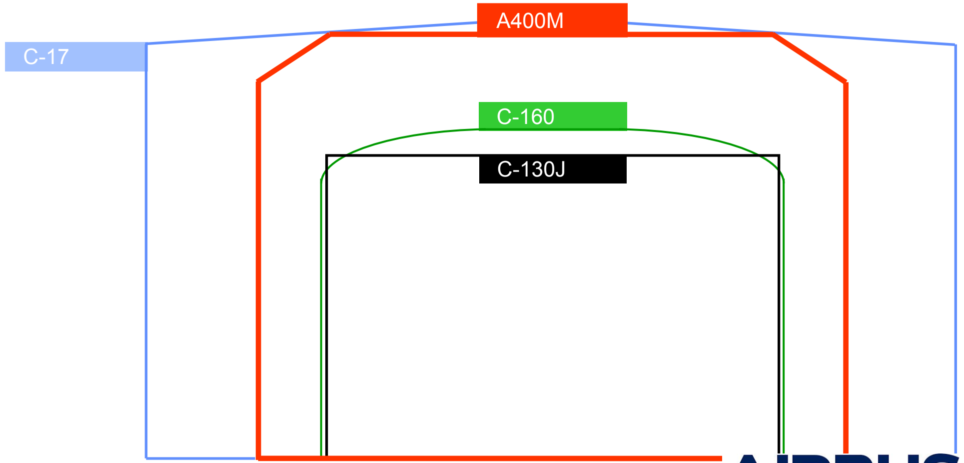
2 x ASLAV-25



NH90



2 x Eurocopter Tiger



AIRBUS

FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

	A300/A310	A220/A320	A330/A340/A350	A380	Total
Total orders	816	15175	3001	290	**19282**
Total deliveries	816	8796	2078	235	**11925**
Aircraft in operation	307	8399	1922	233	**10861**

Summary to 31 March 2019 - version 2

588 delivered in 2012 // 688 in 2016 // 800 in 2018 and counting...

FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

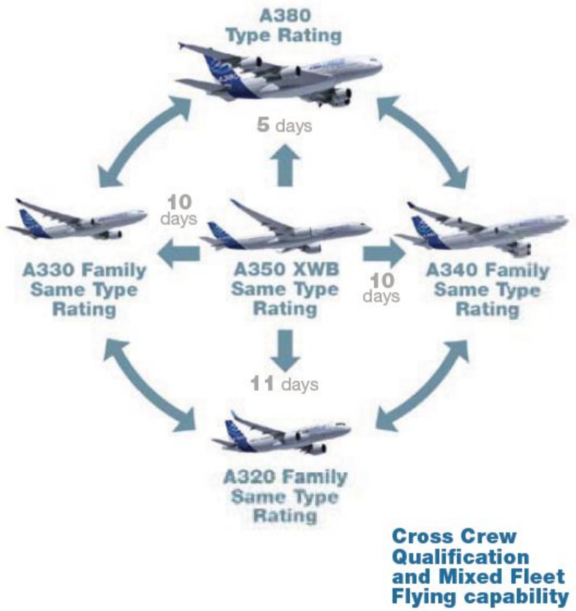
Airbus commonality

Fly-by-wire replaces complex cable and pulley connections between the central control column and the flight control surfaces with electrical wires and a side stick control

Fly-by-wire aircraft share near identical cockpits and handling characteristics and similar maintenance procedures

Pilots require much shorter training times to transfer from one aircraft type to another and can remain current on more than one type simultaneously, creating more balanced workloads

Airlines gain savings from greater operational flexibility, reduced training costs, streamlined maintenance procedures and common spare parts



FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- THE FUTURE: A30X

Goal: Replacing the A320s and GREEN aircraft

- Neither BOEING nor AIRBUS are in a hurry to replace their cash cows especially with all the aircraft to be developed and produced
- Still more carbon
- CO_2 emissions reduced by half
- Consumption per seat reduced by 25% in comparison with the A320 (that is 70% in 40 years), a good sales argument seeing the fuel price
- Noise reduced by 30% (depends on the engine)

- THE FUTURE: alliance with small manufacturers (AIRBUS/BOMBARDIER)

THE NOT SO WELL KNOWN

- ACJ

THE NOT SO WELL KNOWN

- MRTT (Multi Role Transport Tanker)

  - A310

  - A330

ROYAL AIR FORCE 14 FSTA*

5 MRTT*

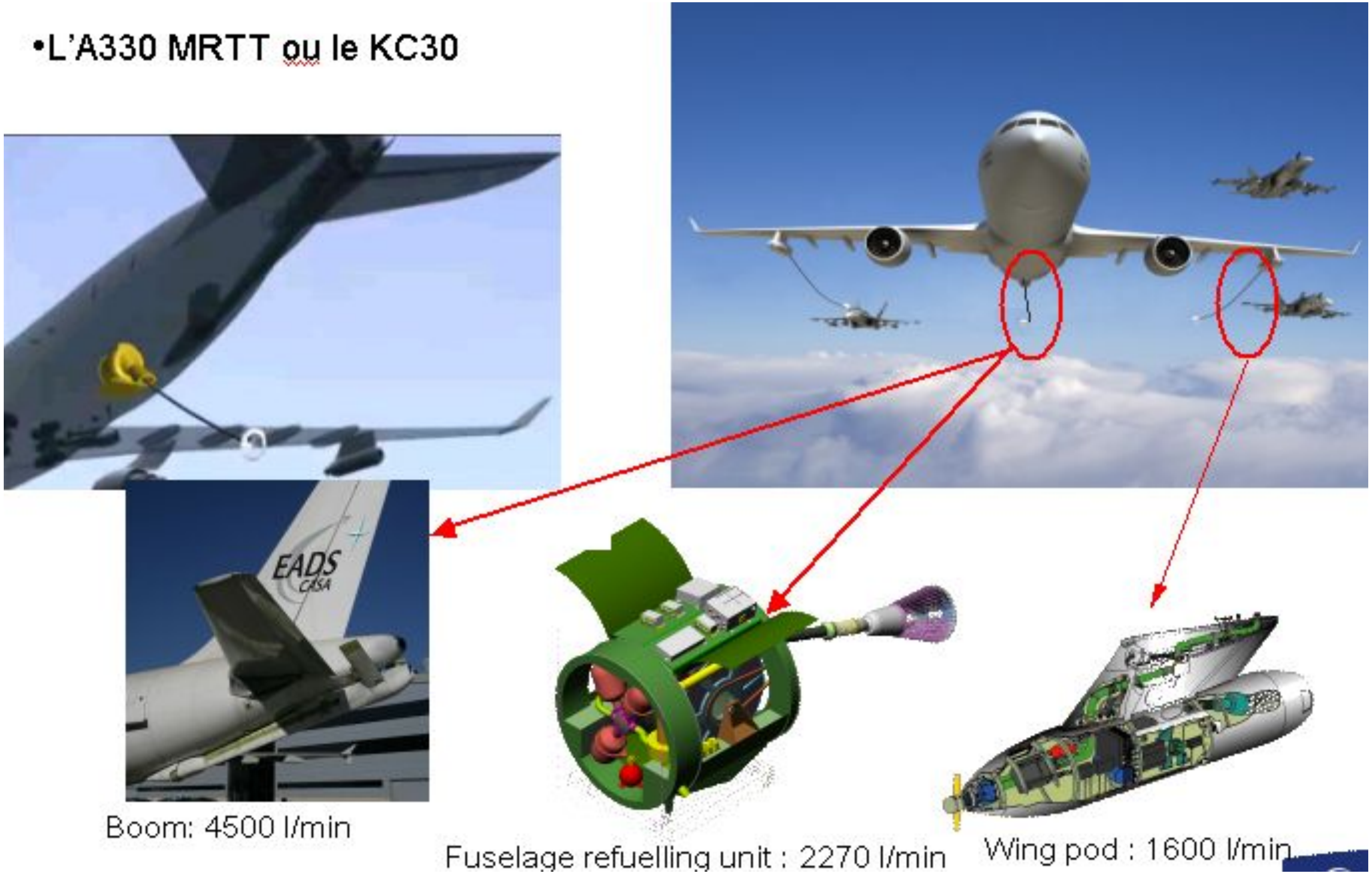
14 MRTT*

3 MRTT*

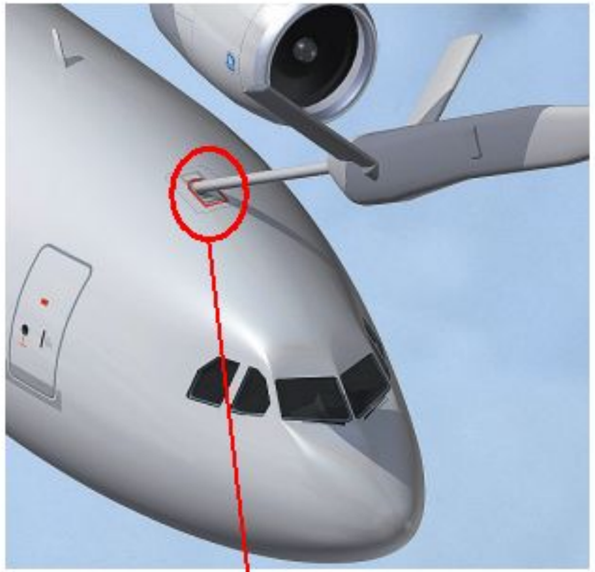
* TO BE UPDATED

THE NOT SO WELL KNOWN

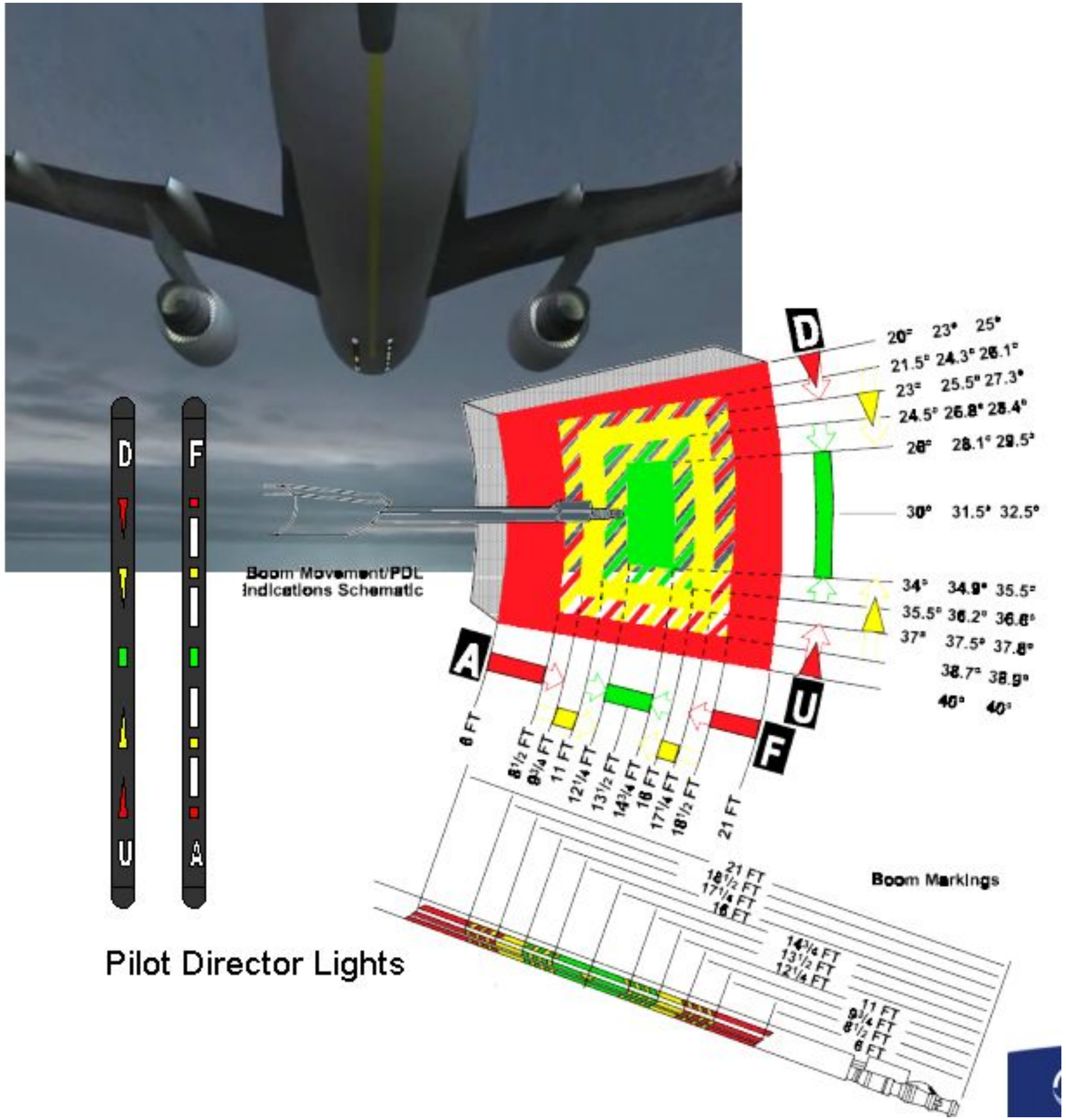
- L'A330 MRTT ou le KC30



THE NOT SO WELL KNOWN

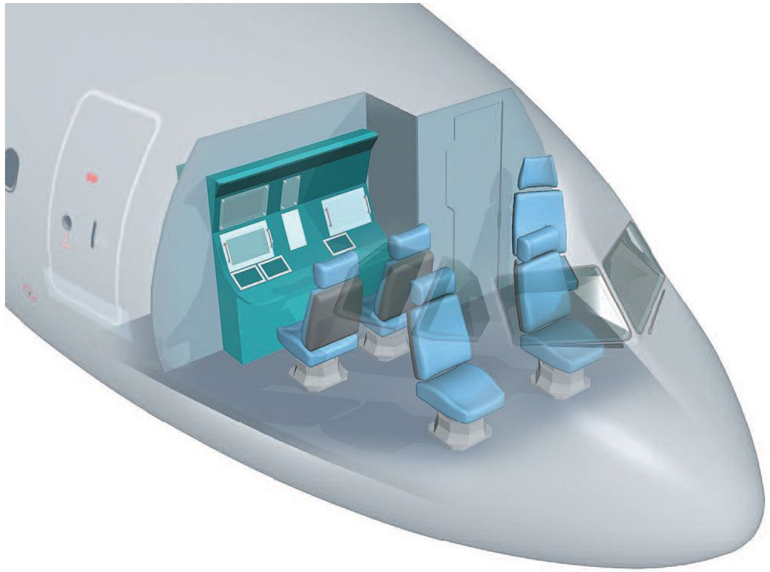


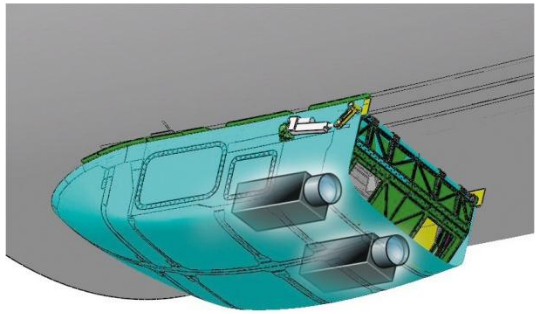
Receptacle:4500 l /min



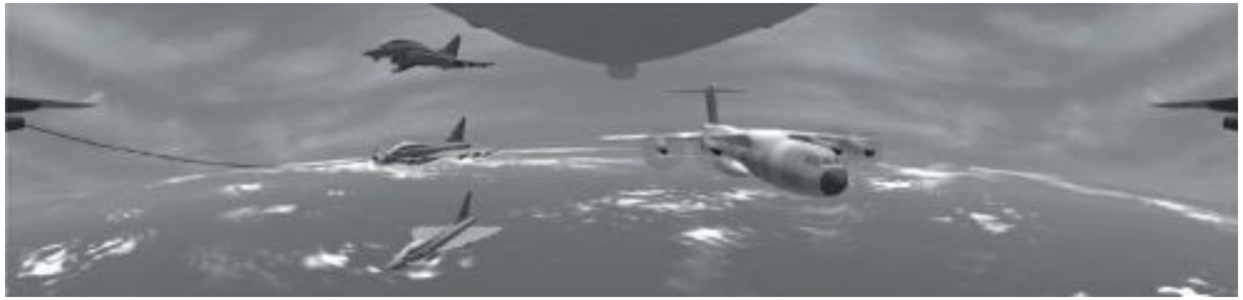
Pilot Director Lights

THE NOT SO WELL KNOWN





- Cockpit station for fuel dispenser
- 3D Vision

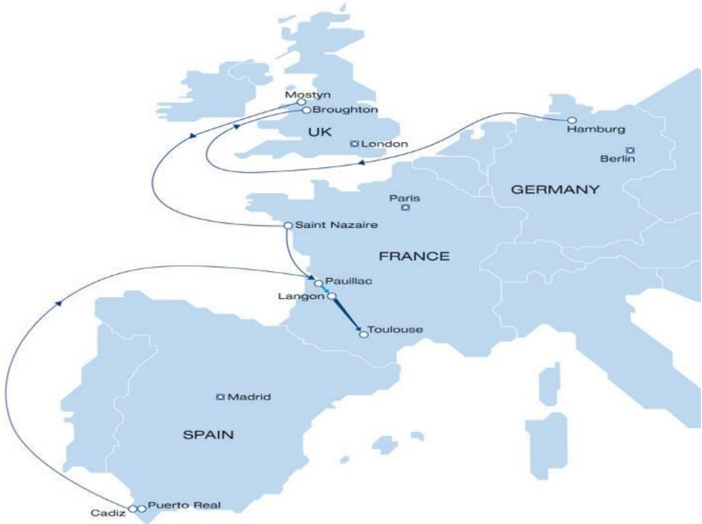


AIRBUS

THE NOT SO WELL KNOWN

The Beluga (A300-ST)

One of the most voluminous cargo hold in the world transports complete aircraft sections from Airbus' manufacturing sites across Europe to the final assembly lines in Hamburg and Toulouse



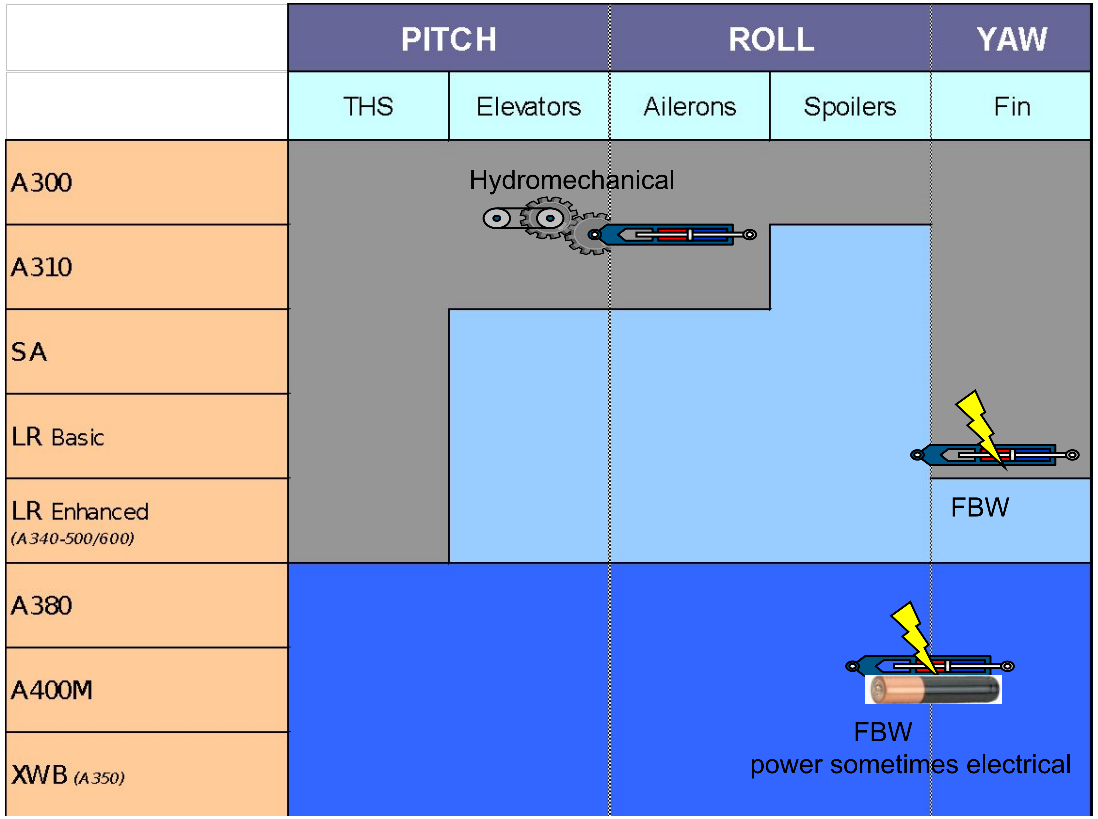
The Beluga XL (A330-743L)

- Bigger to transport larger parts (2 A350 wings)
- Modern platform (A330)
- 2019: in flight test/certification phase of development

AIRBUS

FBW ARCHITECTURE OF VARIOUS AIRBUS AIRCRAFT

- Summary of the various AIRBUS aircraft

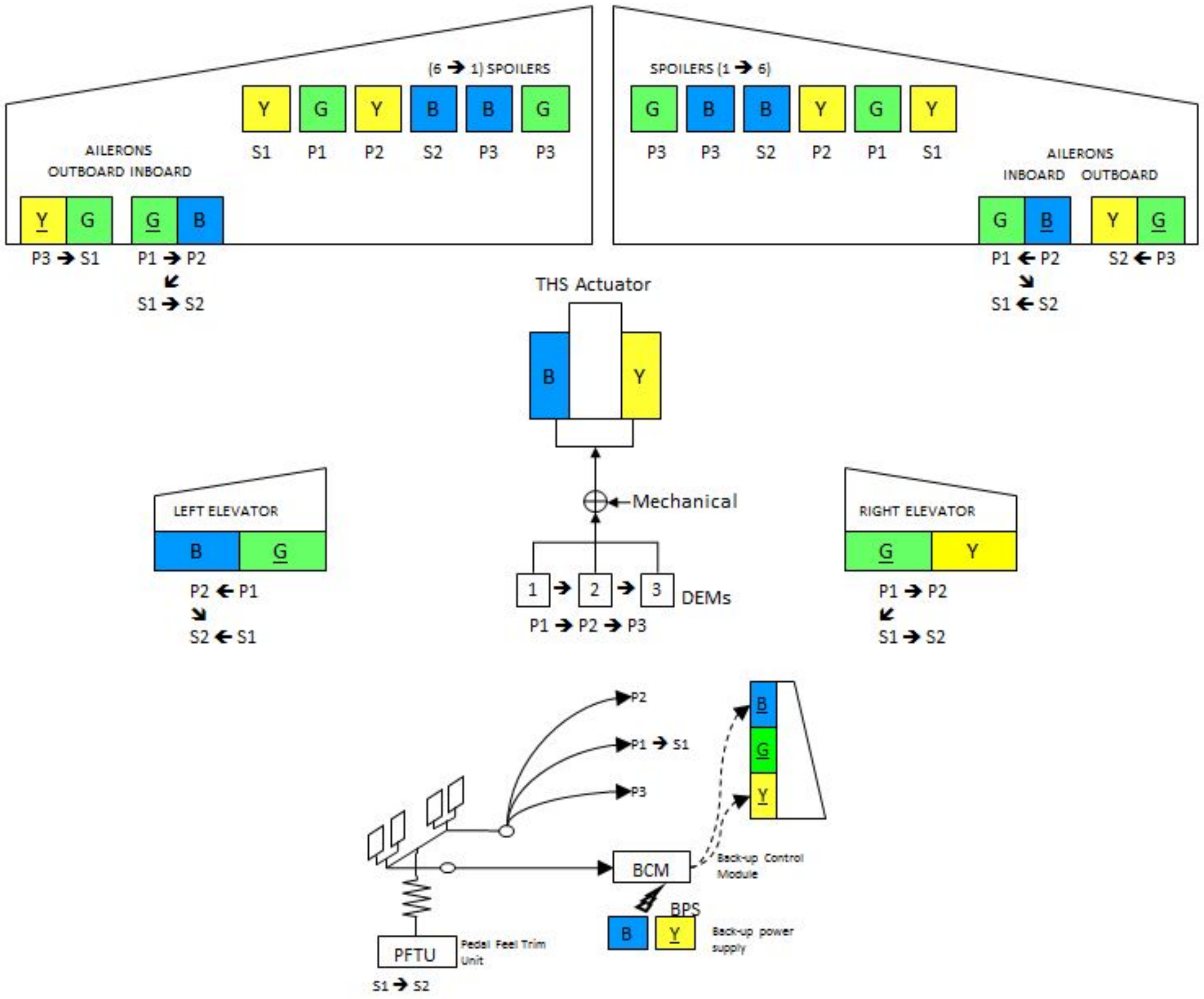


Agenda

- INTRODUCTION
- DESCRIPTION OF FLIGHT CONTROL SYSTEMS
  - THE MEMBERS: CONTROL SURFACES TO BE MOVED
  - THE MUSCLES: ACTUATORS
  - THE BLOOD: POWER SOURCES
  - THE SENSES: FLIGHT CONTROL COMPONENTS
  - THE BRAIN: COMPUTERS WHICH CONTROL
- AIRBUS FAMILY RANGE
- FLIGHT CONTROL ARCHITECTURE
  - ARCHITECTURE: A SYNOPTIC VIEW
  - PROBLEM OF AN FBW ARCHITECTURE
  - PROBABILITY against CLASSIFICATION (1309)
  - SPECIFIC RISKS
  - FLIGHT CONTROL INSTALLATION/SEGREGATION

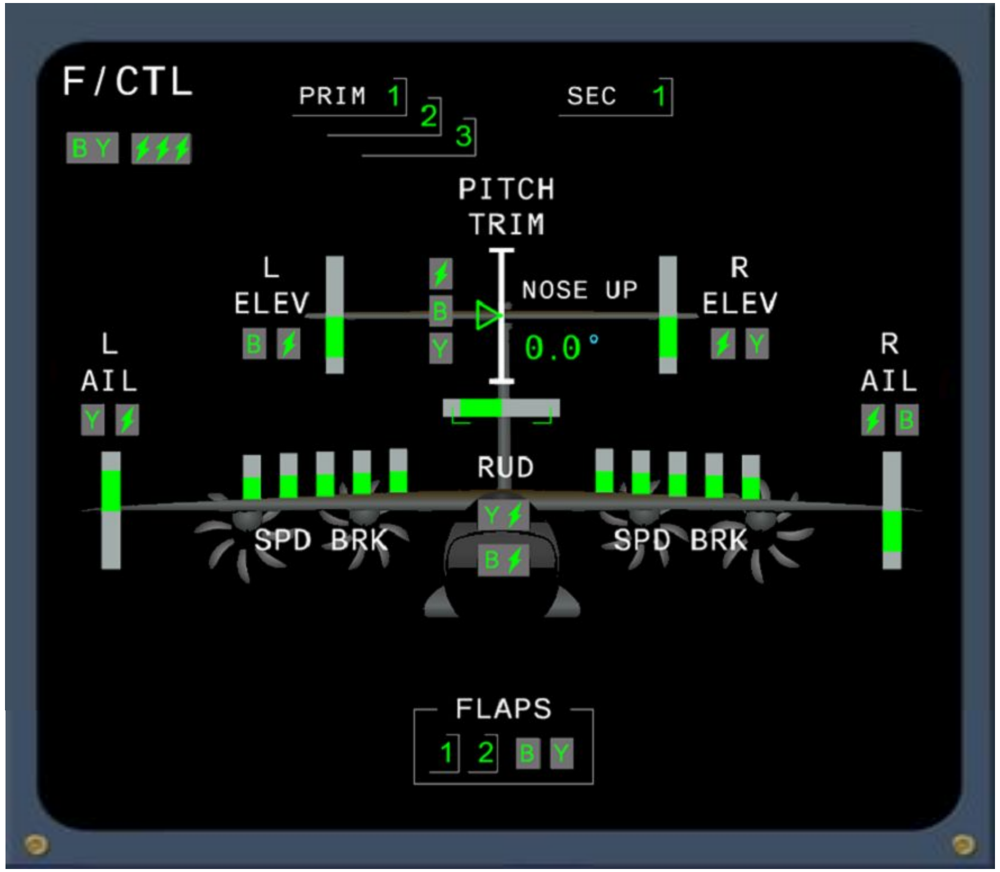
ARCHITECTURE: A SYNOPTIC VIEW (1/2)

Flight control architecture gives a synoptic view of all components of the flight control system



ARCHITECTURE: A SYNOPTIC VIEW (2/2)

This synoptic view is displayed in the cockpit, in order to keep the pilot informed of the status of the system



PROBLEM OF AN FBW ARCHITECTURE

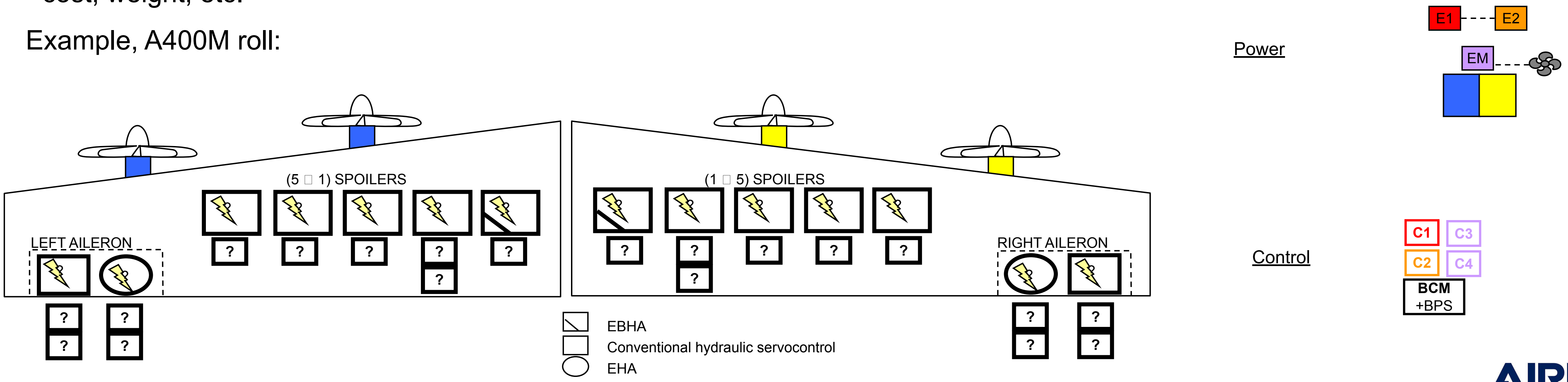
- To design an architecture, we must therefore:

- define the number and type of actuators per control surface
- allocate power sources to these actuators
- lastly allocate control sources

- Whilst meeting requirements concerning:

- safety, quantifiable (1309)
- safety, not quantifiable (specific risks and internal rules)
- Availability (system maintained after failures, MMEL)
- cost, weight, etc.

Example, A400M roll:



AIRBUS

PROBABILITY AGAINST CLASSIFICATION (1309)

- PRINCIPLE

The basic principle of the regulatory library CS 25.1309 is:

- list all system failures (multiple, hidden, etc.)
- assess (engineer's judgement, controlled evaluation in flight or on simulator, etc.) their criticality

FHA
(Functional Hazard Assessment)

- calculate the probability of each failure
- compare criticality and probability to see whether they are compatible (a failure which can occur every day and which can cause the aircraft to crash is not being very serious…)

SSA
(System Safety Assessment)

PROBABILITY AGAINST CLASSIFICATION (1309)

CLASSIFICATION*	**MIN** **minor**	**MAJ** **major**	**HAZ** **hazardous**	**CAT** **Catastrophic**
PROBABILITY of the failure case	$> 10^{-5}$ /fh *probable*	$10^{-7} < \lambda < 10^{-5}$ /fh *rare*	$10^{-9} < \lambda < 10^{-7}$ /fh *extremely rare*	$< 10^{-9}$ /fh** & No single failure *extremely improbable*
EFFECT of the failure case	none	- reduction in safety margins - increase in crew's workload - several people slightly injured	- high reduction in safety margins - difficult for the crew to control the situation - serious injuries, several dead	- loss of the aircraft - many dead

* Classification : Inverse relationship between probability (expressed per flying hours) and severity.

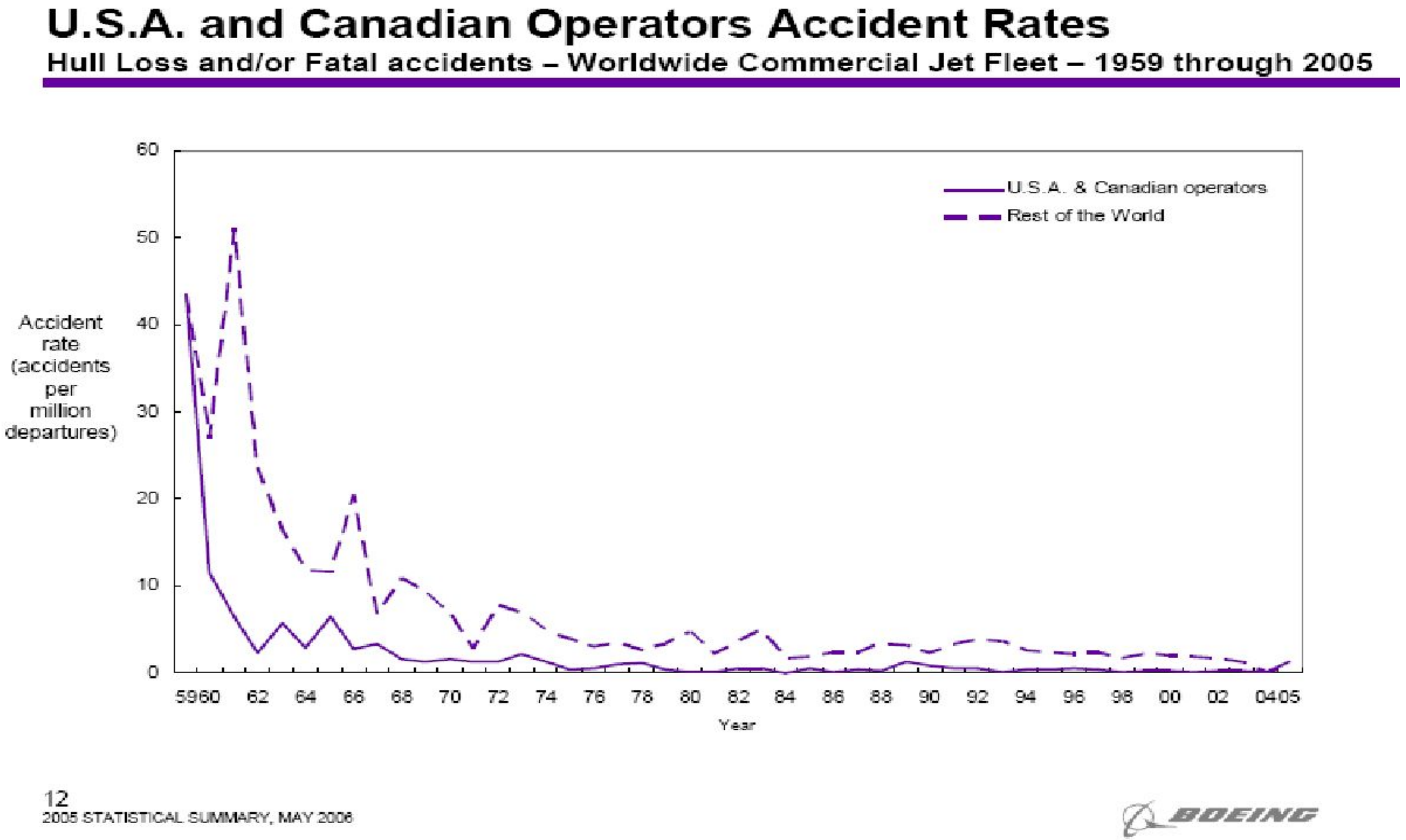
** The 10-9/FH figure at FC level is derived from 10-7/FH at A/C level (probability of a Cat. event caused by system failure,100 Cat. FC / aircraft).

PROBABILITY AGAINST CLASSIFICATION (1309)

Objective : rate of accidents in the range of

1 per million flight hours, for any cause

1 in 10 millions flight hours, for system related causes

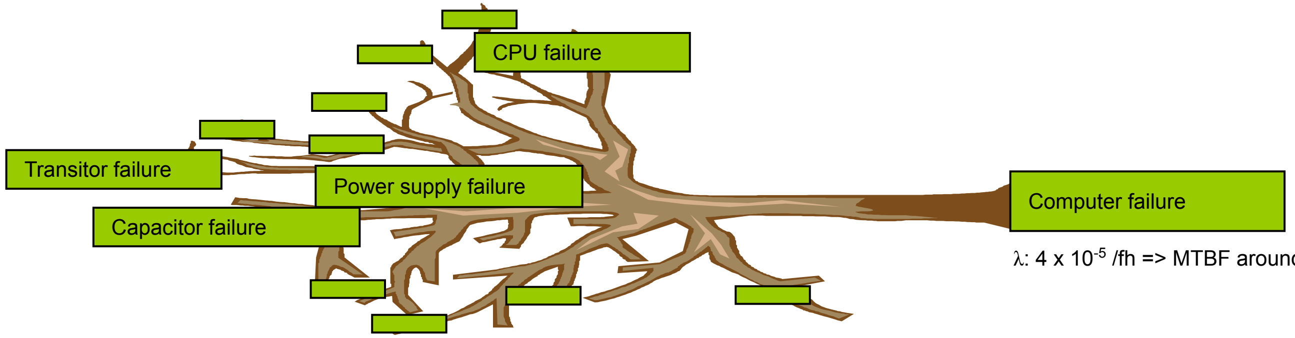


Note : Ratio between number of cumulative flight hours and number of cumulative departures, per year, is in the range of 2

PROBABILITY AGAINST CLASSIFICATION (1309)

- CALCULATING A FAILURE PROBABILITY
  - "Top-down" approach: statistical analysis of past flights, all aircraft combined and drawing up of statistics

    E.g. For AIRBUS aircraft in general, total loss of the 4 engines is around 5×10^{-8} per flight hour (that is a probability of 5×10^{-7} on a 10-hour A340 flight, that is once every 2 million flights)
  - "Bottom-up" or "tree-structure" approach: sum of elementary failures to cause a more global failure



λ: 4×10^{-5} /fh => MTBF around 25,000 h

Important

  - Multiple failure calculation principle

Elementary failures with a rate of λi

λi: rate of failure No. °i (/fh)
Ti: exposure time for failure i
T_o: average flight time

Summed failure

$$\lambda = \frac{\prod_{i=1}^{n} \lambda_i . T_i}{T_0}$$

/fh

PROBABILITY AGAINST CLASSIFICATION (1309)

Important

- CALCULATING A FAILURE PROBABILITY

Example:

If, on an A400M, we lose all the engines in cruise (TEFO) and if, before approach, C3 fails, then authority may be missing in pitch and the aircraft may crash (flare impossible).

λ_{TEFO}= 5 x 10^{-8} /fh

T_{CRZ}= 2h30

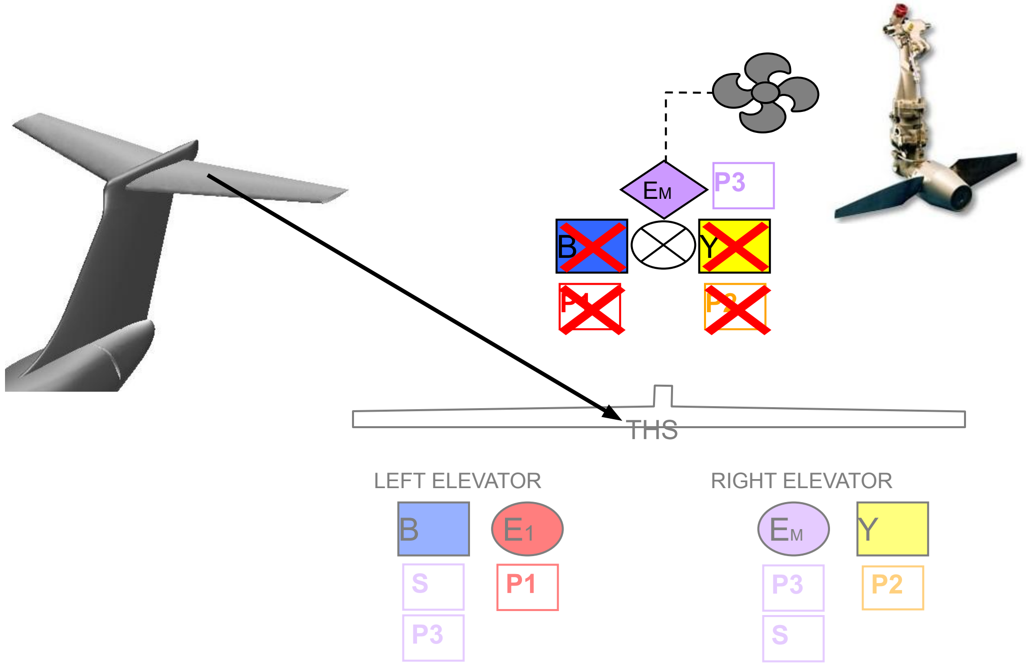
λ_{C3}= 10^{-4} /fh

T_{APP}= 6 min

T_o= 3h

$$\lambda = \frac{P}{T_O} = \frac{P_{TEFO} \times P_{C3}}{T_O} = \frac{\lambda_{TEFO} \times T_{CRZ} \times \lambda_{C3} \times T_{APP}}{T_O}$$

$$= \frac{5x10^{-8} \times 2.5 \times 10^{-4} \times 0.1}{3} = 4.1x10^{-13} \quad / fh$$



PROBABILITY AGAINST CLASSIFICATION (1309)

- CALCULATING A FAILURE PROBABILITY

  – However, with this approach, care must be taken on the <u>common point</u> as we only have the right to do this type of calculation if the failures are independent.

  – Indeed, we can obtain a low probability by combining the probabilities of the elementary failures whereas these failures have a common point, more probable point. The most explicit example is quadruple engine failure (e.g. A340):

    – If quadruple (TEFO) means 4 times single failure (OEI: One Engine Inop):

$$\lambda_{TEFO} = \frac{(\lambda_{OEI} \times T_O)^4}{T_O} = \frac{(10^{-4} \times 10)^4}{10} = 10^{-13} / fh$$

    – In fact, on account of common modes (contaminated fuel, maintenance botched in same way, etc.), the quadruple engine failure is:

$$\lambda_{TEFO} = 5x10^{-8} / fh$$

PARTICULAR RISKS

- A particular risk is:
  - a failure which cannot be covered by a statistical analysis or which is extremely improbable but which can be considered anyway
    E.g. losing 3 flight control computers is extremely improbable but we wish, however, to cover the case
  - or a failure which can be covered by statistics but which may not be coherent with the 1309 analysis
    E.g. engine burst occurs frequently (around one aircraft per year throughout the world) and therefore is not extremely improbable ($<10^{-9}$ /fh), however, the consequences may be catastrophic (technological limit: "we do our best but we are powerless faced with certain cases" => "best design effort").

- The main "official" specific risks are:
  - Uncontained Engine Rotor Failure (UERF)
  - Propeller Blade Release (PBR)
  - Wheel & Tyre Failure (WTF)
  - Bird Strike
  - Hail
  - RAT Blade Release
  - Homemade bomb
  - Wheels Up Landing
  - Accumulators Burst (hydraulics, water, oxygen, etc.)
  - Uncontained APU Rotor Failure
  - Leaking Fluids
  - Engine / Propeller Imbalance
  - Bleed Air Duct Leakage / Rupture
  - Fire Explosion
  - Wheel Imbalance
  - Electromagnetic Hazards (lightning, HIRF)
  - Thermal Risk
  - Fuel Tank Explosion
  - Single shot

Details of route damaging particular risks on following sheets

PARTICULAR RISKS

- SINGLE SHOT

Shot of 12.7mm

Vitesse: 610 m/s
Masse: 45 g
Effet: Penetration
Energie: 8.37225 KJoules

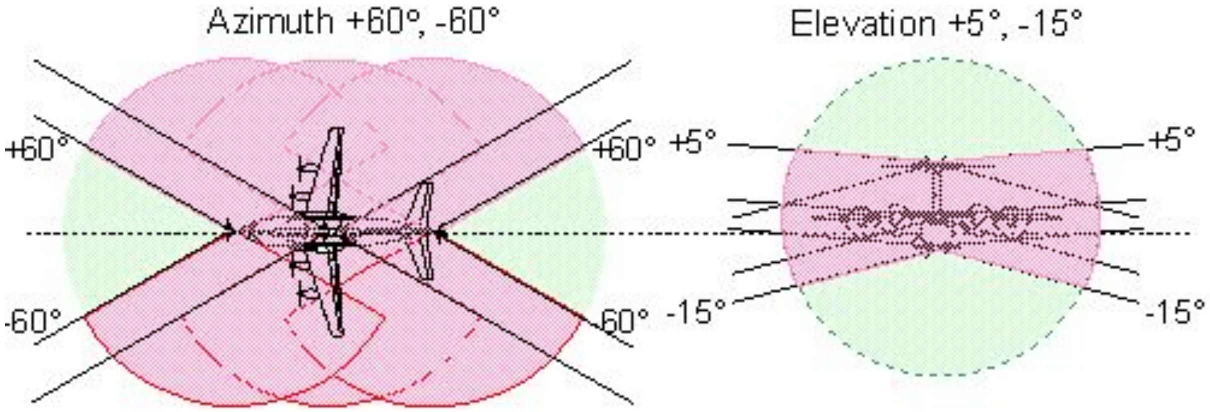
Can be stopped by a shield

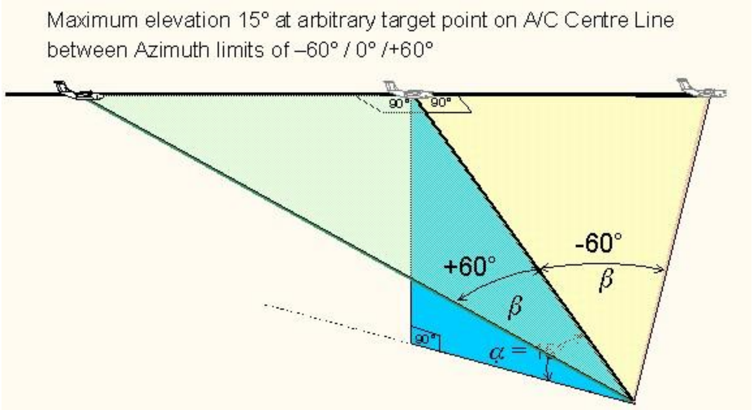
An A400M specificity ? Not really: DHL Bagdad…

PARTICULAR RISKS

- SINGLE SHOT (2/2)

No bullet trajectory in the DEF STAN cone should have CAT consequences.

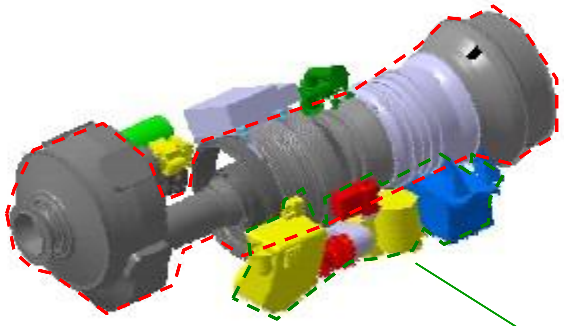




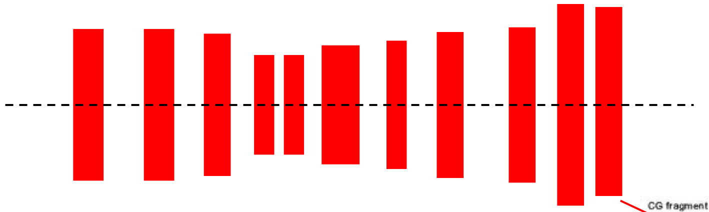
PARTICULAR RISKS

- UERF (Uncontained Engine Rotor Failure)

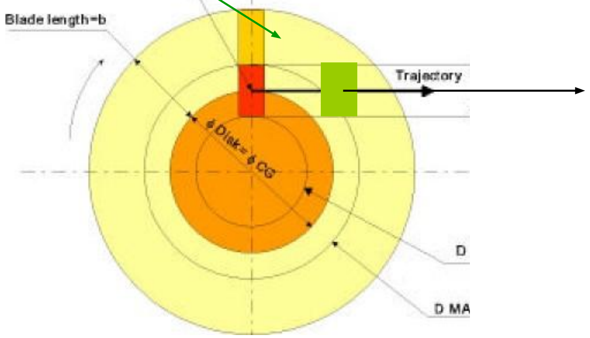
We list all the rotating parts of the engine and we consider that they can break off (see cone below) and cleanly cut anything that they come into contact with (almost infinite energy) except another engine. No *small fragment* trajectory must be CAT and only 5% of the *large fragment* trajectories can be CAT (impossible to protect everything, even with armour).



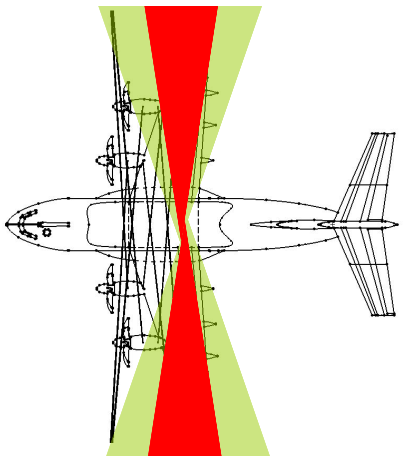
Rotating discs

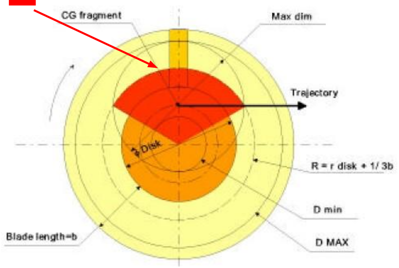


"small fragments"



1/3 discs





Projection cone:

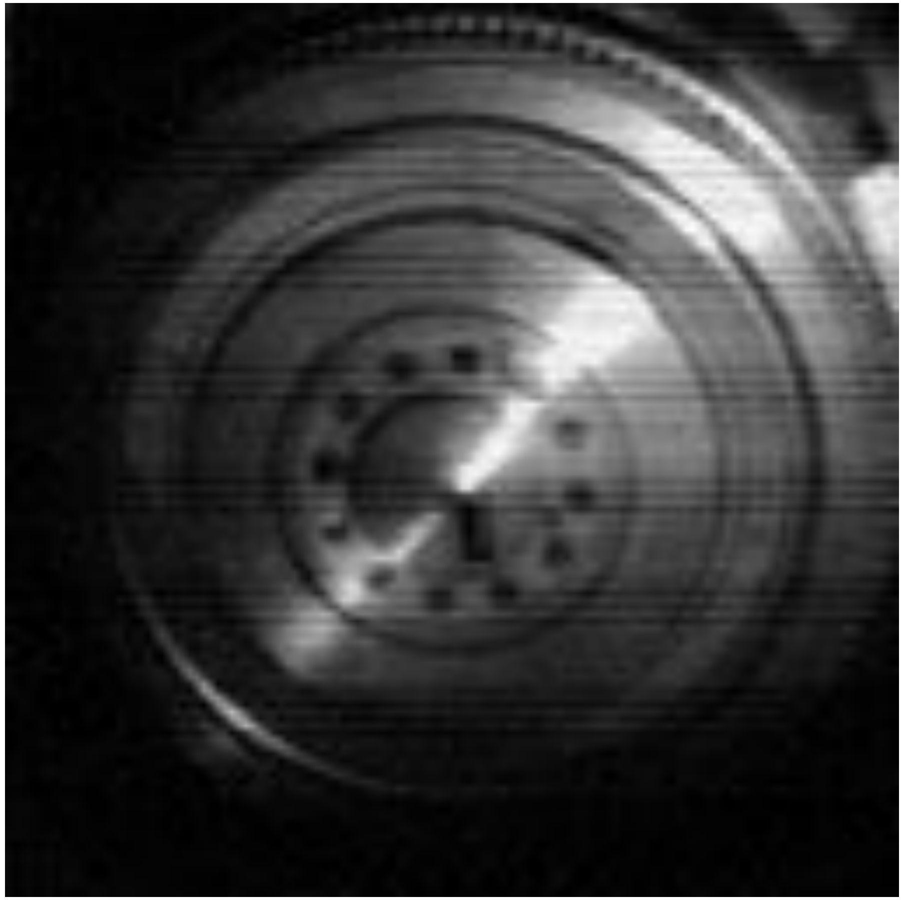
large fragments: +/- 5° laterally

small fragments: +/- 15° laterally

- 360° around aircraft centreline

PARTICULAR RISKS

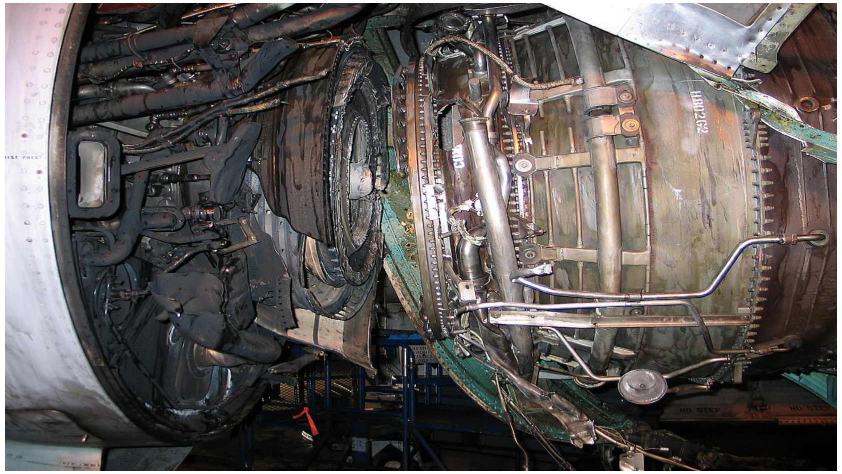
Engineer delirium ? Are those hypothesis realistic ?



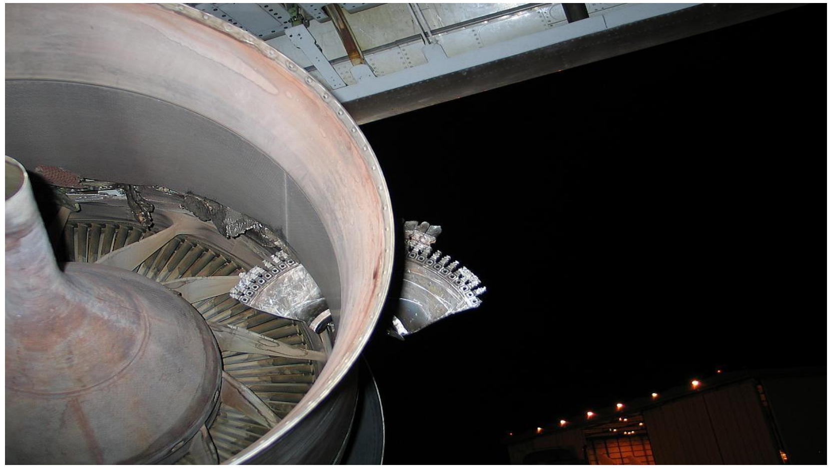
PARTICULAR RISKS

Engineer delirium ? Are those hypothesis realistic ?

Disk release



Nice 3rd disk stopped by other engine



Infinite energy, surgery cut

And at the end, a fire …

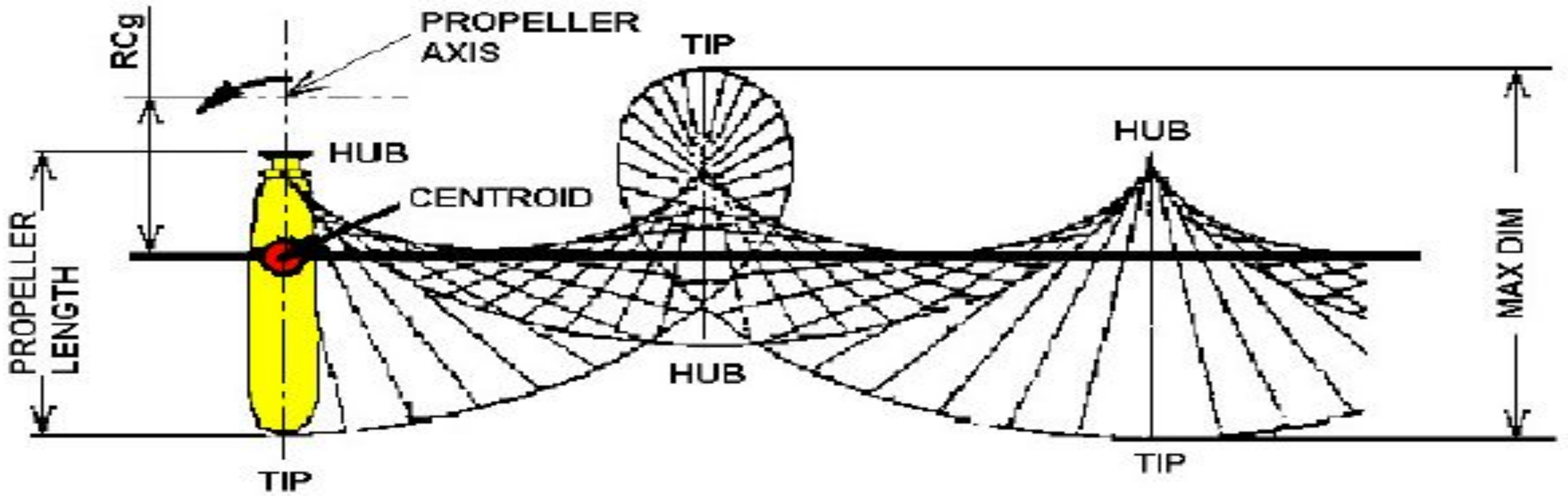
AIRBUS

PARTICULAR RISKS

PARTICULAR RISKS

- PBR (Propeller Blade Release)

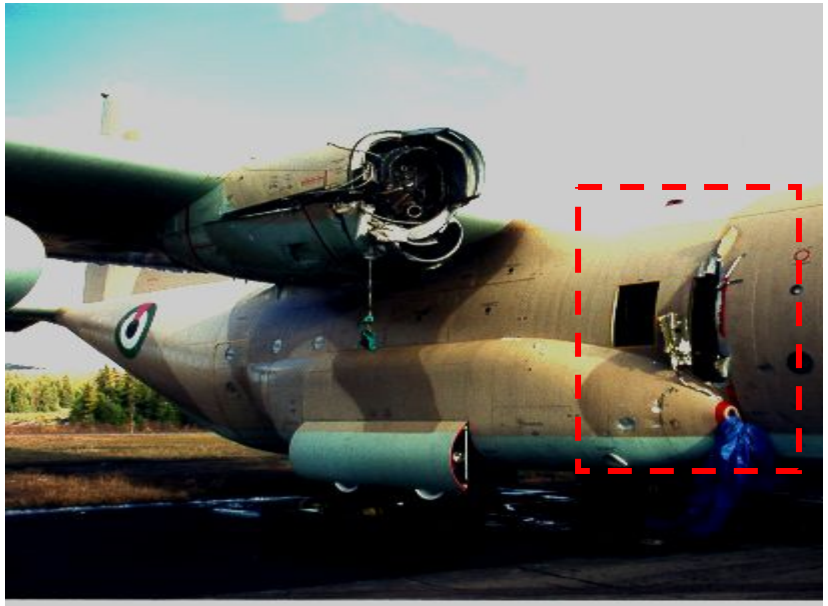
The blade breaks off at its base (the weakest part) and cuts all it encounters in the same way as UERF.

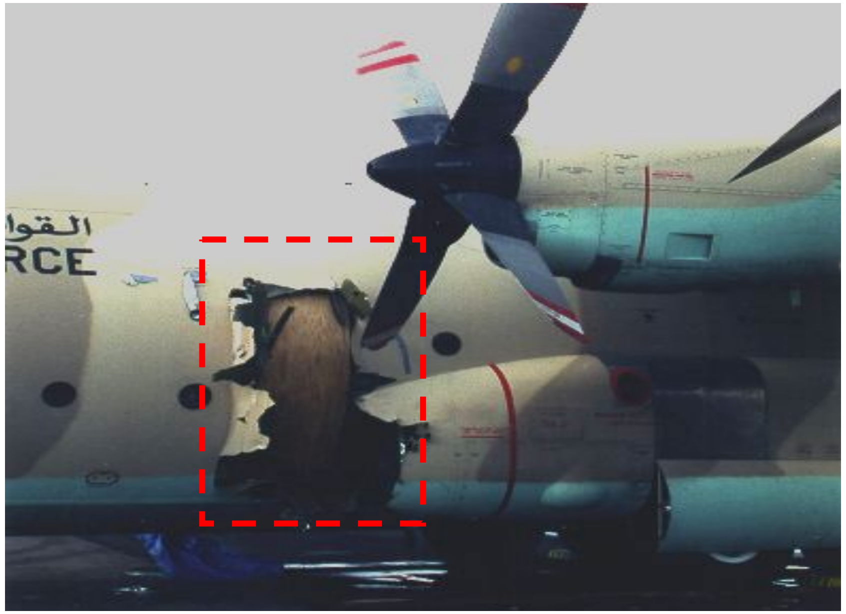


≈ 2930 mm on TP400 with current design

PARTICULAR RISKS

- Example





Conclusion: when flying ATR, avoid to seat close to the red line on the fuselage …

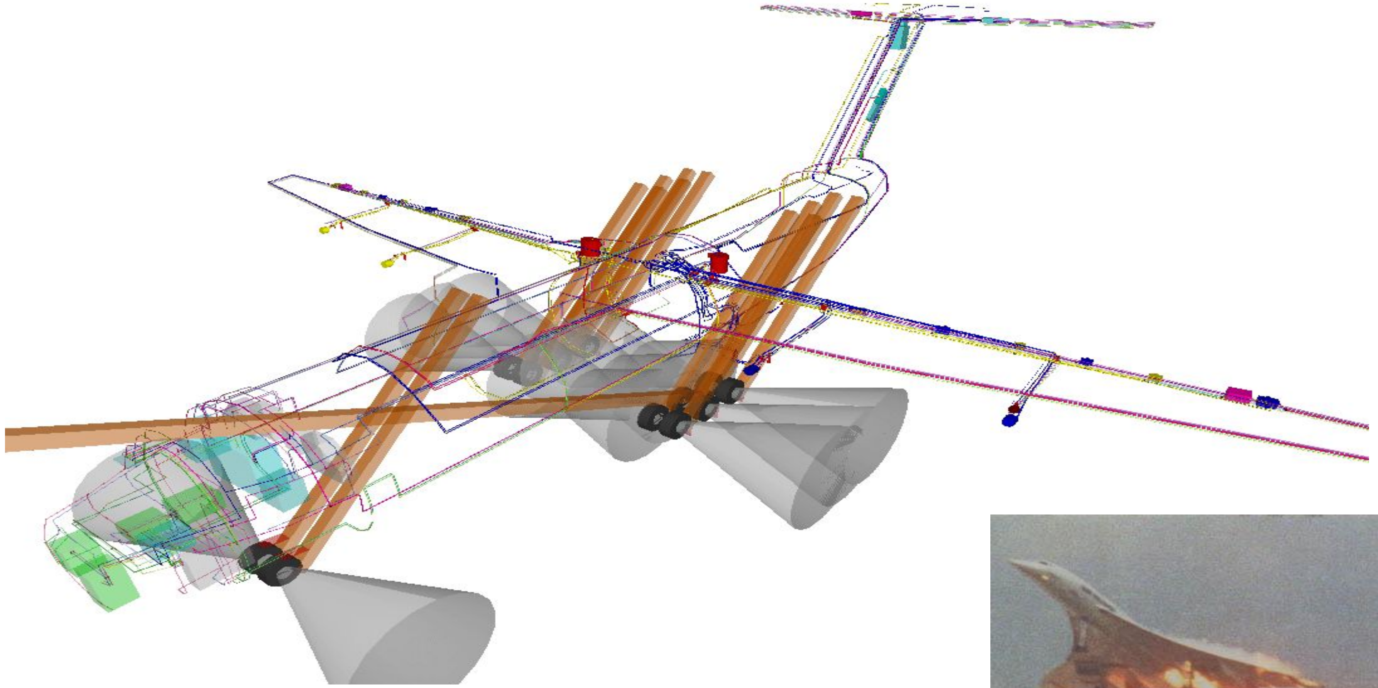
PARTICULAR RISKS

- Example

PARTICULAR RISKS

- Wheel & Tyre Failure (WTF)

We consider that the wheel parts can break off in a cone of around +/- 30° and that tyre fragments can fly off in all directions in a plane perpendicular to the axis of the wheels. The energy is not infinite (light armour may be sufficient). There must be no CAT trajectories.



Example: Concorde accident

PARTICULAR RISKS

- Wheel & Tyre Failure (WTF)

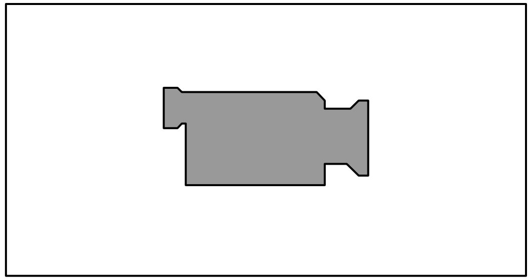
Perforated metal

PARTICULAR RISKS

- Wheel & Tyre Failure (WTF)

PARTICULAR RISKS

- Bird Strike



PARTICULAR RISKS

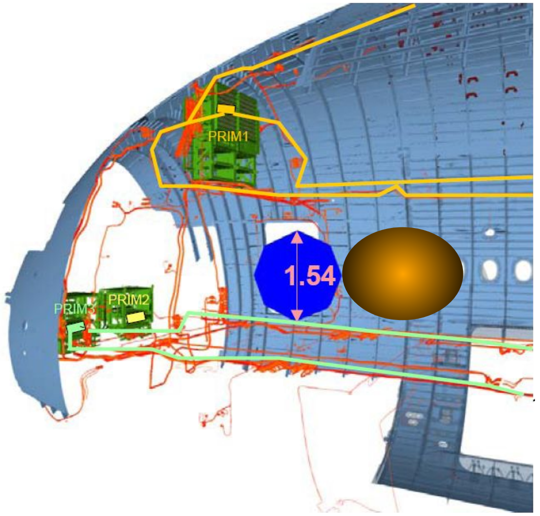
- Hail event: B737 Easy Jet
  - 15 August 2003, Geneva
  - IFTB 20 minutes after Take-off

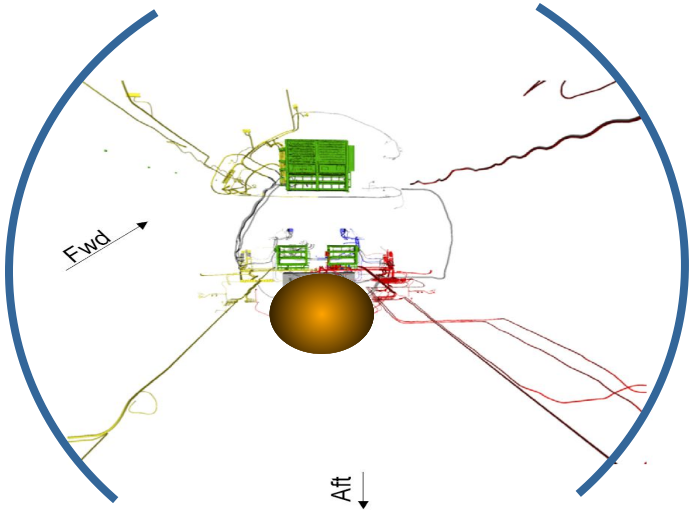
AIRBUS

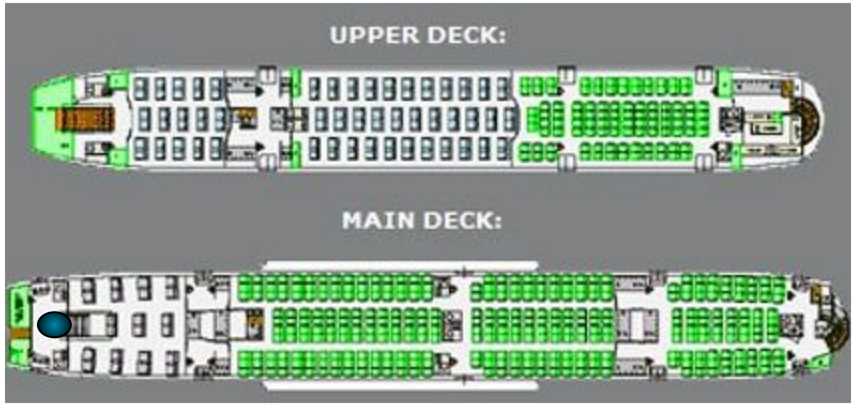
PARTICULAR RISKS

- Homemade bomb

We consider that a light explosive damages everything within a 1.5 m diameter sphere and it can be placed in all zones accessible to a human being or to baggage (cabin*, cargo compartment). The effect of this bomb must not be CAT (direct human losses are not to be considered).







* recently, and in spite of the armoured doors, the risk is also to be considered in the cockpit

FLIGHT CONTROL INSTALLATION/SEGREGATION

- INSTALLATION PRINCIPLE

The fundamental rule which guides the installation is that **"we do not put all our eggs in one basket".**

This leads in concrete terms to segregations of all items of the flight control channel to electrically or geographically isolate the redundant items: :

- Two electrical routes on the aircraft
- Segregation up to the computer connectors
- Computers correctly distributed
- Subroutes S, M and P
- Three geographical routes or more
- Flight controls, no sharing
- Lastly, segregation of the energy sources

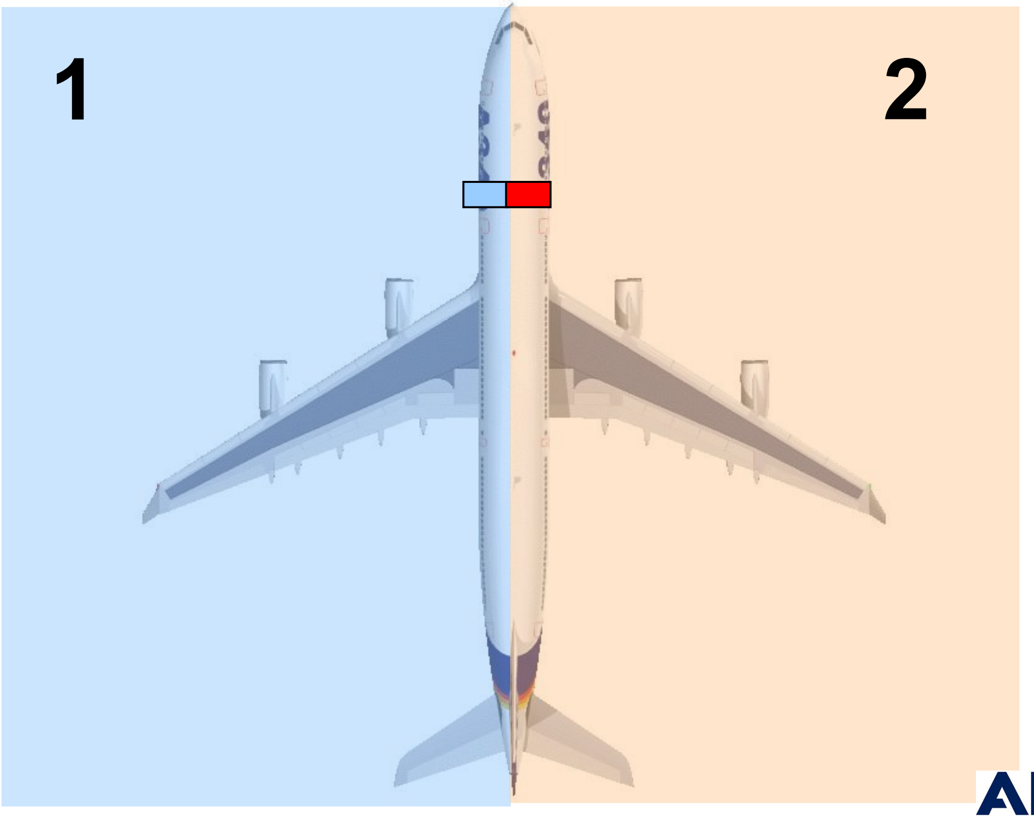
FLIGHT CONTROL INSTALLATION/SEGREGATION

- Two electrical routes on the aircraft

The aircraft equipment is placed in one of two electrical categories depending on the route to which it belongs, that is according to the electrical power centre to which it is connected. Whenever possible, we try to geographically position each item of equipment of a given route on the same side of the aircraft to avoid potential crossings over which may (if incorrectly isolated) be detrimental to good segregation.

This installation covers the case of an electrical power centre which destroys everything connected to it.

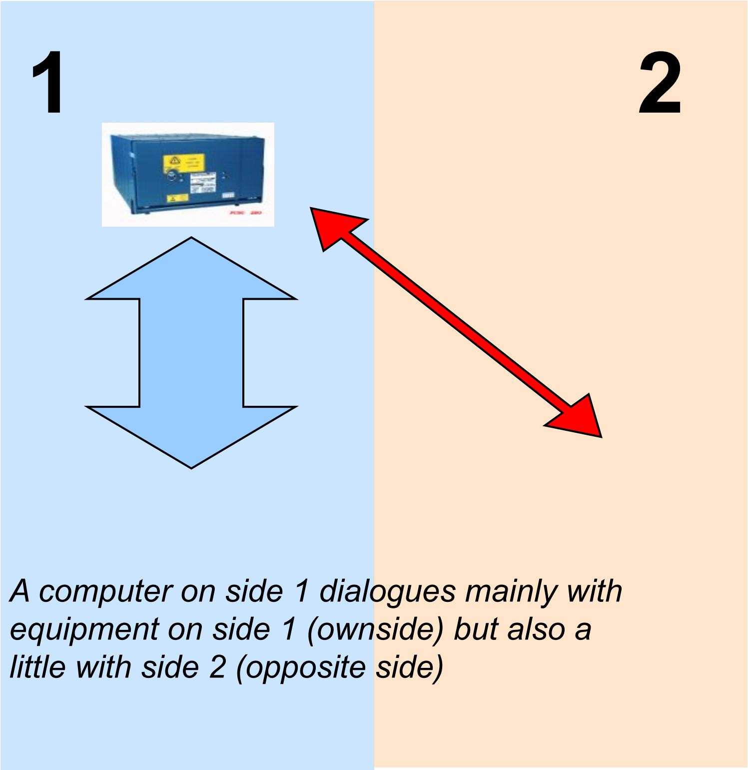
More generally, this covers any electrical event on one side such as, for example, an electric arc on a loom (wires in contact subsequent to the melting of the shelves => ALIFAX, MD11)



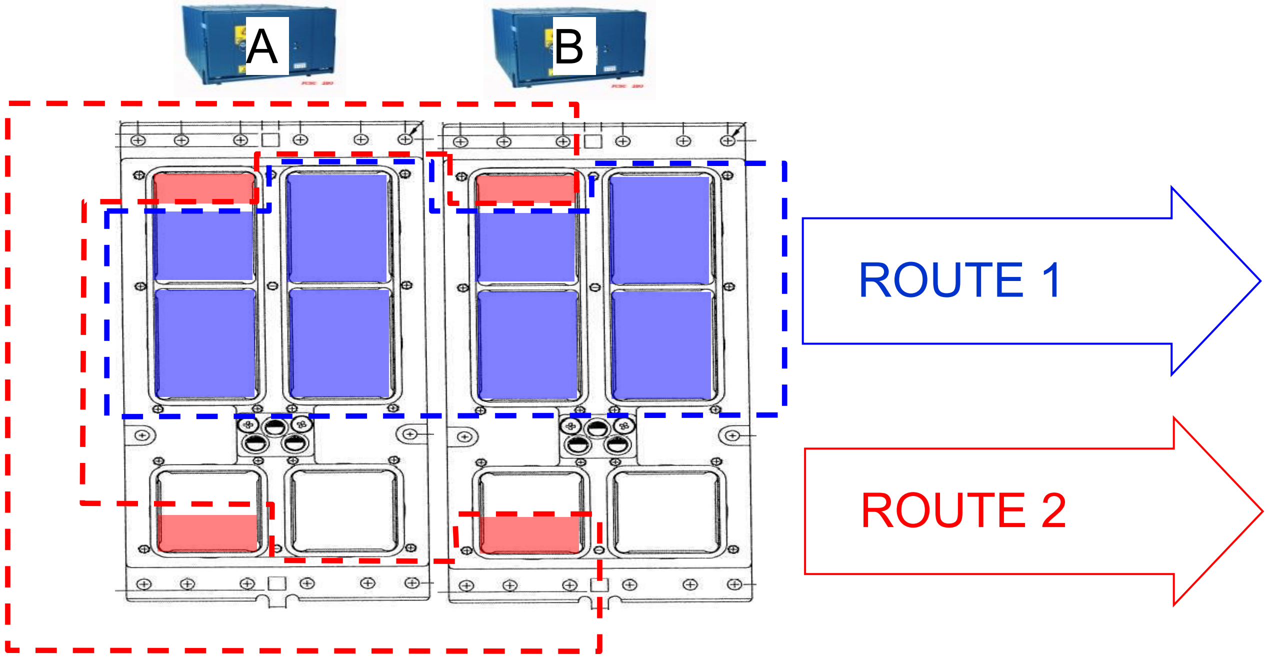
FLIGHT CONTROL INSTALLATION/SEGREGATION

- SEGREGATION UP TO COMPUTER CONNECTORS

The connector of each flight control computer is designed to accommodate the two electrical routes of the aircraft. Protections are used on the backplane boards to prevent electrical disturbances from propagating from one route to another.



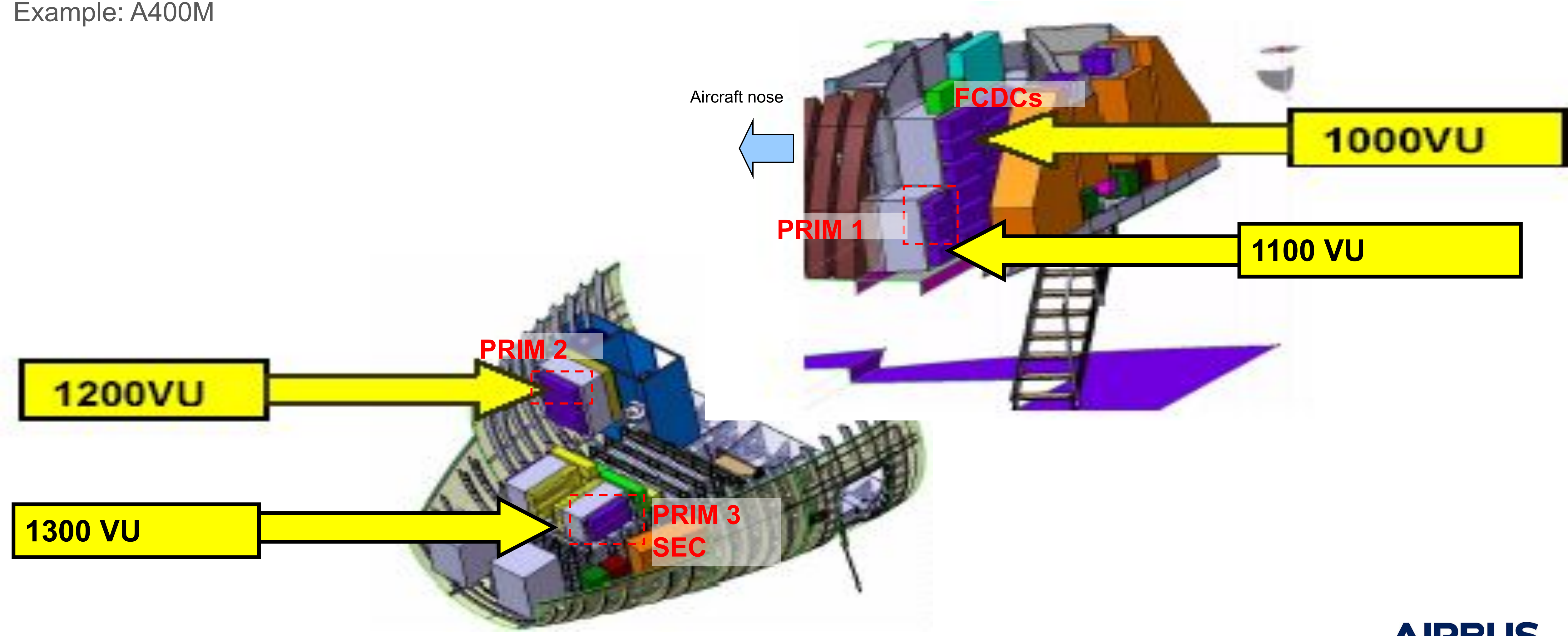
E.g. A380 FCGC consisting of 2 FCGUs



FLIGHT CONTROL INSTALLATION/SEGREGATION

- WELL LOCATED COMPUTERS

Example: A400M



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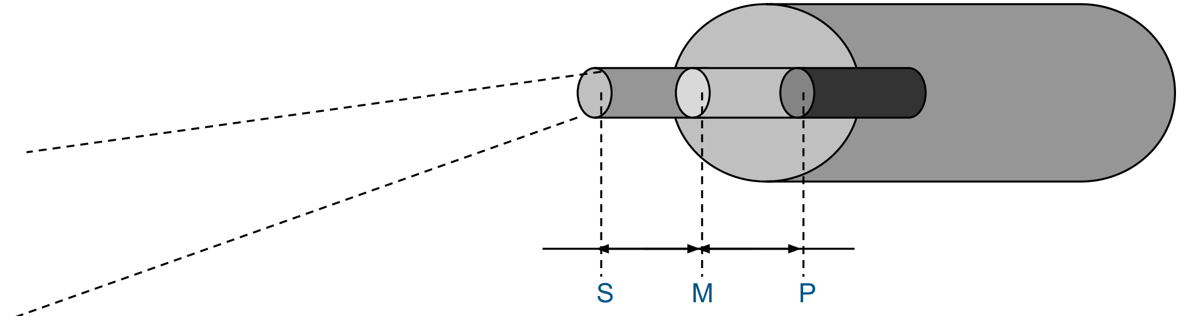
FLIGHT CONTROL INSTALLATION/SEGREGATION

- ROUTES S, M and P

A **R**oute consists of 3 subroutes, that is 3 looms with wires of coherent characteristics:

- S for "sensitive": sensitive signals, that is not very tolerant to electrical disturbances (command signals)
- M for "miscellaneous": or monitoring signals (control surface position sensors, etc.)
- P for "power": power sources (115V, etc.), generally polluting

A minimum space is obviously required between routes (as for an installation in a house: 220V and telephone or TV)



- distance between S and M of 10 cm
- distance between P and S/M of 15 cm

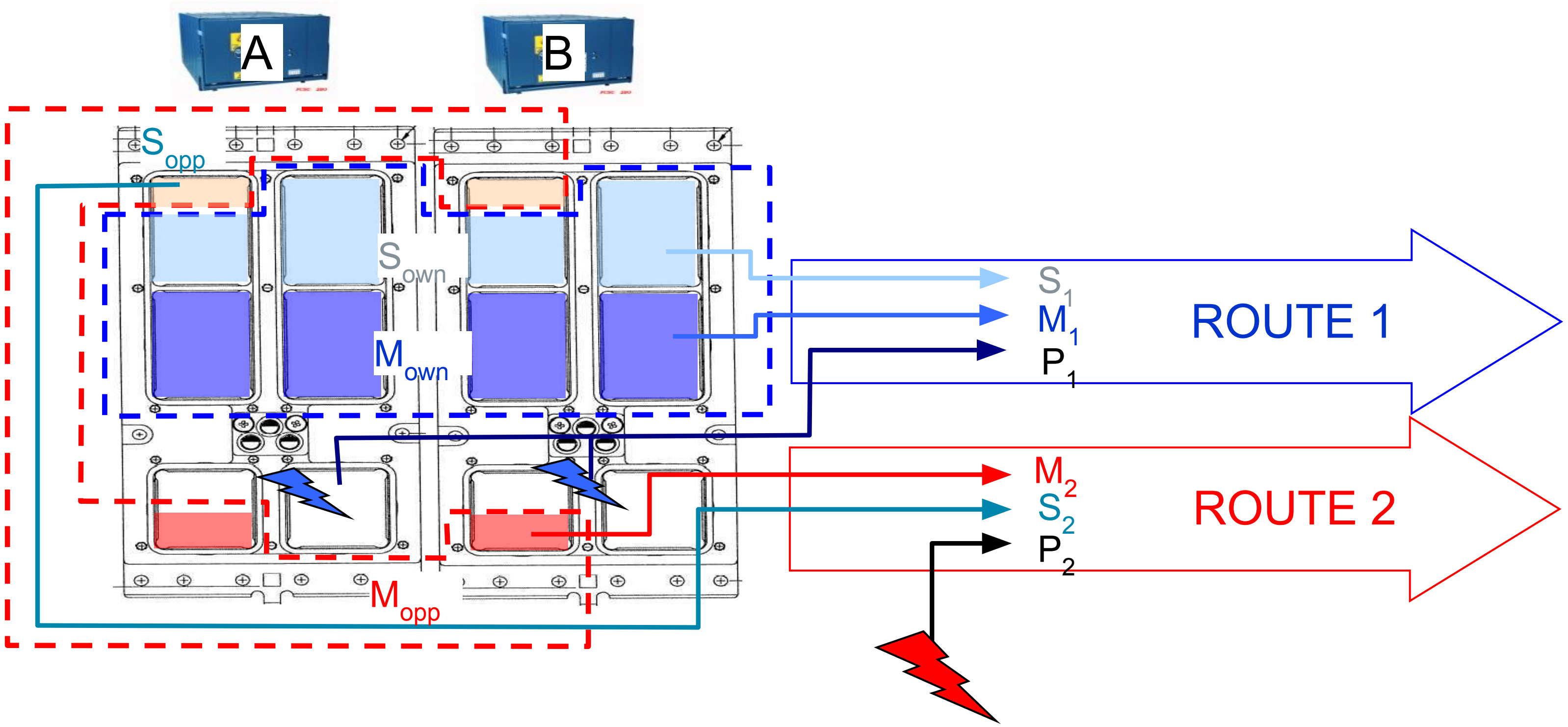
Note: if there are electrical protections, can be reduced to 2.5 cm

FLIGHT CONTROL INSTALLATION/SEGREGATION

- S, M et P ROUTES

Segregation can be seen in the connector

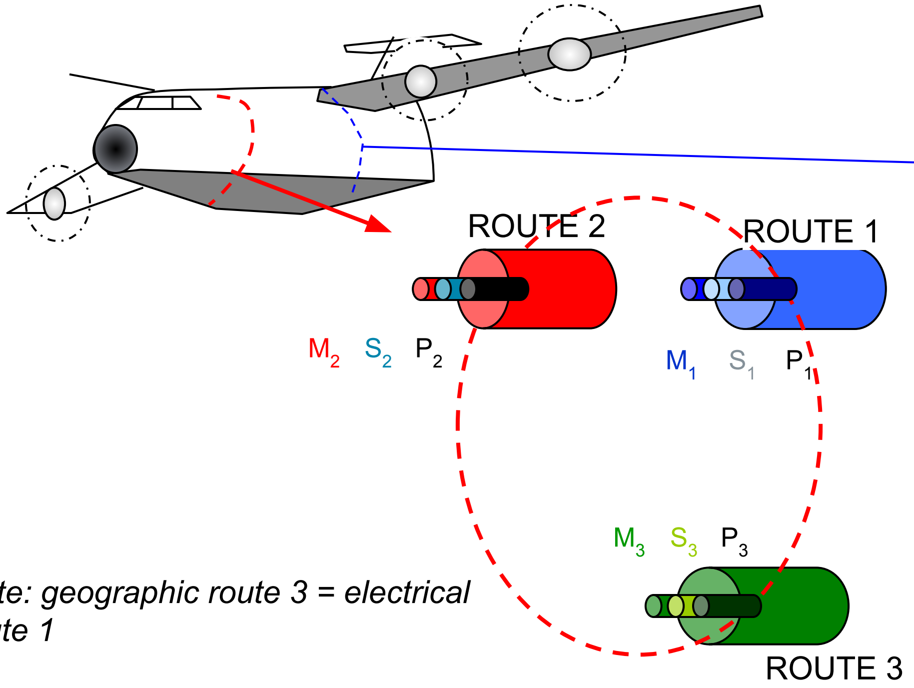
Ex: FCGC A380 side 1



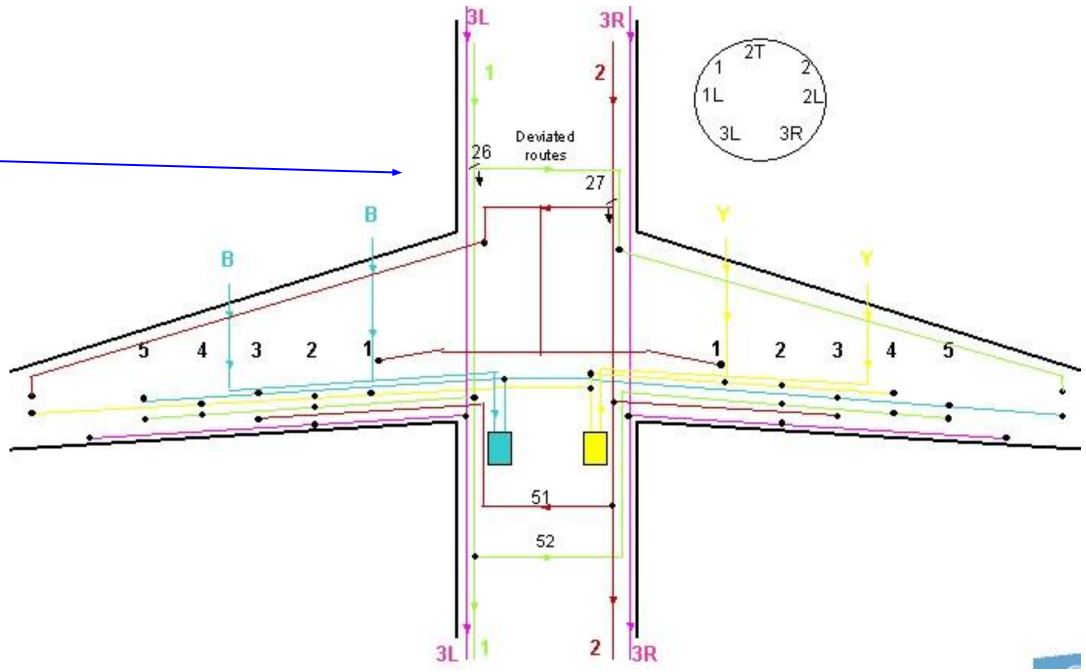
FLIGHT CONTROL INSTALLATION/SEGREGATION

- GEOGRAPHICAL ROUTES, 2, 3 OR MORE

Faced with specific risks which can destroy the routes, multiple geographical segregations must also be ensured: at least 3 routes along the A400M fuselage (single shot: impossible to destroy the 3 apexes of a triangle with a single shot) and the number of subroutes required in risky zones (A400M wings, 20 "deviated" subroutes to allow for UERF)



Note: geographic route 3 = electrical route 1



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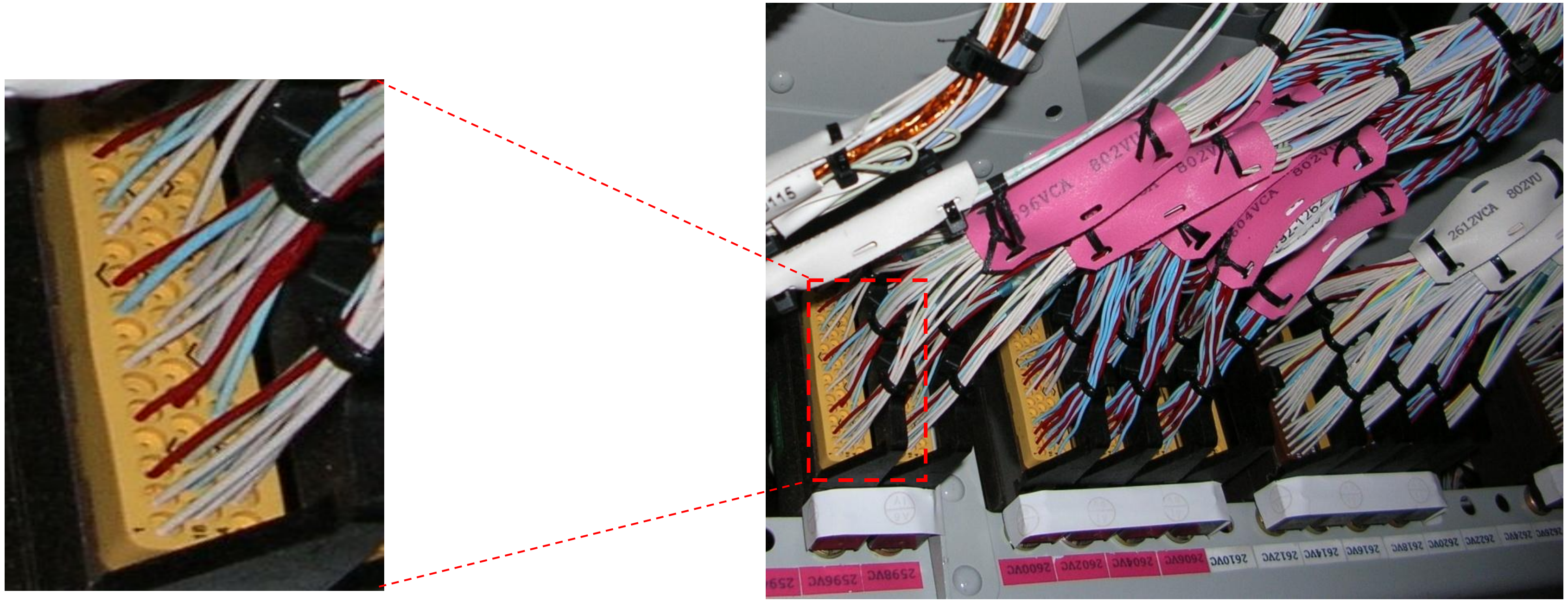
FLIGHT CONTROL INSTALLATION/SEGREGATION

- FLIGHT CONTROLS "NO SHARING"

The choice of the routes, the subroutes and the allocation of the pins in the connectors is under full control of the flight control designer (unlike most of the other systems). To avoid disturbances that certain systems may induce on the flight controls, the connectors are not shared.

To avoid these connectors being "inadvertently" used (nature abhors a vacuum), all flight control wiring is pink. The instruction for the airlines is simple: "don’t touch the pink wiring" otherwise specific test procedure.

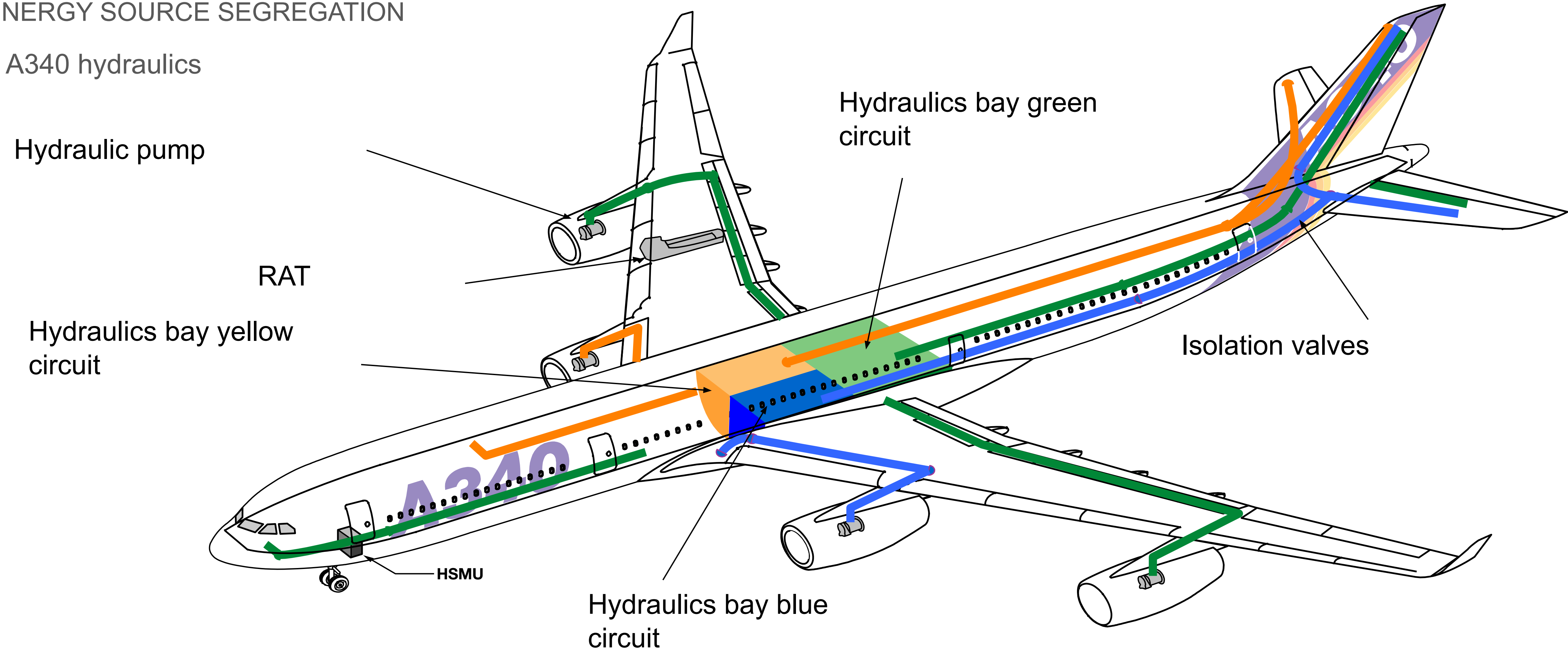
A somewhat empty connector



FLIGHT CONTROL INSTALLATION/SEGREGATION

- ENERGY SOURCE SEGREGATION

Ex: A340 hydraulics



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Thank you