AIRCRAFT ACTUATION SYSTEMS

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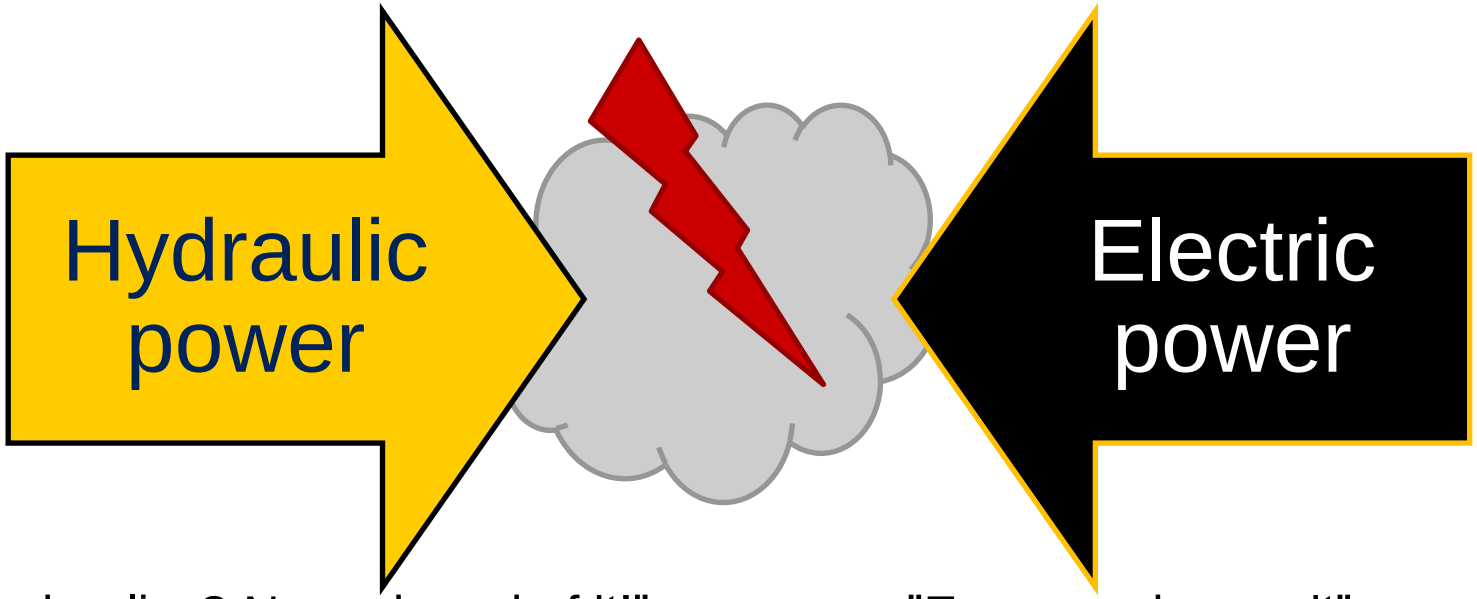
- State of the art today
- Pros and cons of hydraulic and electric actuators
- New actuators
- Future development of actuators

THE FUTURE OF AIRCRAFT ACTUATORS

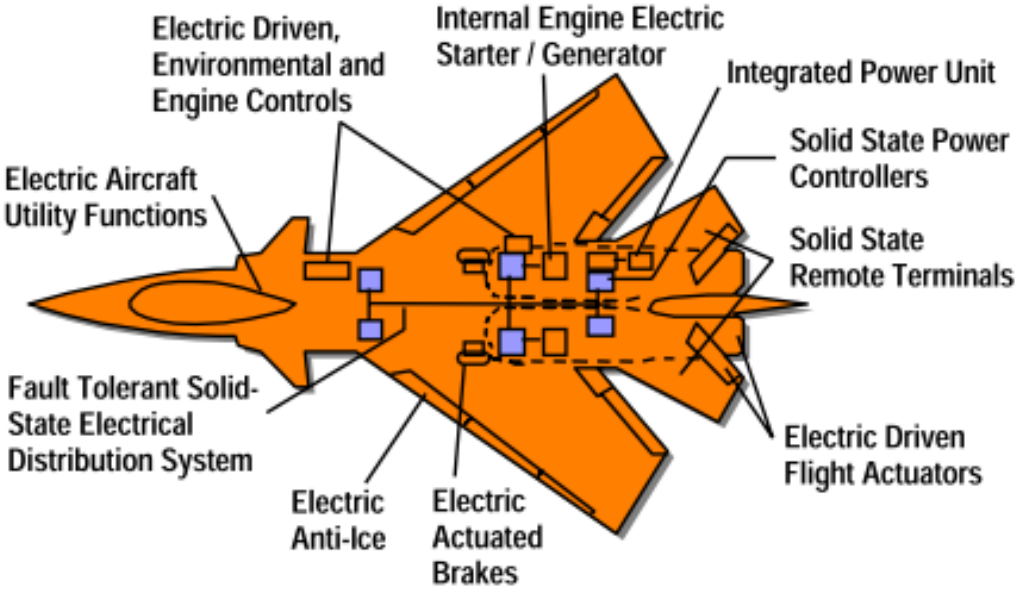


”Hydraulics? Never heard of it!”
”Filthy, leaking”
”Difficult to assembly”

”Everyone knows it”
”Clean”
”Plug and play”

MORE ELECTRIC AIRCRAFT (MEA)

- Electric power to supply:
  - All actuators
  - Environmental control and cooling systems
  - Engine start
  - Ice protection
  - Braking
  - Landing gear
  - (Hydraulic pumps)



- No gearbox from engine

- Nortrope/Lockhead/Boeing estimated MEA to
  - Save procurement cost
  - Save LCC
  - Give a large range improvement

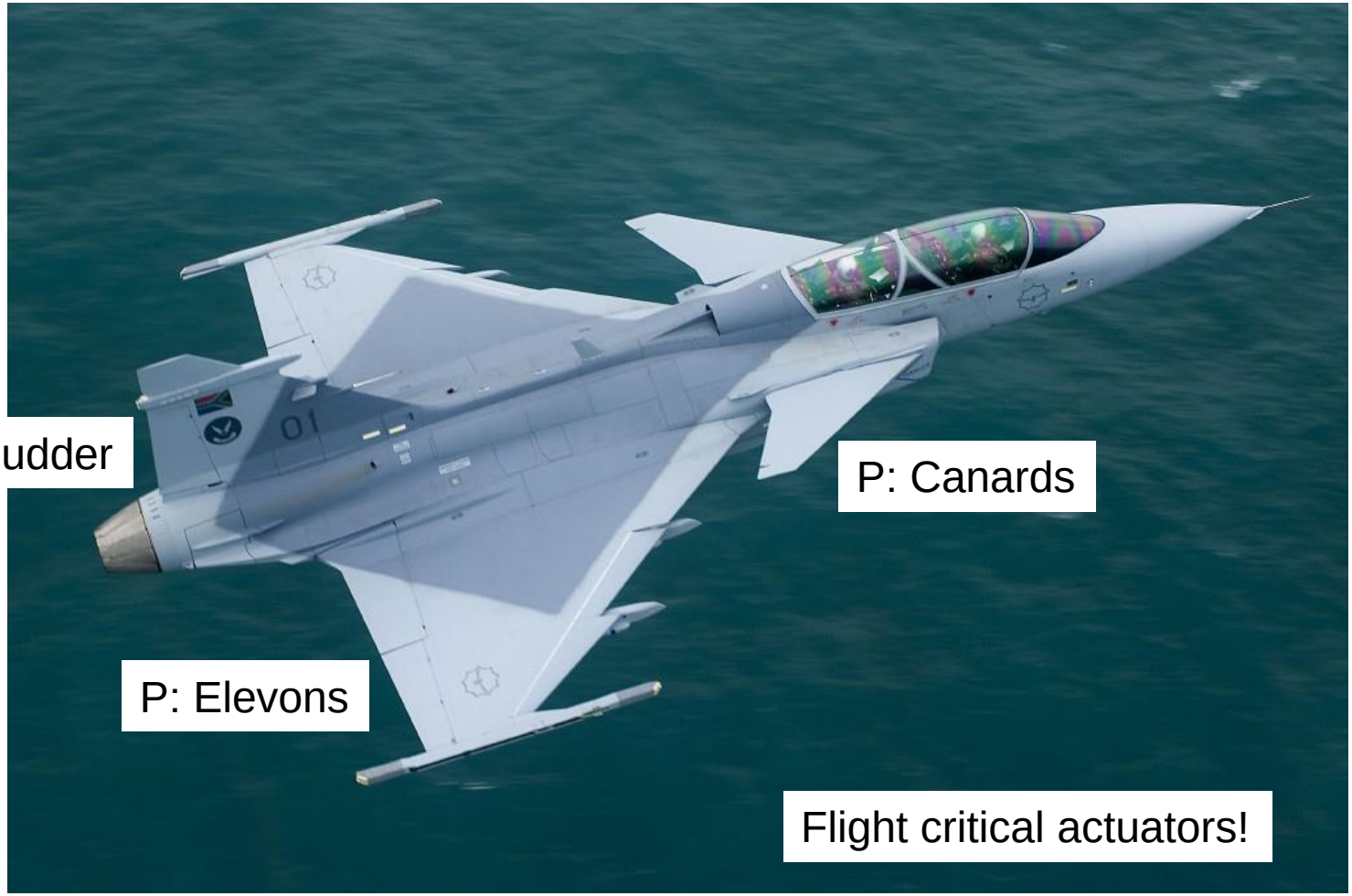
- Saab y2002: Could save up to 100 kg equipment in a fighter

HOW SHALL WE REDUCE ENERGY AND CO2 EMISSIONS FROM AIRCRAFT?

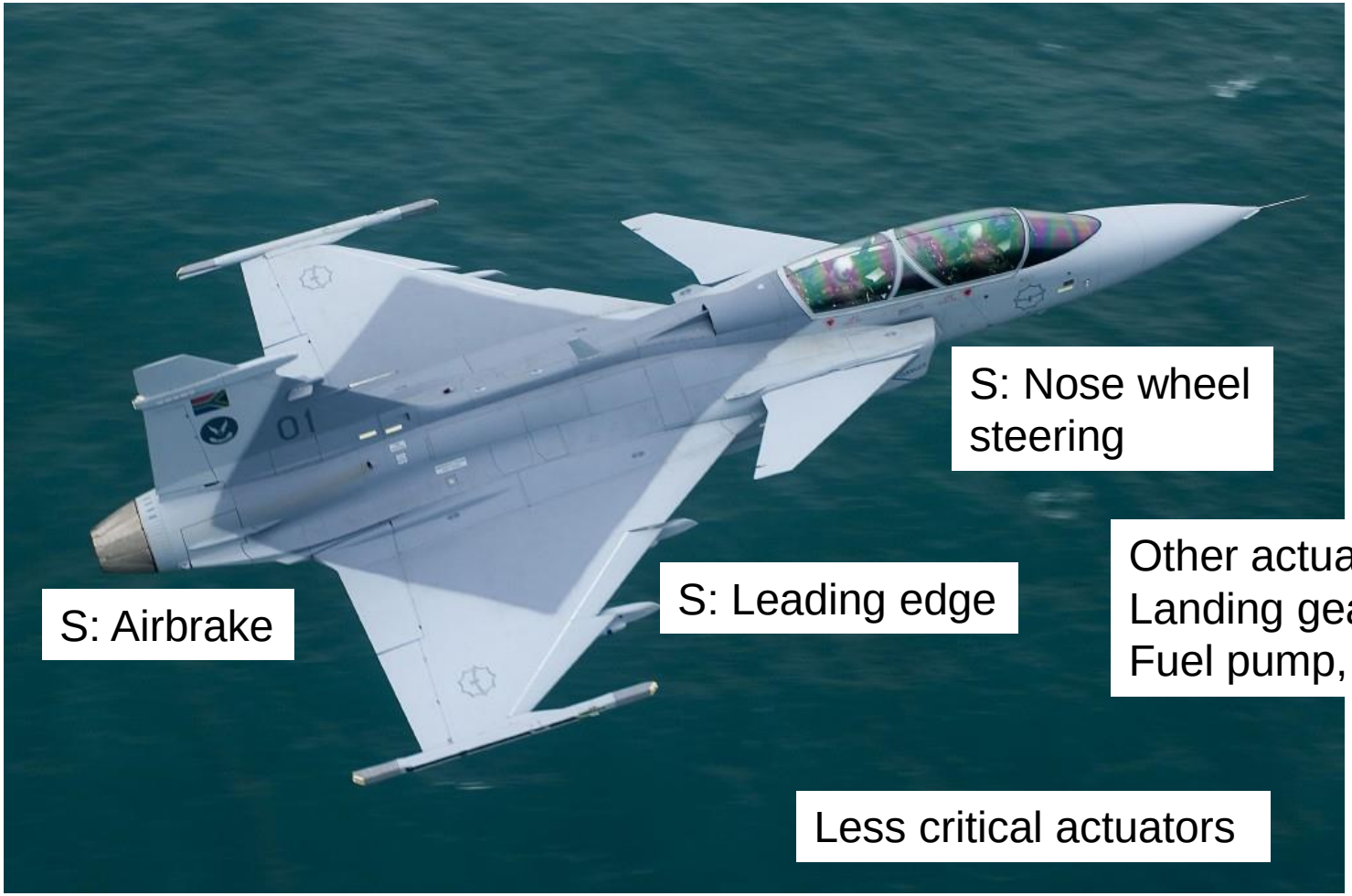
- New ways of planning flights e.g. Just-In-Time to airport
- New technologies to save energy e.g. open rotor, laminar wing, new actuators
- New technologies to save weight e.g. More Electric Aircraft (MEA), more composites

- Research program Clean Sky within EU
  www.cleansky.eu

PRIMARY FLIGHT ACTUATORS FOR PITCH, ROLL AND YAW

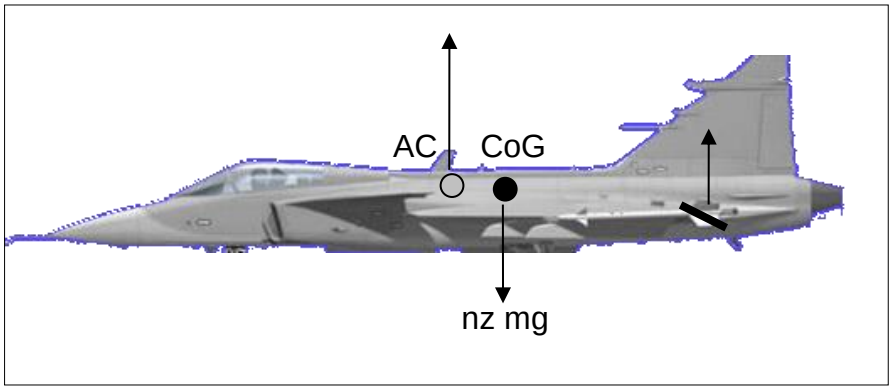


SECONDARY FLIGHT AND OTHER ACTUATORS



A FEW REQUIREMENTS OF AIRCRAFT ACTUATORS

- Fighters are unstable aircraft today
  - Constant control and movement of pitch actuators (canards and elevons)
  - Fly-by-wire
  - Flight critical!



- The more flight critical – The safer equipment!
  - Low probability of faults and damage (in fight)
  - A fault shall not lead to total loss of aircraft
    - Redundancy or Graceful degradation (reduced performance)
    - Identification of fault is essential for redundancy management! Built-in-test (BIT).

A FEW REQUIREMENTS OF AIRCRAFT ACTUATORS

- Low fuel consumption
  - Low weight.1 kg equipment could give 4-5 kg in aircraft
  - Energy waste adds more heat exchangers, cooling system, gear box, ramm air channels, engine, airframe to support, (electric power)
  - Low aerodynamic drag from actuators, control surfaces and ramm air channels

- Performance of aircraft
  - Sizing of actuators are done for a few operations
    - Major actuator weight is rarely used
  - ”Minimal pilot compensation shall be required from pilot”
    - <100 msec from pilot stick to actuator response
    - Nonlinearities (saturation etc) in equipment give lag!

A FEW REQUIREMENTS ON AIRCRAFT ACTUATORS

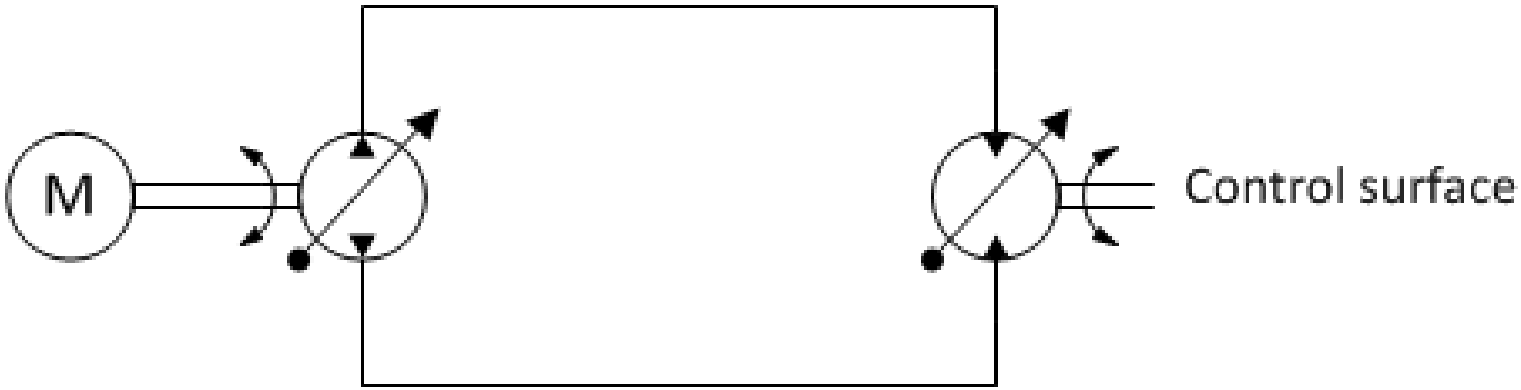
- Always in air!
  - Limited scheduled maintenance
  - Fast identification of faults essential. Diagnostics.
  - Clarification for flight, e.g. refueling and maintenance should not require special tools and special staff
- Low maintenance
  - Avoid open a hydraulic system
  - Open the system before it breaks! Prognostics.

HYDRAULIC ACTUATORS (HA)

- Mature technology
- Integrated redundancy in case of failure
- Free-floating control surface @ jamming
- Overload and end stop protection

ELECTRIC ACTUATORS WITH HYDROSTATIC TRANSMISSION (EHA)

- Mature technology with electric motor
- Hydrostatic transmission replaces gearbox, ballscrew, clutch, torque limiter
- Electric wing: Only wires to the wing, no hydraulic pipes



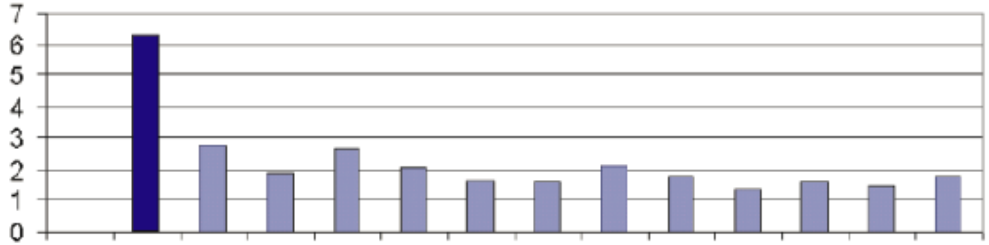
ELECTRIC ACTUATORS WITH MECHANICAL TRANSMISSION (EMA)

- Less mature technology for aircraft
  - Jamming?
- Airbus year 2012 about possibilities with EMA actuators:
  - Should save 500 kg in A380
  - Better redundancy (H+E)
  - Lower maintenance
  - Faster installation

(from Parker, patented jam-tolerant design)

SAAB'S EMA FOR BOEING 787

- In traffic as a backup for high-lift actuator (no jamming redundan)
- High power density, split phase permanent magnet synchronous motor
  - Low weight
  - Internal thermal and galvanic redundancy
  - Low gearing -> Low weight, inertia and freeplay

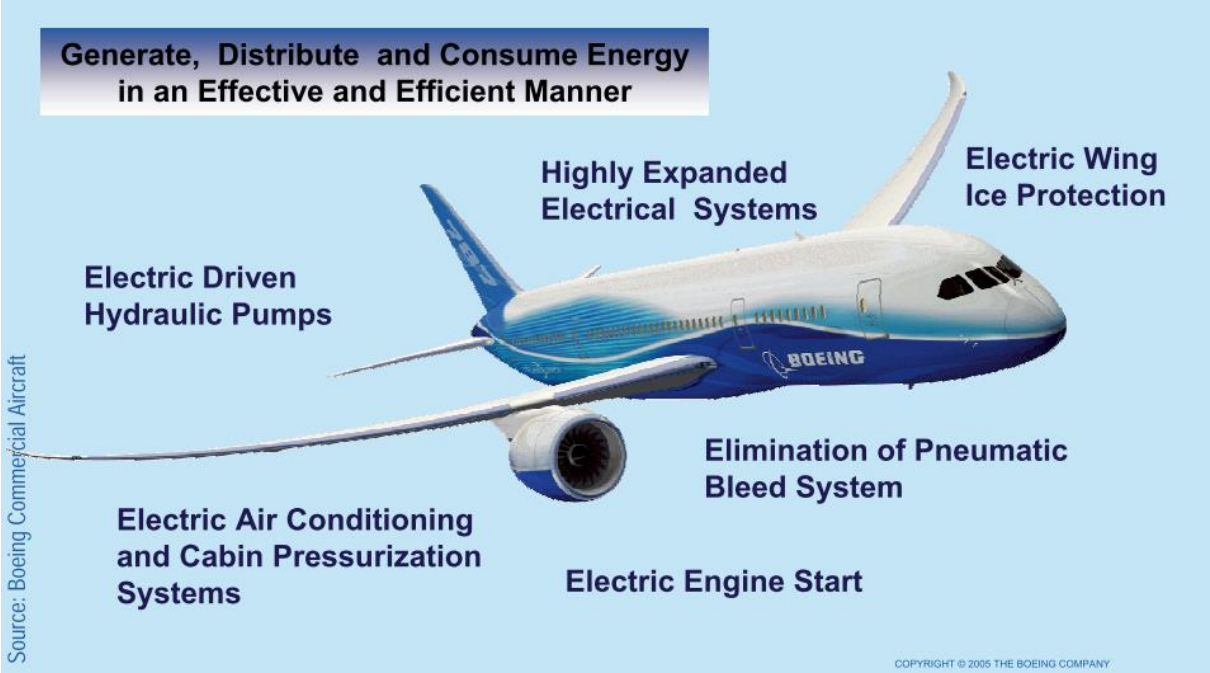


RECENT FIGHTER ACTUATOR CHOICES

- Joint Strike Fighter, Lockhead Martin F-35, USA
  - More Electric Aircraft philosophy
    - Electric cooling system, electric actuators, …
  - 160 kVA electric power -> 300 kVA -> 400 kVA
  - EHA actuators (An overheated primary actuator reported)

- Gripen NG, Saab, Sweden
  - Conventional cooling and hydraulic actuators
  - < 100 kW required for hydraulics and electric power (cooling excluded)

RECENT CIVIL AIRCRAFT ACTUATOR CHOICES



- Airbus A380
  - 2 electric (EHA and EHBA) + 2 hydraulic systems.
    - Maintenance require hydraulic pipes to the hydrostatic transmissions since the oil degrades
  - 900 kVA el power & 800 kW hydraulic pumps
  - FCS & landing gear actuators: 50 – 500 kW

- Boeing 787 ”Dreamliner”
  - Conventional hydraulics. 3 hydraulic systems. 5000 psi. EHBA.
  - Otherwise MEA:
    - 1.4 MW el. power
    - 777: app. 300 kW
  - More composites and other new technologies
  - ”787 saves 3% fuel compared to 777”

MAJOR PROS AND CONS WITH FLIGHT ACTUATORS

(PARTLY DERIVED FROM PROFESSOR J.-J. MARÉ, INSA, TOULOUSE)

	Hydraulic actuator ”Speed on demand”	**Electric actuator** ”Power on demand”
Control of speed and movement	Direct drive or lever arm between actuator and control surface. Linear.	Gearbox and ballscrew between motor and control surface Rotational.
Choice of actuator size (weight)	Maximum force and speed (nominal). Fatigue.	Maximum temperature of actuator (varies with mission profile). Fatigue.
Power losses	Speed dependant + permanent losses (Valves, leakage, friction)	Force dependant (Motor, power electronics,hydrostatic transmissions)
Maintenance cost	High	Low

OTHER TECHNICAL ISSUES WITH FLIGHT ACTUATORS

(PARTLY DERIVED FROM PROFESSOR J.-J. MARÉ, INSA, TOULOUSE)

Hydraulic actuator	Electric actuator
High power losses Leakage Assembly of piping Maintenance (cleanliness) Toxic oil in aircraft Cavitation of pumps (Anti-jamming, damped end stops, overload protection and cooling are OK)	Cooling is problematic (motor, hydrostatic transmission, power electronics) EMI and electric protection distances Jamming has no good solution today. Gearbox introduce start/stop wear on control surfaces, backlash in control loop, maintenance (lubrication) Lack of damped end stop at failure (Torque limiters are OK.)
Lack of training in hydraulics	Electric power knowledge is common. Lack of training in EMI (and cooling among electric engineers)

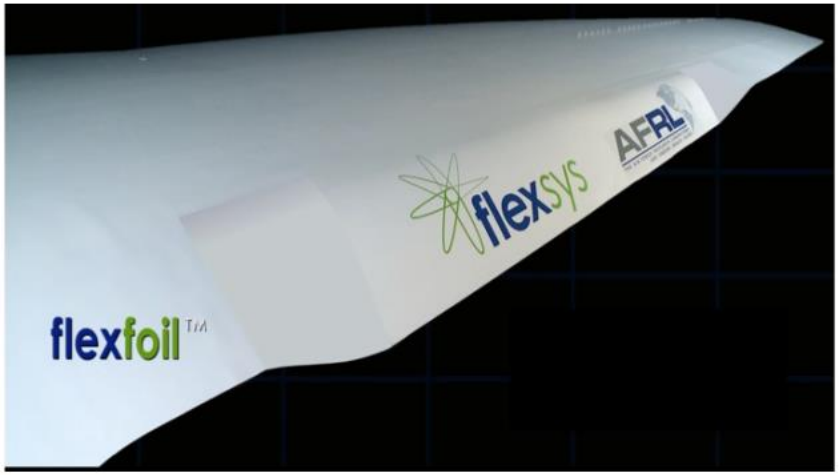
OTHER INTERESTING NEW ELECTRIC ACTUATORS IN AC

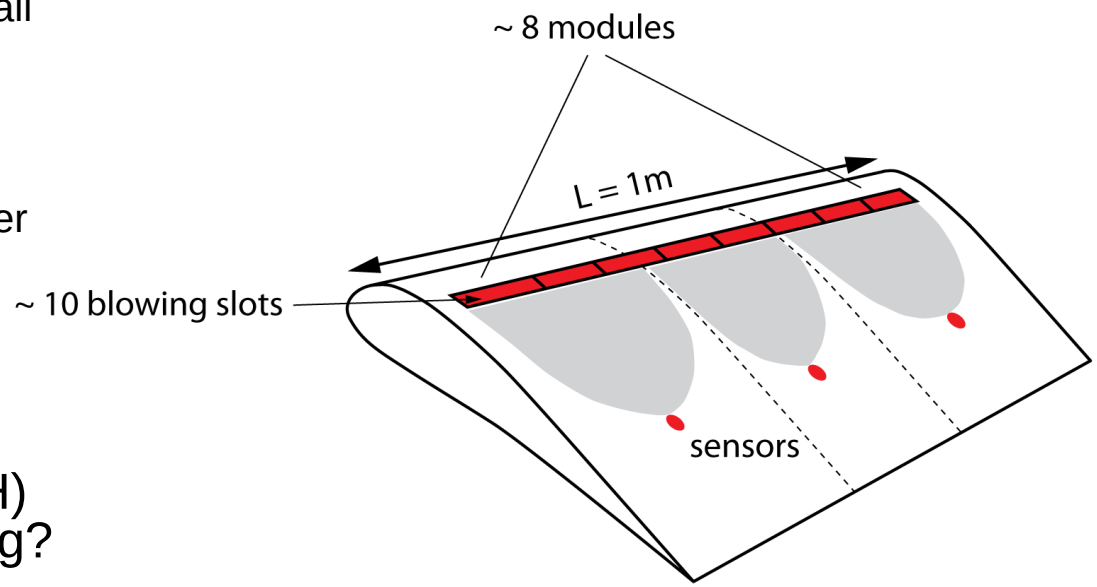
- Green taxiing (Safran, Honeywell)
  - Engine off
  - APU give electricity to electric motor in main landing gear wheel
  - Saves 3% fuel and minutes in gate (ac reverse possible)

- Electric braking (Safran Messier-Bugatti-Dowty) in Boeing 787
  - Electric motor, gearbox and ballscrew instead of hydraulic actuator
  - Same weight and performance
  - Improved assembly, maintenance, monitoring, reliability, availability.
  - Procurement cost increase

FUTURE OF AC ACTUATION

- Morphing wings
  - Variable Geometry Control Surface
  - FlexFoil: Flexible material around control surfaces cut 4-8% energy
- Fluidic actuators
  - Suck (or blow) through small holes to boundary layer of wing.
    - Suction require low power consumption
  - Pulsations in boundary layer
- Plasma around wing (ionised boundary layer)
- Supercavitation. He (or H) around wing to lower drag?





REQUESTED FUTURE DEVELOPMENT OF HYDRAULIC AC ACTUATORS

- Reduced power losses in the hydraulic system
- Maintenance on hydraulic should be reduced
  - Leakage and sealings
  - Oil temperatures
  - Cavitation
- Environmental friendly oil

REQUESTED FUTURE DEVELOPMENT OF ELECTRIC AC ACTUATORS

- Maintenance on the hydraulics in EHA should be reduced
  - No oil change = no maintenance system for oil change

Flight control system group at Airbuse pushes technology:

- EMA should be developed as primary actuators. To do:
  - Reliability, size and price is too poor compared to hydraulics
  - Freeplay and inertia is too high for good control
  - Lubrication maintenance should be removed
  - Power electronics of in total 200 kW in modules of 1-10 kW each (natural convection cooling)
  - Sizing of actuators is difficult
  - The system must be able to handle a jammed actuator (the clutches are too large now)

SUMMARY

- Mature technology (that can still be pushed):
  - Hydraulic actuators
  - Electric actuator with hydrostatic transmission
- Parameters to evaluate to choose actuator
  - Redundancy (safety, reliability, availability)
  - Maintenence
  - Positive or negative change in weight (volume, drag) – Full system incl cooling, el power, maintenance and installation
- Electric actuators gave new possibilities
  - Green taxiing!
  - In combination with hydraulic actuators: Redundancy!
- Knowledge barriers
  - Hydraulics
  - Reduced maintenance of hydraulic actuators
  - EMI in electric actuators
  - Cooling and sizing of low weight electric actuators
- Remember to remove drag of control surfaces!