The More Electric Aircraft

Why Aerospace Needs Power Electronics?

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The More Electric Aircraft

- Motivations
  - Reliability
  - Fuel burn/efficiency
  - Weight and volume [maybe at system level?]
  - Availability
  - Maintainability
  - Running costs
  - Dispachability
  - Passenger comfort and facilities

Introduction

The More Electric Aircraft

- Power Sources
  - Engine used for thrust
    - » Needed to allow the plane to fly ☺

  - Engine power also used for onboard systems
    - » Taken from the engine
      - – Bleed air, examples:
        - » Hydraulics
        - » Pneumatics
      - – Auxiliary gearbox on engine shaft, examples:
        - » Electrical system
        - » Pumps

Power Sources
"Conventional" Aircraft

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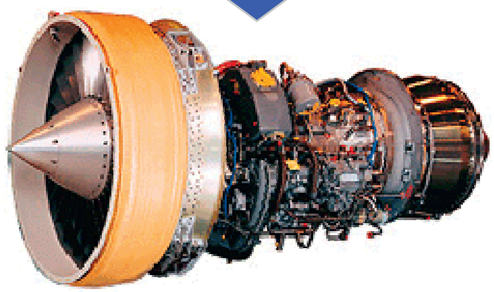
Figures for a typical A320/B737 size aircraft

Jet Fuel



Propulsion Thrust (≈ 40MW)

Gearbox driven generators	High pressure air "bled" from engine	Gearbox driven hydraulic pump	Fuel pumps and oil pumps on engine
Electrical	**Pneumatic**	**Hydraulic**	**Mechanical**
200kW	**1.2MW**	**240kW**	**100kW**

Total "non-thrust" power ≈ 1.7MW

Power Sources
"Conventional" Aircraft

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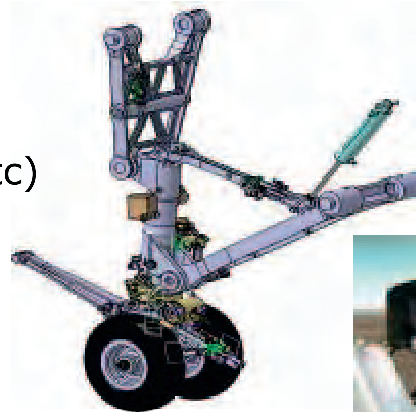
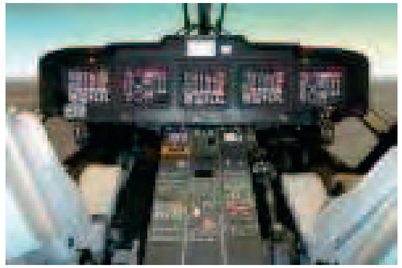
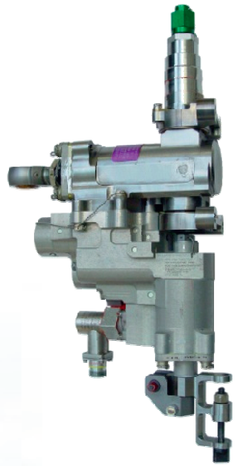
- Electrical
  - » Avionics
  - » Cabin (lights, galley, in-flight entertainment etc)
  - » Lights, pumps, fans
  - » 115V, 400Hz AC
- Pneumatic
  - » Cabin pressurisation
  - » Air conditioning
  - » Icing protection
- Hydraulic
  - » Flight control surface actuation
  - » Landing gear extension/retraction and steering
  - » Braking
  - » Doors
- Mechanical
  - » Fuel and oil pumps local to engine







"More Electric Aircraft" Concept

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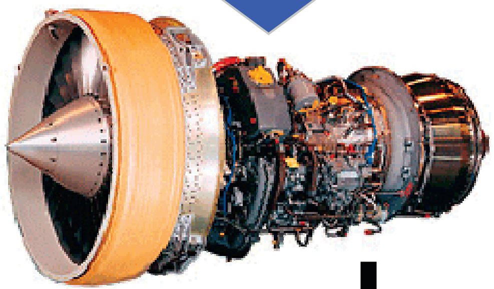
Rationalisation of power sources and networks

"Bleedless" engine

Jet Fuel



Propulsion Thrust (≈ 40MW)

Engine driven generators

Expanded electrical network

Existing electrical loads

ELECTRICAL
Cabin pressurisation
Air conditioning
Icing protection

ELECTRICAL
Flight control actuation
Landing gear/ Braking
Doors

ELECTRICAL
Fuel pumping
Engine Ancillaries

New electrical loads

Electrical system power ≈ 1MW

"More Electric Aircraft" Some Motivations

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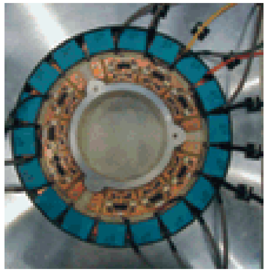
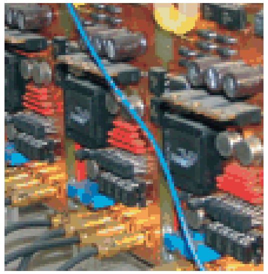
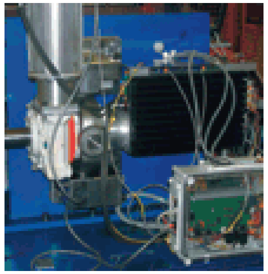
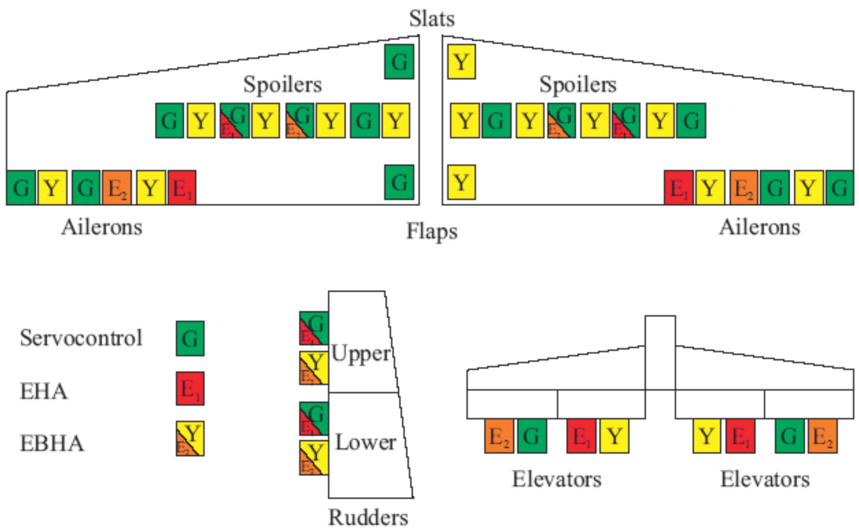
- Removal of hydraulic system
  - reduced system weight
  - ease maintenance
- "Bleedless" engine
  - improved efficiency
- Desirable characteristics of electrical systems
  - controllability
    - » power on demand
  - re-configurability
    - » maintain functionality during faults
  - advanced diagnostics and prognostics
    - » more intelligent maintenance
    - » increased aircraft availability
- **OVERALL**
  - **Reduced operating costs**
  - **Reduced fuel burn**
  - **Reduced environmental impact**



More Electric Aircraft

- Airbus A380
  - 4 x 150kVA Wideband VF on turbofan engines
  - Flight Control Power – 2 H + 2 E
  - Actuator Configuration
    - ➢ Combination of Hydraulic and Electrical Actuation

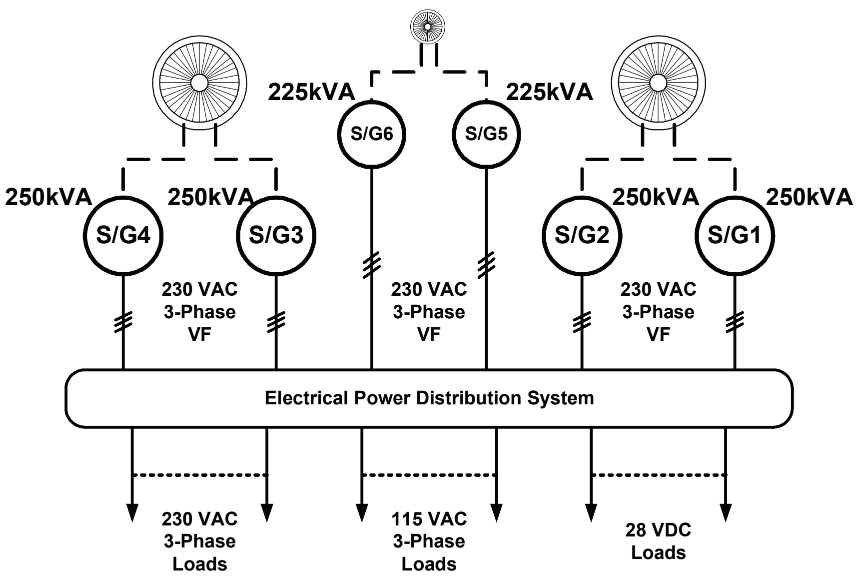


More Electric Aircraft

- Vickers VC10
  - Electrical System – 4 x 40kVA Generators
  - Flight Control Power – 2 H + 2 E
  - Actuator Configuration
    - Combination of Hydraulic and Electrical Actuation
  - Built 50 Years before the Airbus A380

More Electric Aircraft

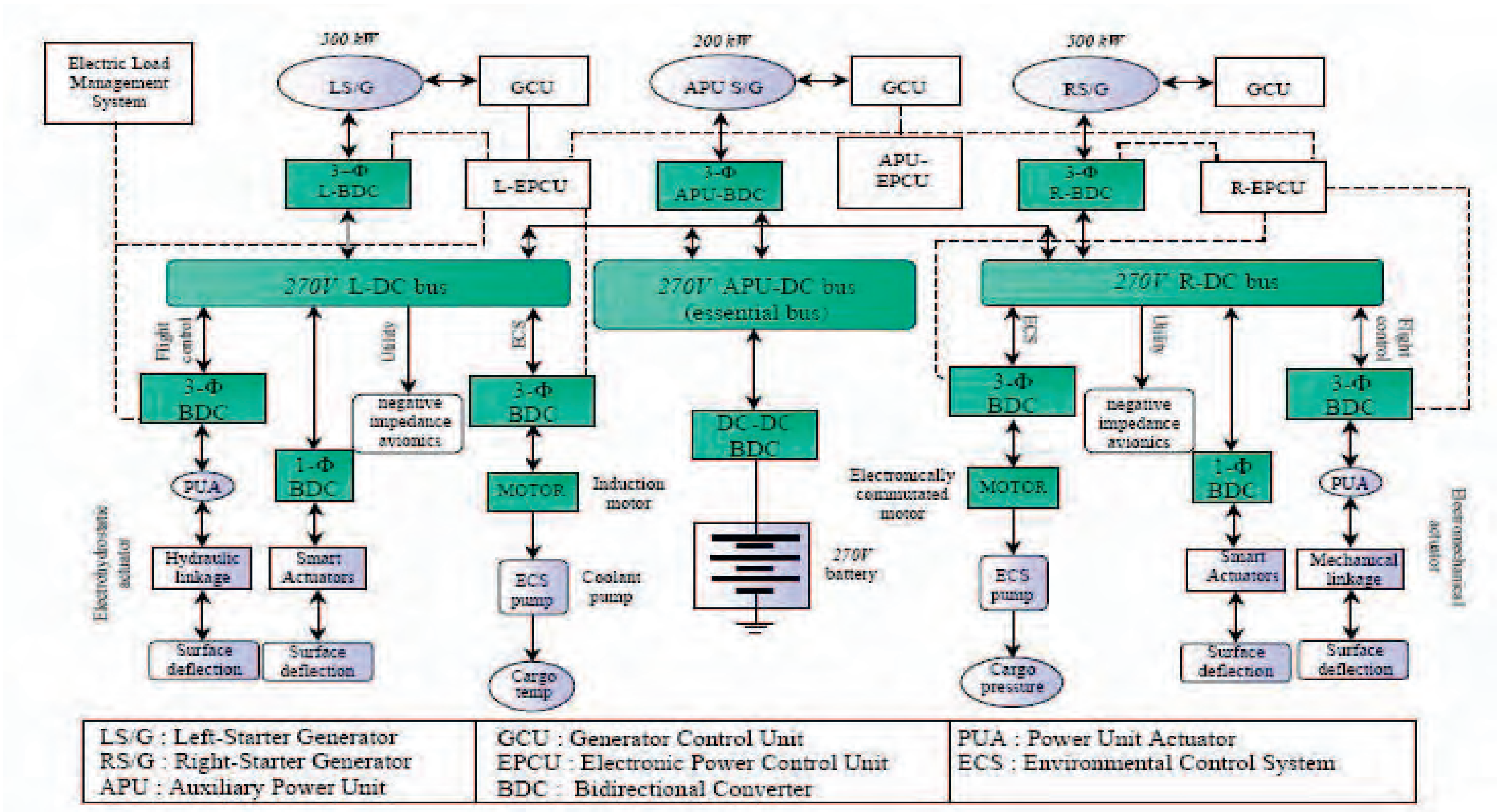
- Boeing 787
  - 4 x 250kVA Primary Channel Starter Generators
    - » 500kVA per channel
  - 230VAC VF Primary Power Generation
  - Electrical Starter/Generators rated at 250/225kVA
  - Electric ECS, pressurisation and wing anti-Icing
  - Removes need for bleed air from engines



More Electric Aircraft

- Joint Strike Fighter
  - 270V DC Power System
  - Electric actuation systems
  - 80kW, 2 channel, switched reluctance generator
  - Reduces cost, size and weight of whole aircraft
  - Relies on Power Conversion technologies
    - » Harsh environment
    - » Efficiency
    - » Reliability

More Electric Aircraft



A Possible MEA DC Power System Layout

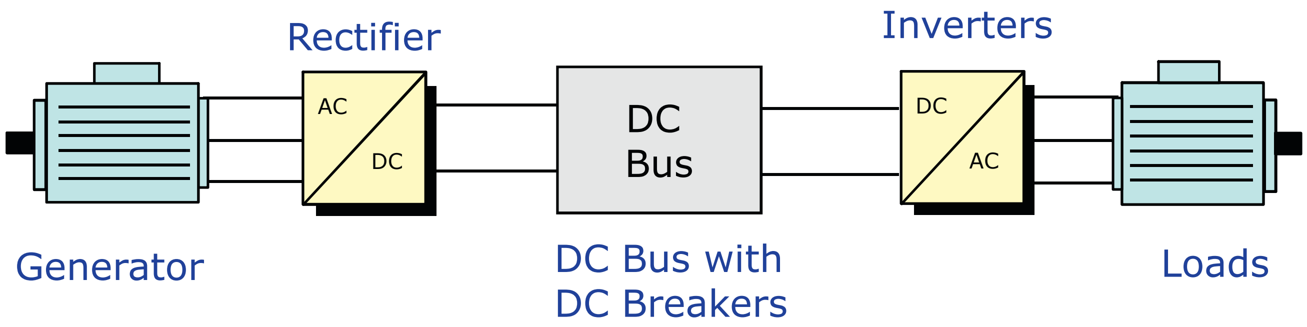
Source: Virginia Polytechnic

Typical Power Levels for Electrical Loads

Power User	Comments	Typical Power level
Air Conditioning	ECS	4 x 70kW+
Flight Controls	Primary and secondary	3 kW to 40kW often short duration at high loads
Fuel pumps		about 10kW
Wing Ice Protection	Thermal mats or similar	250kW+
Landing Gear	Retraction, steering and braking	25kW to 70kW short duration
Engine starting	May be used for additional applications	200kW+ short duration

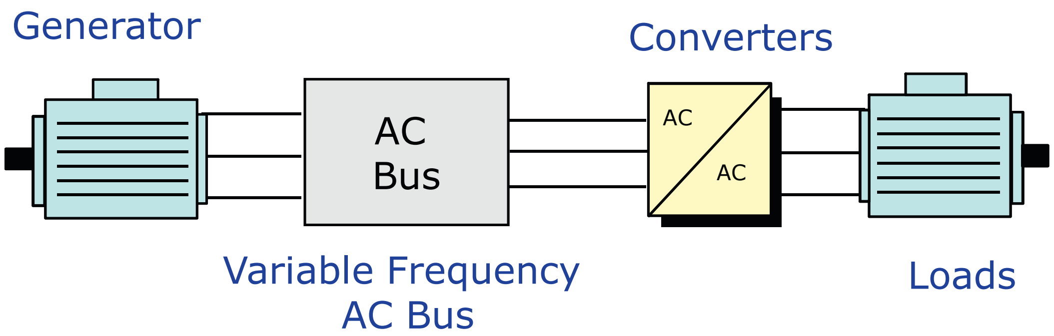
AC or DC Systems

- DC Bus Systems
  - Energy storage requirements within DC Bus
    - » Distributed energy storage possible
  - Circuit Breakers
    - » Traditional solutions are larger than AC breakers
    - » Hybrid or solid state solutions are possible
  - Two power conversion stages
    - » Rectifier in critical path to all loads
  - Fewer conductors required
    - » Better utilization of conductors



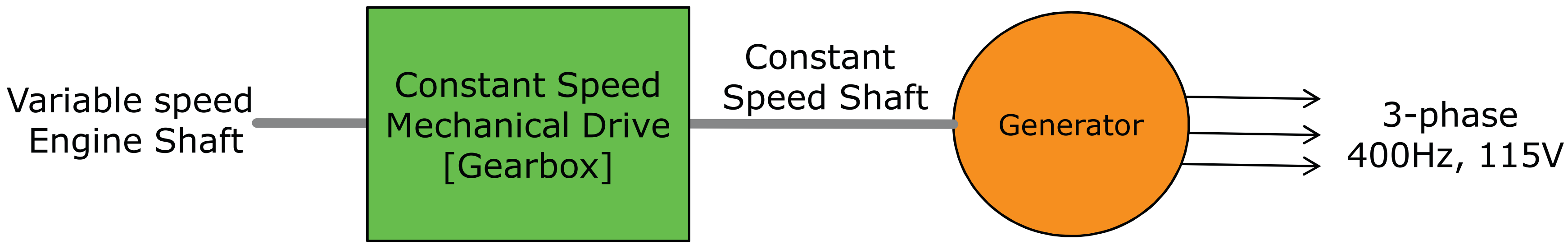
AC or DC Systems

- AC Bus Systems
  - Variable frequency, constant voltage systems are possible
  - Circuit Breakers
    - » AC breakers are small and cheaper than DC breakers
  - Only one power conversion stage required
  - Power stages more complex
    - » Internal energy storage often required
    - » Efficiency of each converter can be lower



AC Power Generation

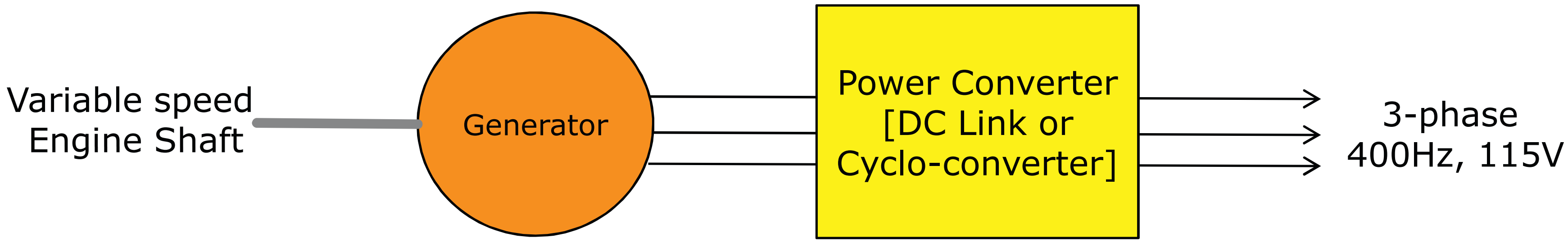
- Mechanical Constant Frequency Generation



- Mechanical gearbox creates a constant speed shaft from a variable speed input
- Constant speed shaft drives the Generator
  - » Voltage control used for the generator
  - » 400Hz voltage supply – fixed frequency
- Expensive to purchase and maintain
  - » Single source due to patents

AC Power Generation

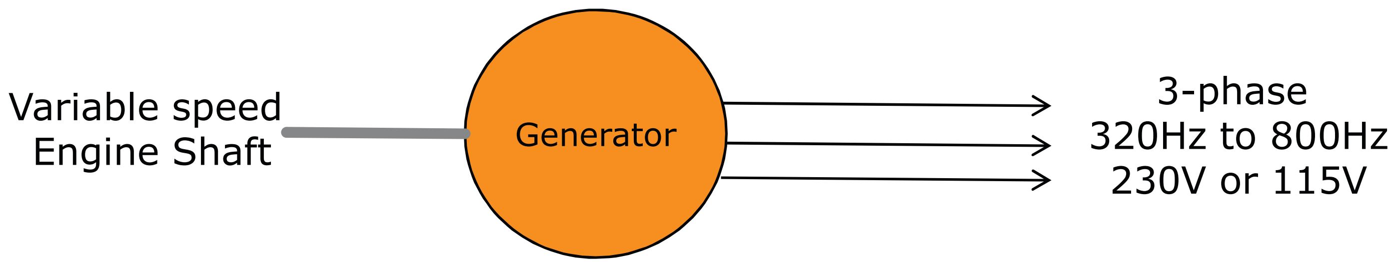
- VSCF Generation
  - Variable Speed/Constant Frequency



- Generator provides variable frequency supply
  - » Voltage control
- Power converter converts to a fixed frequency
  - » 400Hz voltage supply
- Reliability of the Power Electronics is a key driver
  - » Not yet a proven technology
  - » Power converter is a single point failure point

AC Power Generation

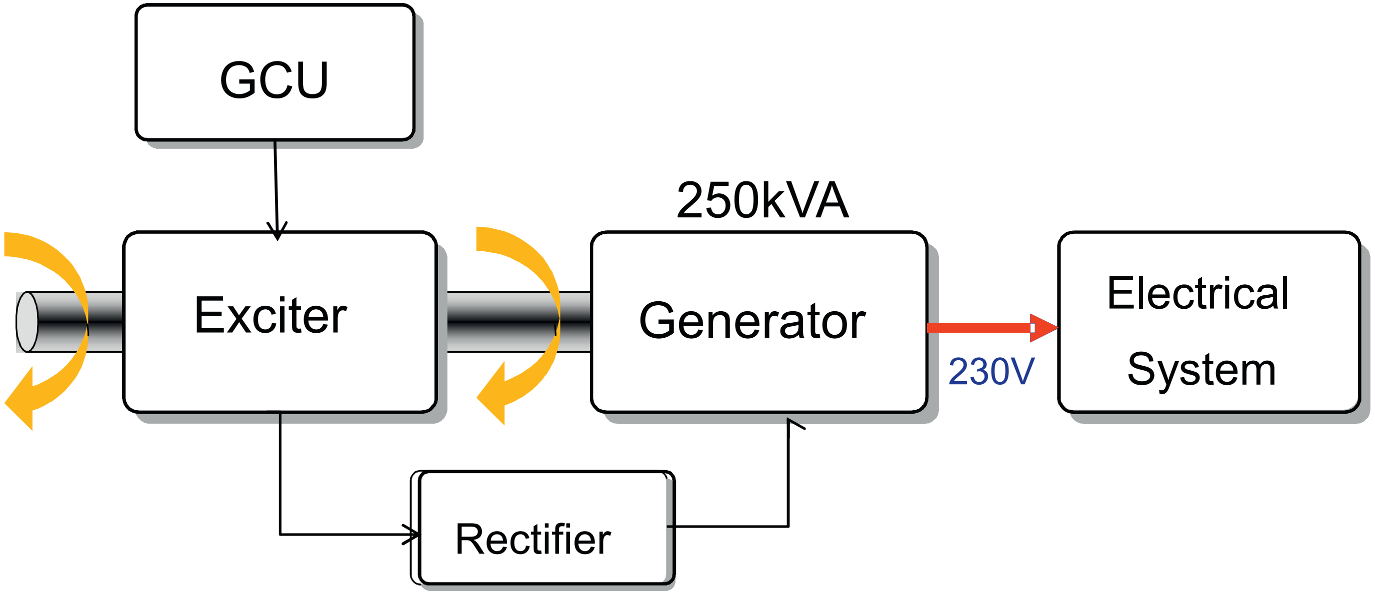
- Variable Frequency Generation



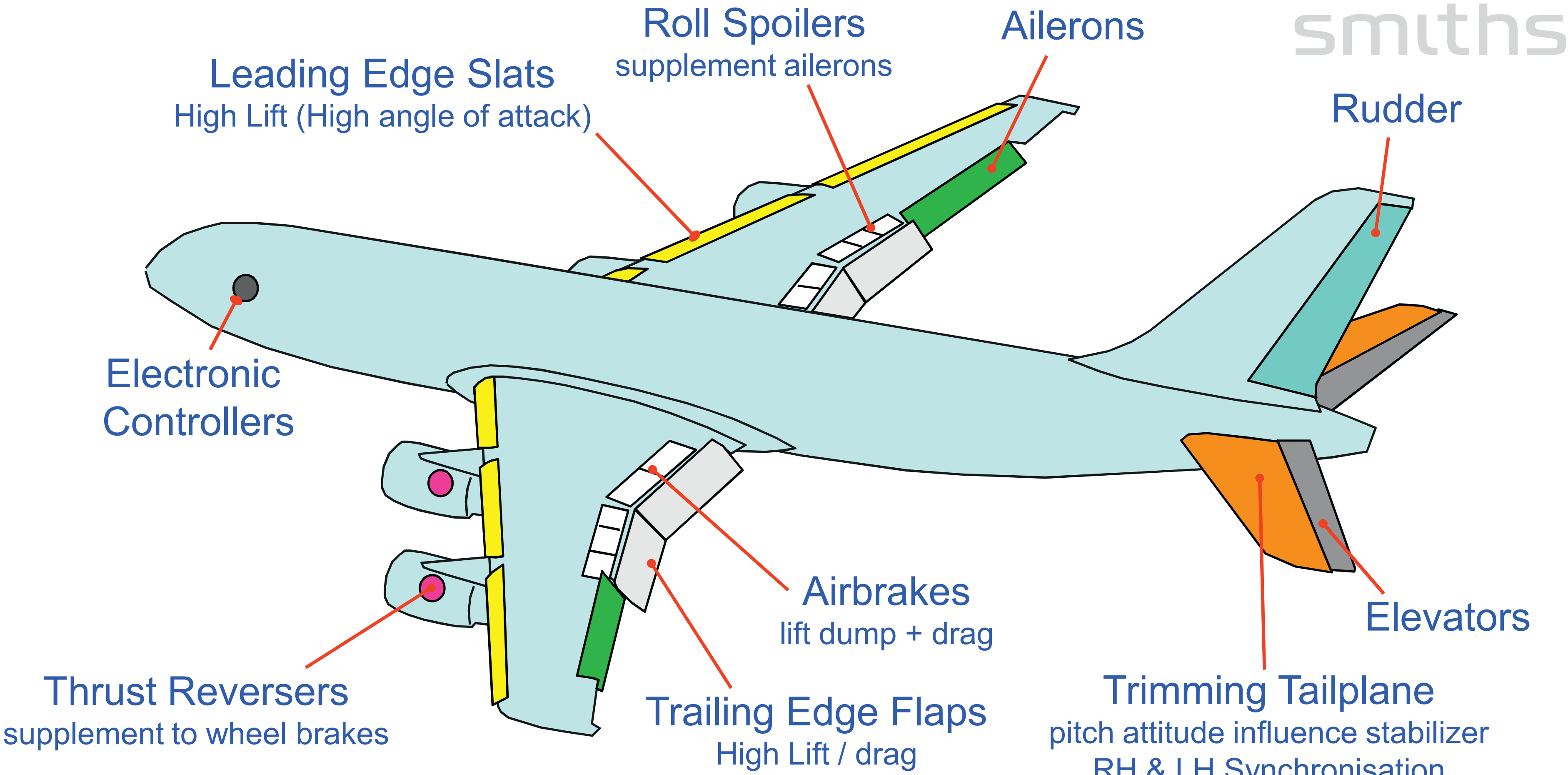
- Generator provides variable frequency supply
  - » Voltage control around generator
- Direct connection between generator and power bus
  - » Simple and reliable generation
- Nearly all aircraft loads will require power converters for control
  - » Good News for Power Electronics Engineers!

Generator Control

- Exciter and generator on main shaft
  - Turn at speed of engine
- Low Power Generator Control Unit [GCU]
  - Voltage control
- High power generator output
  - 230V, Variable Frequency



Flight Control Actuation Systems (civil)



PITCH
Elevators

YAW
Rudder

ROLL
Ailerons
Roll spoilers

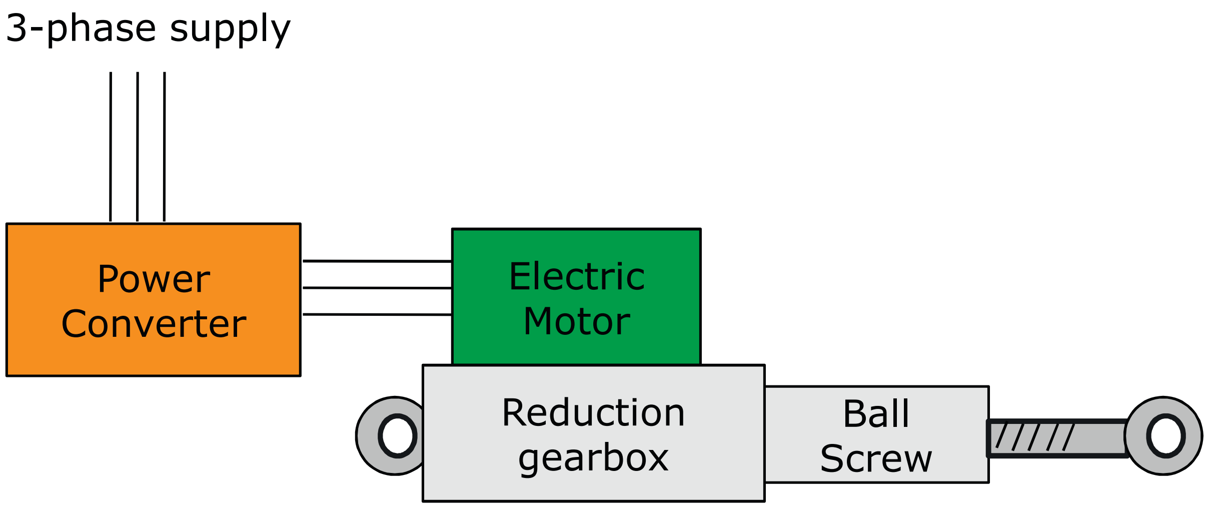
Flight Control - Civil

- Primary Actuation
  - Roll
    - Ailerons on trailing edges of wings
  - Pitch
    - Elevators on trailing edge of tailplane
  - Yaw
    - Rudder
  - **Flight critical**

- Secondary Actuation
  - Flaps
    - Trailing edge of wing
    - Used for take off and landing – increase lift at low speed
  - Slats
    - Leading edge of wing, used for same reason as Flaps
  - Airbrakes
    - Spoilers and lift dumpers on wings – increase drag
  - **Not actually required for flight, but very useful!**

Comparison of Electrically Driven Actuators

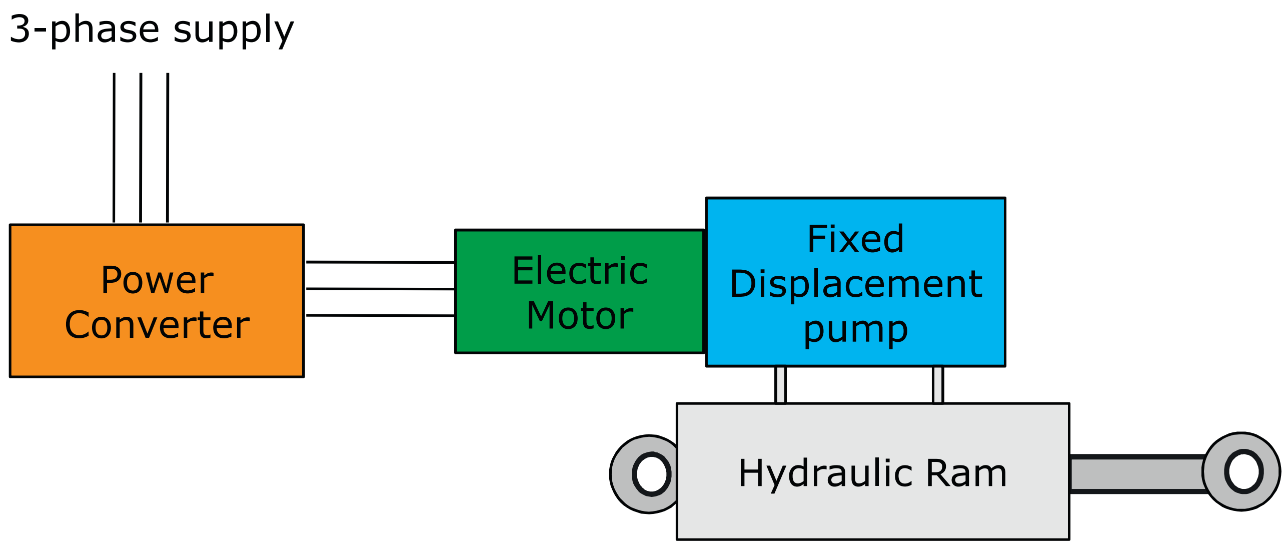
- Electro Mechanical Actuator - EMA



- Actuator is moved as motor spins
  - Each turn of the motor moves the actuator a fixed amount
  - Direct connection between motor and actuator arm
- Hydraulic version uses a hydraulic motor
  - Conventional Mechanical Actuator

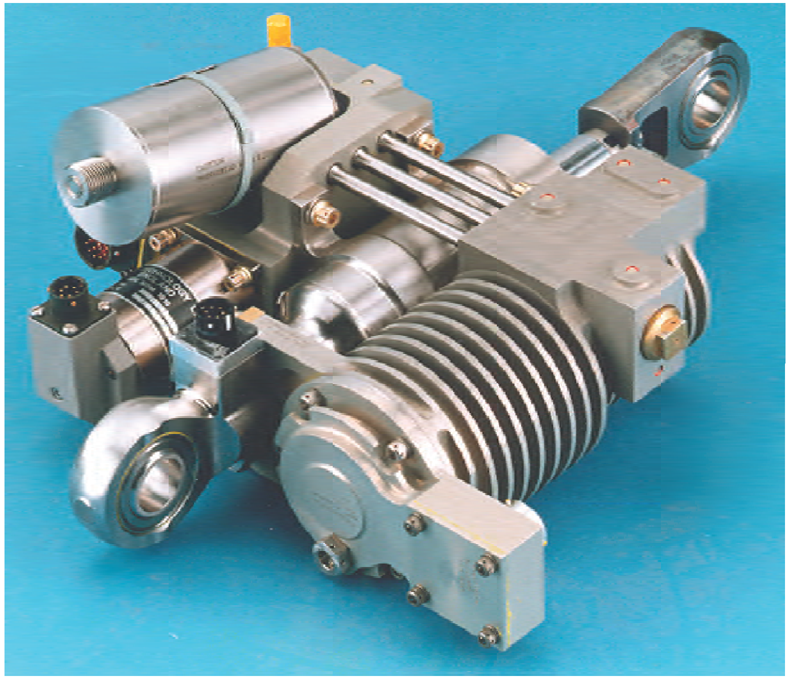
Comparison of Electrically Driven Actuators

- Electro Hydrostatic Actuator - EHA



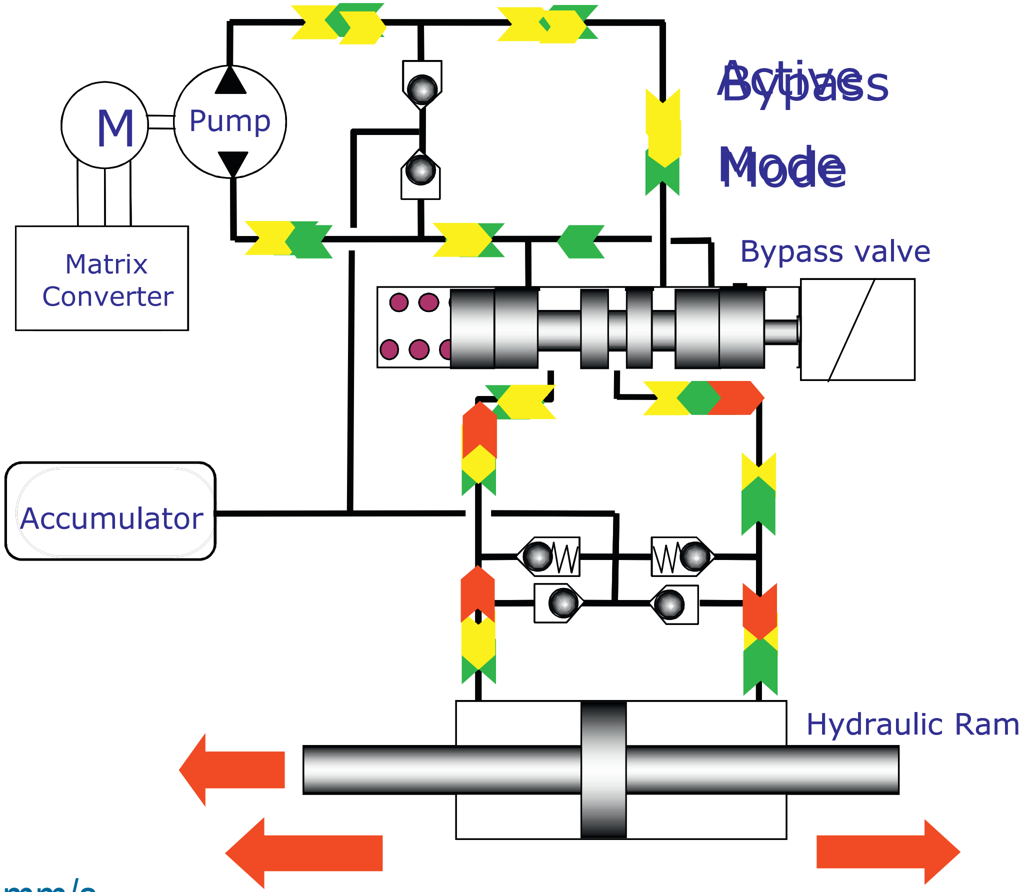
- Actuator is moved as motor spins
  - Each turn of the motor moves the actuator a fixed amount
  - No direct connection between motor and actuator arm
  - Local hydraulic system

Typical Electro-Hydrostatic Actuator



A320 Aileron EHA

- Full Stroke - 44mm
- Max Force - 44500N
- Typical rate – 35mm/s
- Frequency response – 2Hz



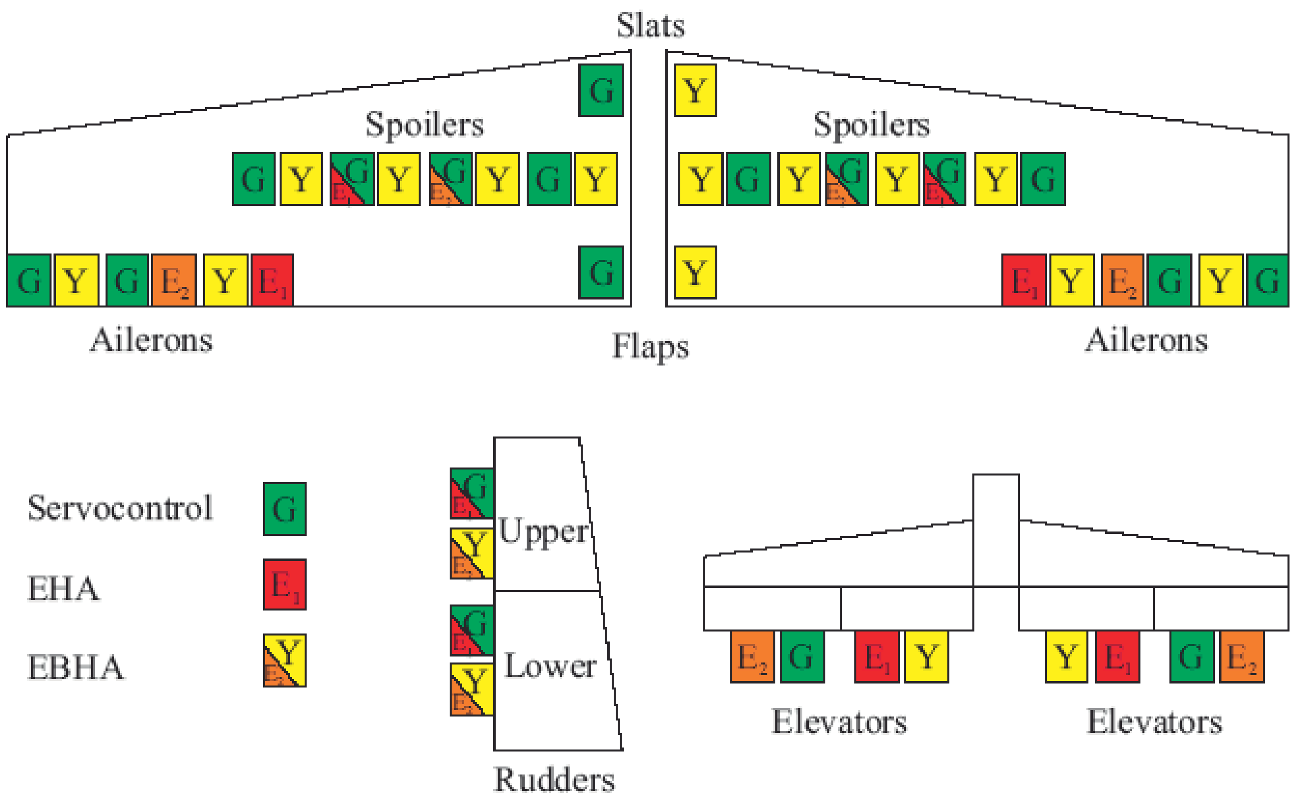
Source: Smiths Aerospace/University of Nottingham

Comparison of Electrically Driven Actuators

- EMA
  - Direct drive solution
  - Any potential jamming failure modes must be addressed
  - Potentially the most compact solution
- EHA
  - Benign failure modes
  - Based on a familiar technology for aircraft component manufactures
  - Hydraulic fluid may leak

A380 Actuation

- Mixed – can fly the plane on either system
  - Electrical (x2) - Red and Orange [backup system]
  - Hydraulic (x2) – Green and Yellow



MOET – More Open Electrical Technologies

- 3-year, EU funded projectwith 63 partners and €67M
- MOET aims to develope the POWER-BY-WIRE concept of which POA has highlighted as having advantages over conventional solutions

TOP-LEVEL OBJECTIVES:

***Objective 1*: Define and validate new electrical networks up to 1MW**

***Objective 2*: Resolve and validate transformation of users into all electrical solutions**

***Objective 3*: Develop and validate power electronics enabler technology**

***Objective 4*: Integration into aircraft**

***Objective 5*: Develop a coherent design environment to support PbW design and validation**

EXPECTED RESULTS

1 - Fuel burn: 2% less,

2 - Maintenance: 15$ cheaper per flight hour,

3 - Unexpected delays for systems: 50% less for power systems

4 - Power electronics weight reduction: 50% less

5 - System improvement: enhanced competitiveness, manufacturing improvement, technology validation & standard proposals

Clean Sky JTI

- Total project budget – €1.6B
  - Duration – 7 years
- Clean Sky JTI work is split into six "ITDs"
- Led by 12 companies [Members]
  - Thales, Liebherr, Airbus, Dassualt, Alenia, SAAB, Rolls Royce, Safran, EADS, ….
- Each ITD then has 5 or 6 other organisations [Associate Members]
- 25% of funding reserved for Calls for Proposals
  - See www.cleansky.eu now for first call and get involved

- The University of Nottingham is an **Associate member**
  - Systems for Green Operations ITD
  - We are the only University which is an Associate Member in our own right
  - Budget of about €10M

Other MAE Sessions

- Industrial Session on the More Electric Aircraft
  - 9.40 Today
- TOES III Forum
  - 9.40 Thursday
- MOET Forum
  - All day Friday
  - Exhibition is running in parallel with EPE Exhibition