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Towards Smart Electric Power Systems in Future Aircrafts

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Presentation Content

- Introduction
- More-Electric Aircraft Concept
- Changes in on-board Electric Power Systems
- Introduction of smart-grid functionalities into aircraft Electric Power Systems
- Key Challenges
- Conclusions

More-Electric Aircraft Concept

Global air traffic market:

- Annual growth: 5-6% per annum until 2025
- Strong competition and new providers
- Environmental impact: 2% of man-made CO_2

Interesting Figures:

- **1kg** saved on each flight would save ~1700 tons of fuel and **~5400** tons of CO_2 per annum for the whole air traffic
- A gain of **1 kg** in onboard systems weight increase the aircraft price by **$1000**

More-Electric Aircraft Concept

Hence, the industry needs technologies which can influence:

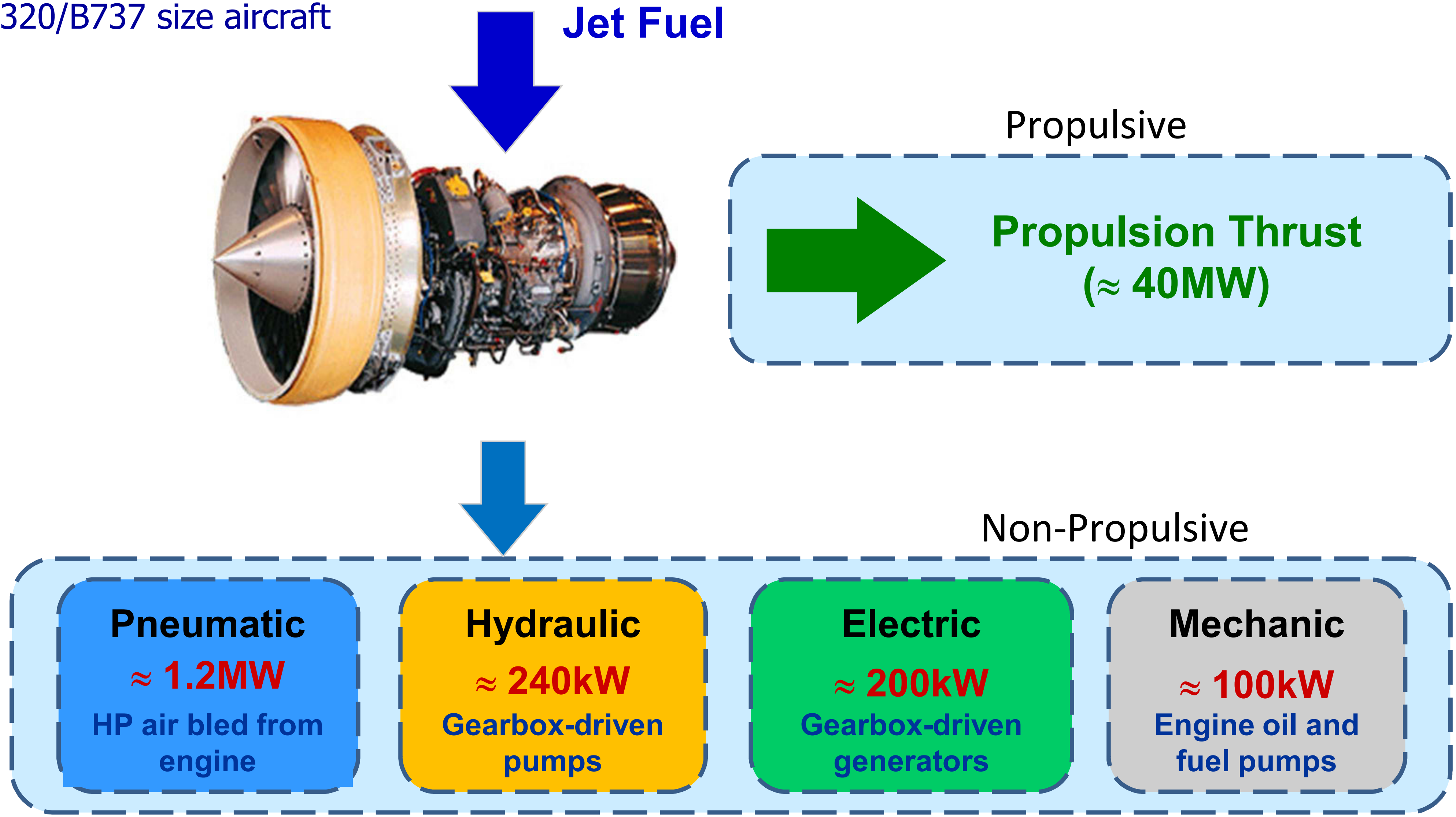
- fuel burn / environmental impact
- overall costs (design, maintenance, operation)

by:

- aerodynamic structure optimization
- engine optimization
- equipment systems design
  - to reduce operation costs
  - with minimum maintenance
  - with maximum availability

Conventional Aircraft: Energy/Power Flows

Figures for a typical
A320/B737 size aircraft



Jet Fuel

Propulsive

Propulsion Thrust (≈ 40MW)

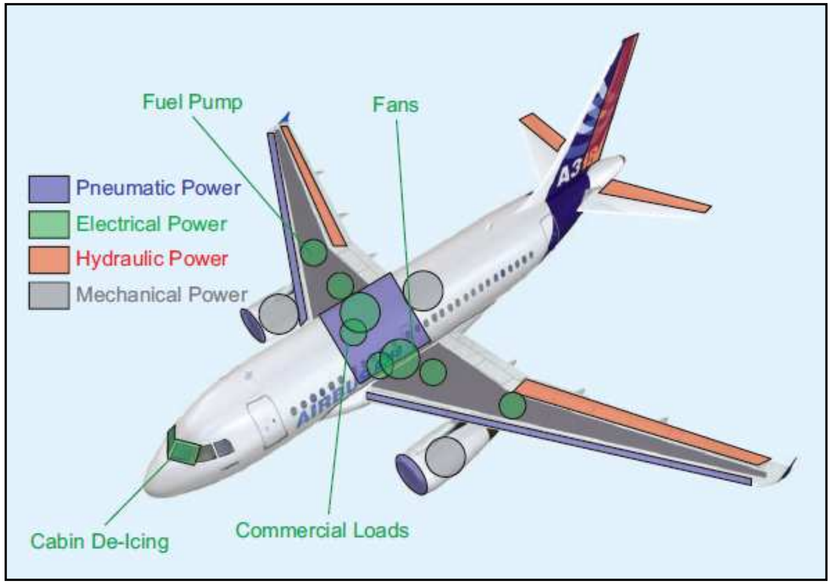
Non-Propulsive

Pneumatic	**Hydraulic**	**Electric**	**Mechanic**
≈ 1.2MW	**≈ 240kW**	**≈ 200kW**	**≈ 100kW**
HP air bled from engine	**Gearbox-driven pumps**	**Gearbox-driven generators**	**Engine oil and fuel pumps**

More-Electric Aircraft Concept

Hence, total non-propulsive budget ≈**1.7MW.** It is huge…

Can we do something to improve usage of it?



The **More-Electric Aircraft**:

- Rationalization of onboard non-propulsive power
- Conventional devices are replaced by electrical systems
  - Ease of electric power generation and transmission
  - Advances in power electronics systems
  - Great level of Availability and Maintainability - low operational costs
  - Controllability – power on demand
  - Green energy

More-Electric Aircraft: Change in non-propulsive power

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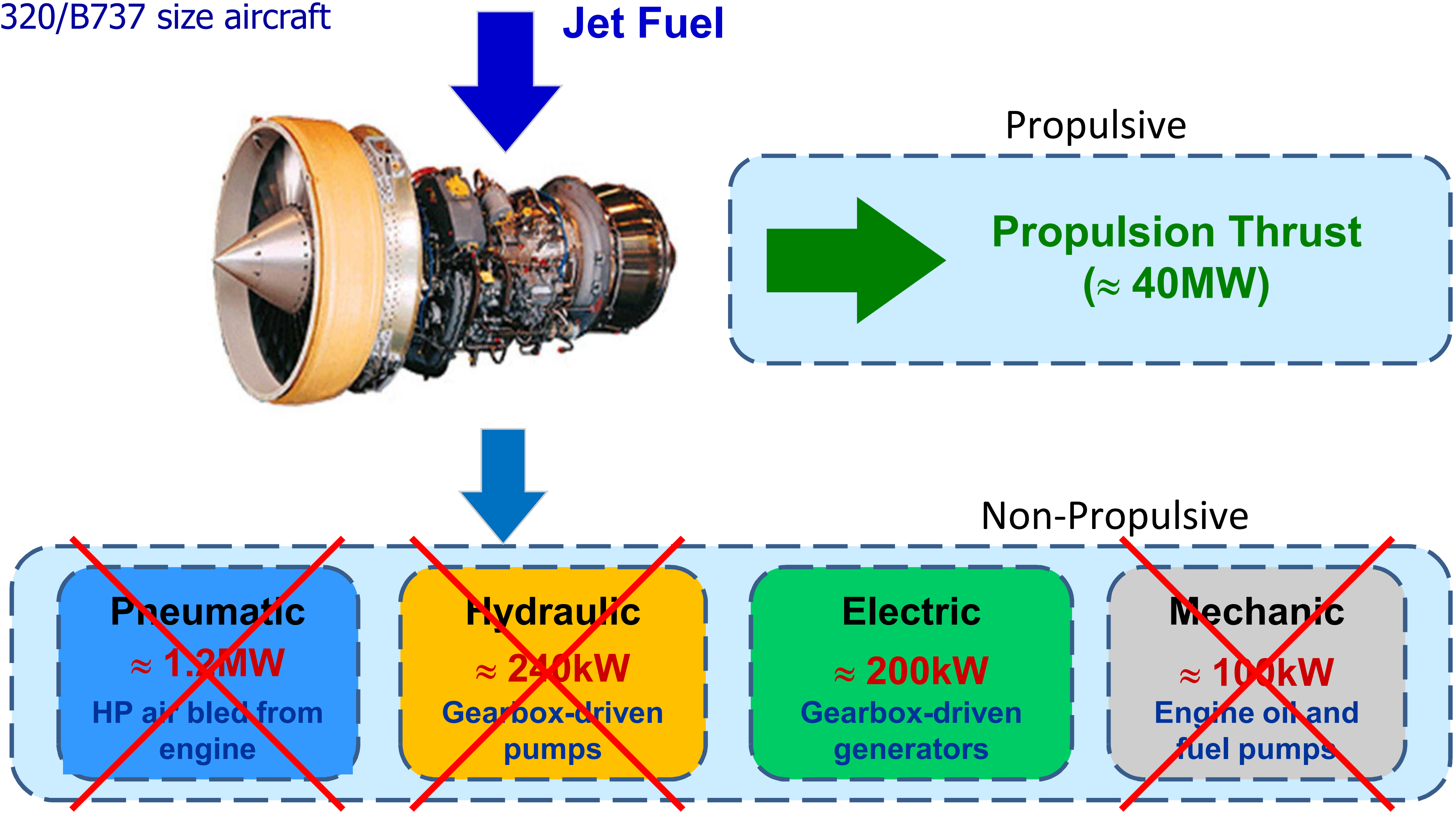

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~~**Pneumatic** **≈ 1.2MW** **HP air bled from engine**~~

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More-Electric Aircraft: Change in non-propulsive power

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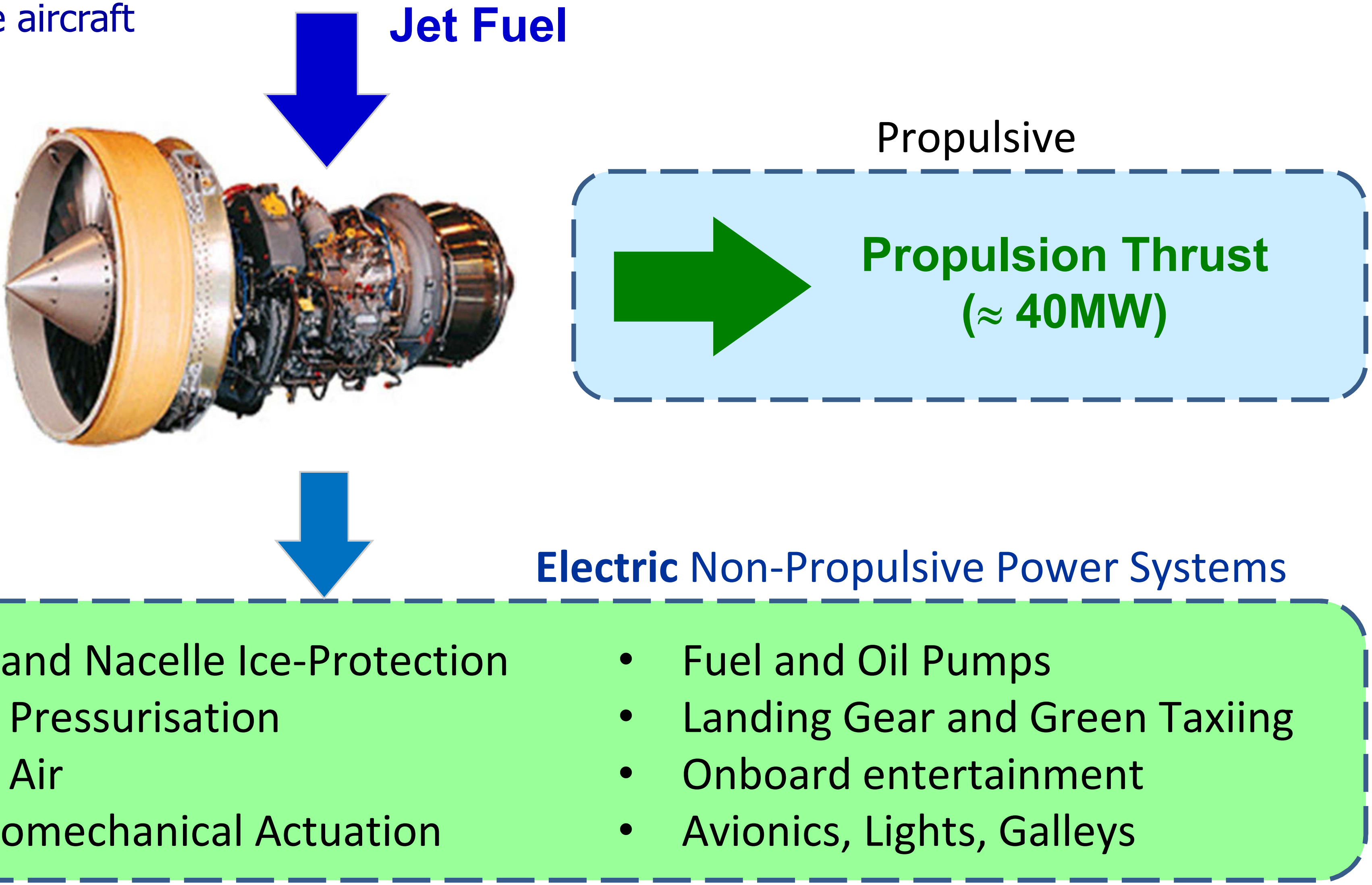


Jet Fuel

Propulsive

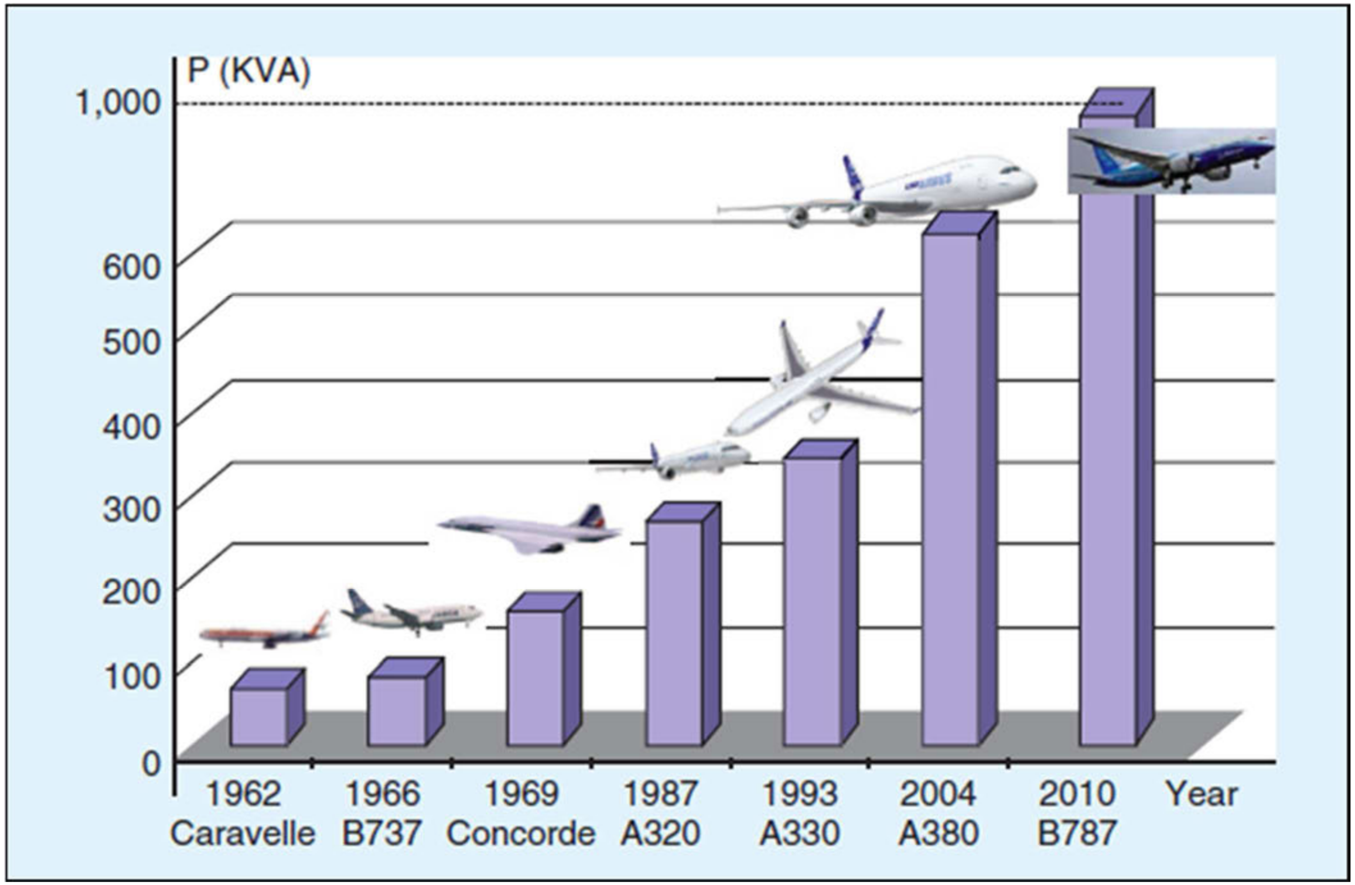
Propulsion Thrust (≈ 40MW)

Electric Non-Propulsive Power Systems

- Wing and Nacelle Ice-Protection
- Cabin Pressurisation
- Cabin Air
- Electromechanical Actuation
- Fuel and Oil Pumps
- Landing Gear and Green Taxiing
- Onboard entertainment
- Avionics, Lights, Galleys

More-Electric Aircraft: Change in non-propulsive power

The **More-Electric Aircraft** concept results in substantial increase in onboard electric power demand:



[X. Roboam, 2013]

More-Electric Aircraft: Change in non-propulsive power

Hence, many on-board EPS technologies are to be re-considered as a result of MEA development:

- Electric energy utilisation (new loads)
- Electric energy generation (new sources)
- Electric energy distribution and management

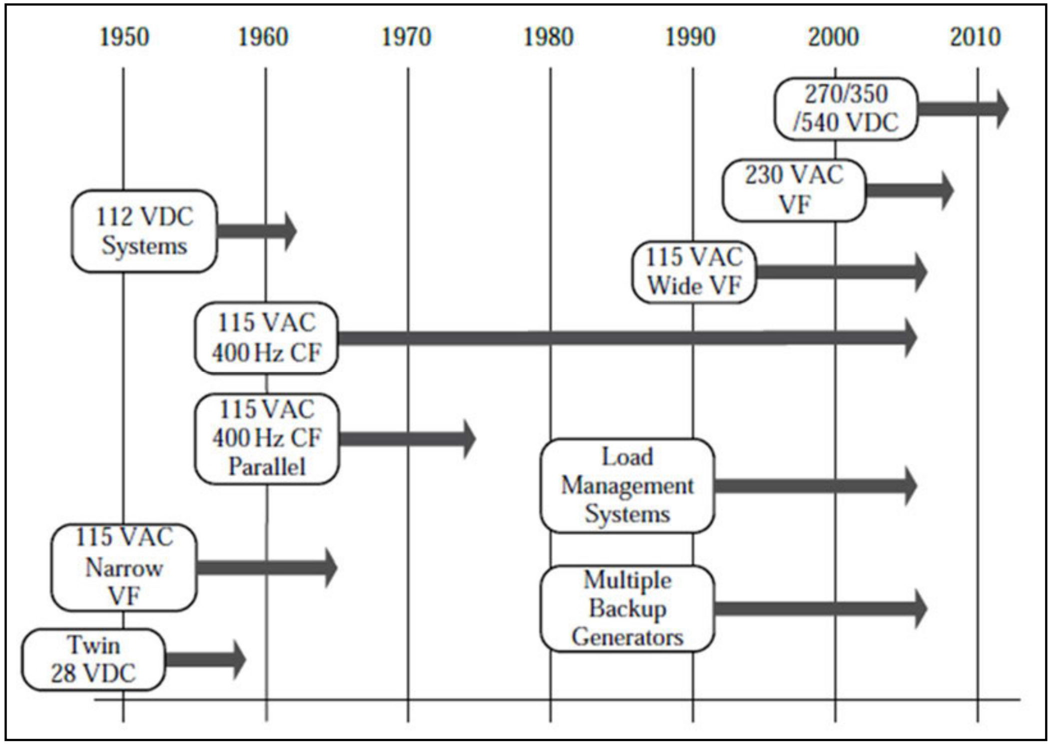
Development of innovative EPS is a trendsetter in state-of-the-art aerospace engineering:

- Architectures/Topologies
- Controls
- Power management

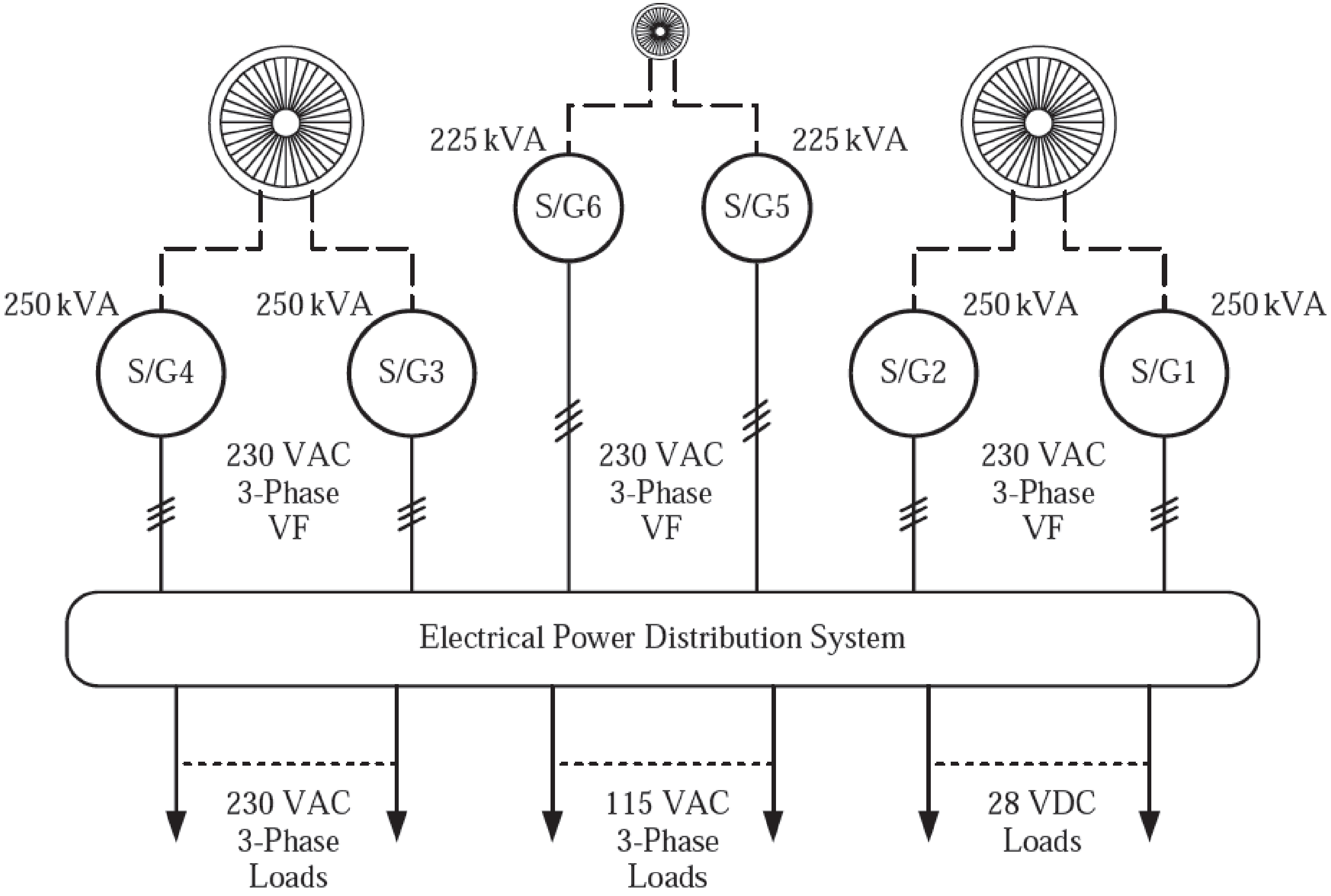
More-Electric Aircraft: Change in non-propulsive power

Aircraft EPS evolution:

- Architectures/Topologies
- Power management
- Controls



B787 Electric Power System:

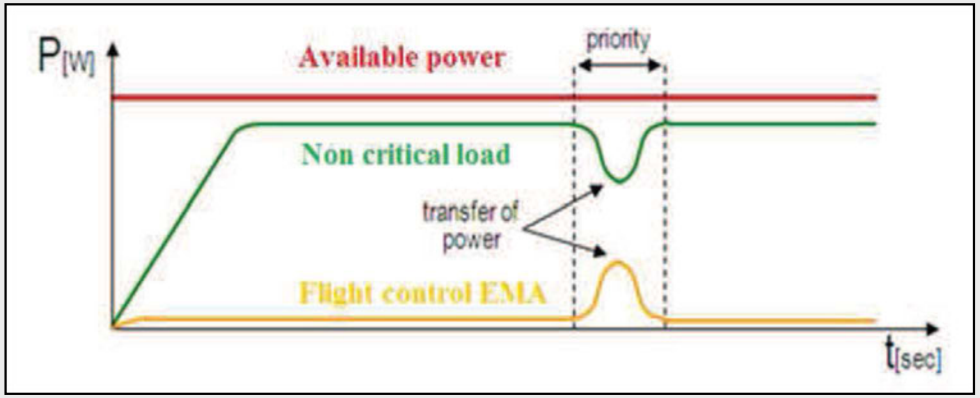


More-Electric Aircraft EPS: Intelligent Load Management

Power Electronic Converters allow for introduction of some innovative functions

- "Intelligent Power Management" – I-LPM, based on high-frequency switching SSPCs
- Modulating "fixed" loads (e.g. ECS) voltage hence their power
- Higher priority loads can use energy saved from lower priority ones

- Significant reduction of generators overload capacity requirements can be achieved – hence overall EPS weight



[B. Guida, 2014]

More-Electric Aircraft EPS: Smart Grid Behaviour

Introduction of smart-grid concept to:

- Achieve further reduction of overall EPS weight
    - By optimisation of energy flows hence reducing sizing requirements for main generators and other equipment
- Maximising robustness and reliability (safety)
    - By exploiting “multicellular” HVDC/LVDC converter
    - Introduction of “grid supervisor”
    - Faults prognostic, diagnostic and management algorithms

Smart Connection and Protection System Design:

Each cell may be used separately to connect HVDC bus “m” to LVDC bus ‘n”. Can be implemented either using:

- 2 individual EPC composed by N switches per cell

Smart Connection and Protection System Design:

Each cell may be used separately to connect HVDC bus “m” to LVDC bus ‘n”. Can be implemented either using:

- 2 common EPCs used to feed cells
  - Better modularity
  - Ease of maintenance

Safety Features:

2 contactors (SSPCs) can be added to protect the EPS in case of the cell fault

C1, C2 will be open if two out of three neighboring cells decide to “kill” a cell, or the manual operator wants to disconnect the cell (hardware-coded logic)

Analytical Design of Supervisor:

- How to manage the cells and decide the connection sequence depending on the state of the generators, loads and the priority table
- Multi-objective “*knapsack-problem*” based design methods to satisfy few constrains:
  - Total absorbed power must be less than the total available power
  - Each load must have a different level of priority
  - Each source must have a different level of priority defined by a dynamically generated table
  - Each cell can only be connected to one bus on each side (i.e. one connection for the HVDC side and one for the LVDC side)

More-Electric Aircraft EPS: Smart Grid Supervisor Design

- Multi-objective “*knapsack-problem*” formulation example:
  - To find matrix X that maximises the priority rules

$$\max\left(Z(X)\right), \text{ where } Z(X) = C \cdot X$$

  - In addition to “priority rules” satisfaction, the matrix *X* should satisfy:

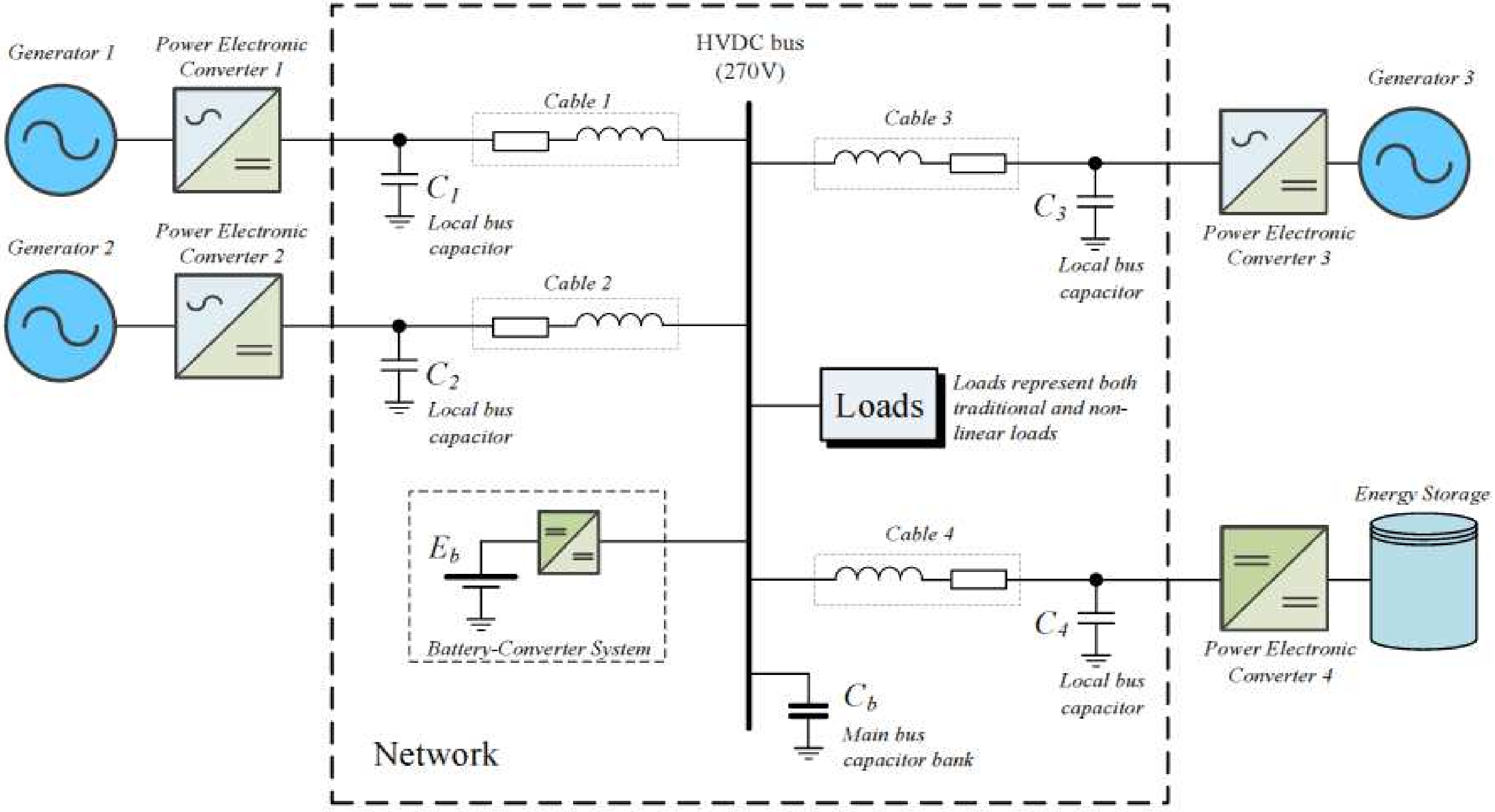
$$\begin{cases} P_S(X) \leq P_{MAX} \\ P_L(X) \leq P_{REQ} \end{cases}$$

  - More constrains can be added to the matrix
  - Power flow direction change (regeneration management?) is also possible

More-Electric Aircraft EPS: Paralleled Source Operation

Paralleled Sources Operation:

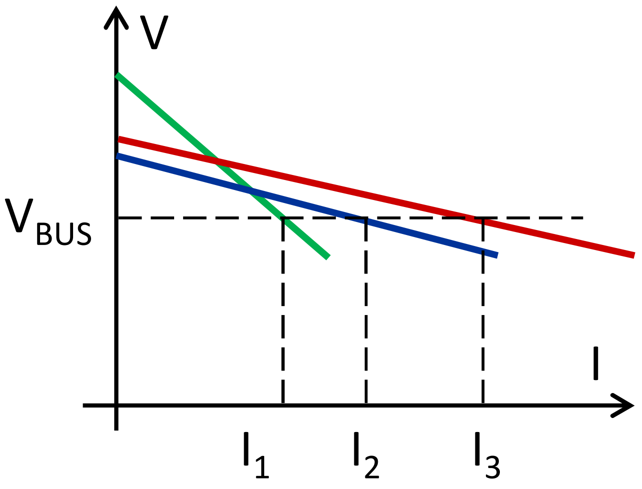
- Generally not allowed by existing design rules
- Further reduction of EPS weight/size?

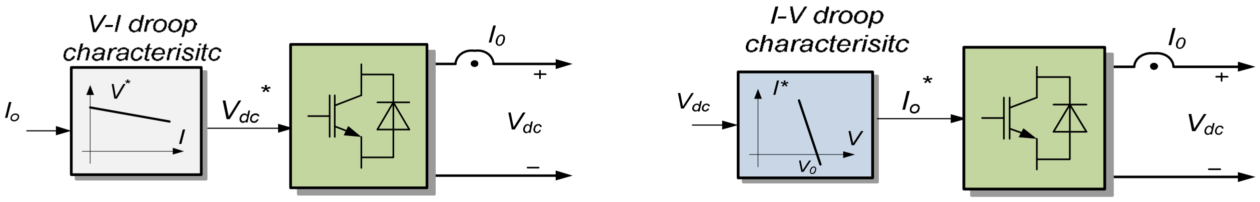


Paralleled Sources Operation:

Load sharing control

- Centralized and decentralized methods
- V-I droop control
- I-V droop control (LVF and GVF)

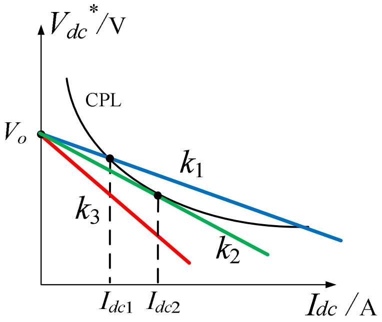


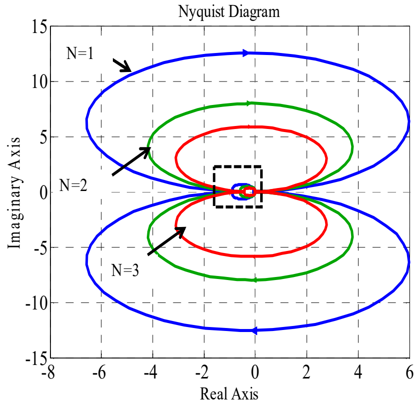


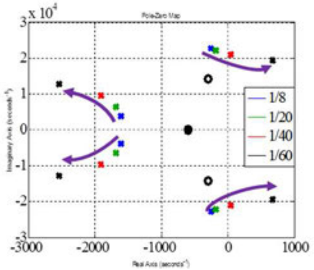
- The task is to define an optimal “share” of power to be delivered by each source at different flight scenarios
- Additional optimisations are possible
- Tough power quality requirements (DO-160, MIL-STD-704F)

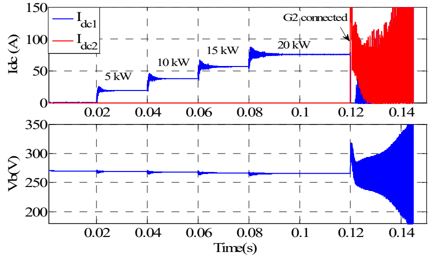
Stability of Multiple-Sources Grid:

- Increased penetration of power-electronic driven loads
- Tightly controlled hence behaving as “constant power loads”
- Resulting in negative small-signal impedances
- Degrading EPS stability margins (system eigenvalues moves towards right semi-plane)
    - Middlebrook criteria
    - Nyquist criteria
    - Eigenvalues movements
    - Robust stability analysis
    - Bifurcations and Chaos Theory









Smart More-Electric Aircraft EPS: Conclusions

Summary:

- Demand of electric power onboard modern More-Electric and future All-Electric aircraft has substantially increased
- Radical changes in all EPS design aspects (innovative architectures/topologies, hardware solutions, control methods
- Smart control concepts offer answers for many challenging issues

Thank you for your attention!

Any questions?