PRESENTATION OVERVIEW

- Presentation overview
- General Aviation
- Commercial aircraft
- Challenges
- Functional safety
- Power converter components
- Simulation tools
- Power demand
- Electric roadmap
- UK Universities
- Warwick University
- Government
- Conclusion
GENERAL AVIATION

Wright Brothers to current state

Use of GA aircraft:
Training, Personal and Business travel

The state of electrification has a wide range
Most advances and adoption in avionics, glass cockpits, handheld devices. Still the average fleet age is 33 years.

General Aviation Statistical Data Book 2014

Wellesbourne Airfield

Little change in the mechanical system since the beginning for the smaller aircraft

However experimental aircraft are adopting more and more electronic system due to less stringent certification rules

E.g. electronic ignition vs. magneto ignition

Business aviation has adopted jets and full cockpit automation

Change is coming
General Aviation
Propulsion applications
Farnborough July 2014
Specification
Battery Lithium Ion 29kWh 167kg
Motors 2 x 30kW
Performance 86kt
Endurance 60min

AERO 2015
Specification
Power battery 17kWh
Motor 85kW / 14kg
Performance N/A

AERO 2106
Specification
Power battery specs N/A
Motor 260kW / 50kg 5min
Performance N/A
Primary flight controls
Ailerons  Bank
Elevator   Pitch
Rudder    Yaw

Secondary flight controls
Slats      High lift
Flaps      High lift

These actuators are driven by high speed motors up to 30000rpm. These motors in the actuation system of the aircraft have power up to 150kW per motor and 40 motors can be in a drive system once full electrification has been reached. Today these are mostly backup systems.

The total system needs a high level availability 10 E-9 per flight hour.

Source: www.NASA.gov
A380 Primary Flight Control Actuation

- Aileron / Elevator / Rudder applications
- Brushless Motor and Motor Drive Electronics integrated onto actuators – motors flooded with hydraulic fluid – tolerant to 5000PSI
- Highest power application: approx. 30kW HVDC

A380 Slat Power Drive System

- 25kW dry motor with power-off brake
CHALLENGES
SOME UNEXPECTED

Ambient conditions
-55°C to +70°C condensing
High random vibration 20g and more

Long aircraft development cycles
Next new designs are expected to start not earlier than 2019

Opportunity
Refine technologies

Weight
B777 10kW / kg GE90-111 Brayton

Reliability
10 E-9 / flight h failure rates

Cost
5x reduction

Many boxes today still would fit well into the golden age of aviation

Picture: www.airpowerworld.info

UTC Aerospace Systems
Controlled under UK Dual Use Goods: PL9009.c
FUNCTIONAL SAFETY
IMPLEMENTATION

Safety is driven by requirements as performance is e.g.: Failure rates, Failure Modes, Failure states

Government agencies FAA and JAA give direction through FAR, JAR and advisory materials

Reliability and safety are related but independent areas of concern

Safety requirements exist on aircraft systems, equipment, down to component level

The equipment in itself might be considered a hazard depending on its implementation and will be reviewed

Functional requirements can be negotiated
Safety can’t
Functional Safety requirements are entered as part of the requirements gathering process.
Development Assurance Level according to DO254A

- Five Development assurance levels exist DAL-A to DAL-E
- The Level determines the likely impact on the outcome of a flight
  - A: Catastrophic
  - B: Hazardous / Severe
  - C: Major
  - D: Minor
  - E: No effect
- The assigned Level for a component determines the allowable failure rate
- Special analysis considerations are applied in particular DAL-A and B systems
  - Safety Specific Analysis
  - Functional Failure Path Analysis FFP
  - Mathematical formal Methods
- Mitigation Strategy
  - E.g. Flight control system DAL-A 1.0 E-9 /hour,
  - Entertainment system DAL-E n/a, still the hazard of that system is evaluated like cell phone issues
Key Power Components through UK supply chain
- Power switching devices up to 1200V, 800A
  - IGBT devices
  - Compound Semi Conductor devices
  - Liquid cooling strategies – direct/indirect
    Transition from Custom made to limited Customization

Power capacitors
- Thin films and new winding techniques

Power Inductors
- Silicon Iron and Cobalt Iron
- Current sensing – up to 1000 A AC/DC
- Robustness testing undertaken e.g. 1500 thermal cycles

Key Control components
- FPGA
- Memory chips
- Microcontrollers
Many companies and Universities have power system simulation tools to test functionality of components and determine the stability of aircraft power grids. Many are Matlab or Modelica based. However because they are so versatile they don’t facilitate the convergence to a certain type or voltage of power grid.

**Companies and UK Universities using / developing simulation tools**
- DLR offers libraries
- Safran uses system simulation
- UTAS deep component simulation
- Airbus simulation of power system
- Stratchlyde University
- Nottingham University

**Government funded activities**
- EU: Clean Sky 2 CS2, Actuation 2015
- UK: Integrated complex systems
Comparison of installed electrical power in commercial aviation

**B 747:**
Electrical power generation 4 x 90kVA
3ph 115Vac 400Hz
Constant frequency constant voltage
Avionics
Customer comfort
Galley supply

**B 787:**
Electrical power generation 4 x 250kVA
3ph 235Vac 360Hz – 800Hz
and +/-270Vdc
Primary Flight control
Avionics
Pressurization and air-conditioning
Customer comfort
De-Icing Wing & Nacelle approx. 90kW
Galley supply
Existing Systems with PE enabling new More Electric Aircraft (MEA) topologies with less Power Take Off points (PTOs) per engine

- Fuel pumping
- Oil pumping
- Pressurization
- Hydraulic power
- De-icing

<table>
<thead>
<tr>
<th>System</th>
<th>Power Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gear box PTO</td>
<td>30kW</td>
</tr>
<tr>
<td>Shaft PTO</td>
<td>9kW</td>
</tr>
<tr>
<td>Pneumatic PTO</td>
<td>1MW</td>
</tr>
<tr>
<td>Pump PTO</td>
<td>200kW</td>
</tr>
<tr>
<td>Pneumatic</td>
<td>90kW</td>
</tr>
</tbody>
</table>

Note: * early stage of development

Electrifying these and more systems allows for the Bleed less engine and better control and more efficient installation, not necessarily less weight. While engines get more efficient the cores get smaller and smaller making it harder to fit all PTOs.

Picture: Boeing.com
Electric Roadmap

Airbus

Boeing

Superconducting Turbo-Electric Propulsion (STEP) system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range, km</td>
<td>5 500</td>
<td>7 500 (+33%)</td>
</tr>
<tr>
<td>Payload, kg</td>
<td>10 000</td>
<td>15 000 (+50%)</td>
</tr>
<tr>
<td>Fuel weight, kg</td>
<td>17 100</td>
<td>10 000</td>
</tr>
</tbody>
</table>

Remaining the same power plant weight!

29 MW propulsion system

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine, kg</td>
<td>1 x 3600</td>
</tr>
<tr>
<td>Generator, kg</td>
<td>1 x 960</td>
</tr>
<tr>
<td>Cables, kg</td>
<td>50 m x 25</td>
</tr>
<tr>
<td>Motors, kg</td>
<td>6 x 160</td>
</tr>
<tr>
<td>Cooling for 3h, kg</td>
<td>2740</td>
</tr>
<tr>
<td>Total STEP pwr plant, kg</td>
<td>9 540</td>
</tr>
<tr>
<td>A318 pwr plant, kg</td>
<td>7 600</td>
</tr>
</tbody>
</table>

Starting points:

- Hybrid turbo-electric propulsion is an enabler of advanced more fuel efficient aircraft concepts
- Superconductivity is the only possible way to achieve the electric part requirements of such hybrid powertrain
- Actual superconductors are cryogenically cooled materials

© 2007 The Boeing Company

How to analyze and evaluate the power system?
This list is not exhaustive in what UK Universities are involved with aerospace and power electronics, but it shows the strong interest in the field. UTAS has some connections to all these institutions, but no projects as we speak.

**UK Universities**

- **Sheffield**
  Electric Machines and Drives (EMD) group at Sheffield

- **Stratclyde University**
  Aero-electrical research team located within the Institute for Energy and Environment

- **Nottingham University**
  Power Electronics, Machines & Control Group / Virginia tech collaboration

- **Newcastle University**
  Electrical power research group
Philip Mawby
PEATR (Power Electronics Applications and Technology in Energy Research)
In the School of Engineering

Mike Jennings
- Silicon Carbide (4H- and 3C-SiC) Power Semiconductor Device Fabrication and Characterisation
- Reliability of Silicon Carbide Metal Oxide Semiconductor Field Effect Transistors (MOSFETs)
- Silicon Carbide (4H- and 3C-SiC) to Silicon Direct Wafer Bonding
- Silicon Carbide Epitaxial Growth

Mike’s and his team’s outstanding capabilities are of particular interest to UTAS since he is involved in the field of compound semiconductors that promise to allow for the next jump in efficiency and power density. This can not only be achieved through the components alone but through a combination of packaging and Compound semiconductors and passive components.
GOVERNMENT
PE Technology involvement

- Actuation 2015
  - Modular standardized actuators for the aviation industry
  - Development tools in modelica

- Mission program Clean Sky 2
  - Research and innovation project aiming to create TRL6 level novel aerospace technologies
  - Modelling platform based on modelica

- Technical Strategy Board UK
  - Low cost inverter LAMPS
  - Integrated Complex Systems ICS simulation tool
# Conclusions – Fuel Burn

<table>
<thead>
<tr>
<th>BCA – Advanced Concepts</th>
<th>BR&amp;T – Platform Performance Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ The NASA fuel burn goal of a 70% reduction is very aggressive</td>
<td></td>
</tr>
<tr>
<td>▪ A combination of air traffic management, airframe, and propulsion improvements were shown to achieve a 44-58% reduction in fuel burn for conventional propulsion</td>
<td></td>
</tr>
<tr>
<td>▪ The addition of hybrid electric propulsion to the technology suite has the potential for fuel burn reductions of 70-90%</td>
<td></td>
</tr>
<tr>
<td>- If electric energy is considered in a modified goal of “energy usage”, then a 56% or greater reduction in energy use is possible</td>
<td></td>
</tr>
</tbody>
</table>

**POWER ELECTRONICS and UK UNIVERSITIES ENABLE A WHOLE INDUSTRY**
Questions?