Innovation in Aircraft complex systems integration

Presented by:
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August 31st, 2015
Aviation has improved a lot over the past 50 years…

- Over 20 dB aircraft noise reduction

- 75% Fuel Burn
- 75% CO₂ Emissions
State of the Art Airliners feature excellent systems integration, resulting from multiple requirements
Our industry will face higher expectations and more competition

- **Safe**
- **Fuel price**
- **Simple**
- **Eco-efficient**
- **Growth**
- **Competition**
- **Affordable**

ICAS, Krakow, August 31st, 2015
... so we have to do more

The Passenger of 2050 (2012 Survey)

96% of respondents believe that aircraft in the future will need to be more environmentally sustainable

Ambitions:
-75% CO₂
-90% NOx
-65% Noise
vs 2000
Traditional optimization has limits…

… and NOx increases with BPR (due to OPR and T3)
… new options can be considered

**Full Electric Propulsion:**
- No CO2
- No NOx / Emissions
- Significantly reduced Noise

**Hybrid Electric Propulsion:**
- Reduced CO2
- Reduced NOx / Emissions
- Reduced Noise
What others say…

Electric Propulsion is a Bigger Change than Going from Piston to Turbine Engines

**Electric Propulsion Penalties**
- Energy Storage Weight (60x worse than aviation fuel)
- Energy Storage Cost (Tesla 65 kWhr battery is ~$25,000)
- Certification?

**Electric Propulsion Benefits**
- ~2x efficiency of turbine engines, 3-4x efficiency of piston engines
- High efficiency across 50% rpm range
- 6x the motor power to weight of piston engines
- None air breathing - No power lapse with altitude or on hot days
- Extremely Quiet
- Zero vehicle emissions
- 10x lower energy costs

**Electric Propulsion Integration Benefits**
- Scale independent
- Power to weight and efficiency don’t degrade at smaller sizes
- Extremely compact
- High Reliability – Few moving parts

Abstract from:
“Misconceptions of Electric Aircraft and their Emergent Aviation Markets”

Hydrocarbon fuel cost has tripled in constant year dollars since 1999 with constant energy density, while batteries have tripled in energy density.
Innovation in Aircraft Complex Systems integration

A R&T Roadmap Approach

- E-Fan: Fully Electrical Training Aircraft
- Helicopter Hybrid-Propulsion
- E-Star2: Fully Electrical Experimental Aircraft
- E-Thrust Hybrid-Propulsion

MW class

0.1 1 10 100
What others do...

Porsche Panamera Hybrid
0.07 MW / 5500 rpm
1 to 2 kW/kg

Liebherr Mining Truck
3 MW
0.25 kW/kg

Queen Mary 2
20 MW / 180 rpm
0.2 to 0.4 kW/kg
New challenges & requirements

- **Energy storage distribution & Power generation**
  - Energy density >350Wh/Kg, batteries life & security
  - Electrical motors/generators, power electronics (> 15 kW/Kg incl. cooling)
  - High voltage electrical network & associated ancillaries

<table>
<thead>
<tr>
<th>Batteries</th>
<th>Key performance indicators:</th>
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<tr>
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<td>Energy/Mass ratio</td>
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<tr>
<td>Short term (5-10 years)</td>
<td>150 - 350 Wh/kg</td>
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<td>Mid Term (10 to 15 years)</td>
<td>350 - 600 Wh/kg</td>
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<tr>
<td>Long Term (&gt;&gt;15 years)</td>
<td>500 - &gt;&gt;1000 Wh/kg</td>
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- **Propulsion system integration**
  - Control system, Thermal management, ECM compatibility

<table>
<thead>
<tr>
<th>Superconducting machines</th>
<th>Electric machines</th>
<th>Power / mass ratio</th>
<th>Efficiency</th>
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New challenges & requirements

• **Novel configurations**
  • Explore potential benefits of hybrid / electric propulsion (e.g. distributed propulsion, aircraft sizing…)

• **Scalability & Modeling**
  • Systems level performance & economics, Transients, Failure cases

• **Certification & Operations**
Innovation based on in-flight experience…
... starting by in-flight demonstration, with DGAC support

**E-FAN 1.0**

**TECHNICAL DATA**

- **Wing span:** 9.50 m (31 ft)
- **Length:** 6.67 m (21.88 ft)
- **Height:** 2 m (6.56 ft)
- **Empty weight:** 500 kg (1102 lb)
- **Lift/drag ratio:** 16
- **Total engine power:** 60 kiloWatt
- **Battery system:** 120 cells (Lithium Polymer)
- **Energy density per battery cell:** 207 Wh/kg
- **Endurance:** 45 min – 1 hour
- **Maximum speed:** 220 km/h (119 kt)
- **Thrust:** Over-wing mounted twin ducted fans producing 1.5kN of thrust
- **Structure:** Full carbon composite with integrated aileron, elevator, and rudder control

100th Flight performed on June 19th, 2015
E-Fan Channel Crossing  (July 10th, 2015)
« It always seems impossible until it’s done »

Nelson Mandela