Systems Aspects of Electric Commercial Aircraft (SAECA)

Hybrid-electric and Electric Aircraft – Researching the Challenges to Introduction

Woburn House, London, 30 May 2017

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In collaboration with:
Electric Aircraft Ecosystem

- Emissions (lifecycle perspective)
- Aircraft noise
- Fleet adoption
- Flight network
- Business models
- Airline competition
- Industrial competitiveness
Focus on Narrowbody Aircraft

UK Departures in 2015

Narrow Bodies (SA Classes 3-5)

1,667 km (900 nm)

SA: Sustainable Aviation
Electric Aircraft Characteristics (MIT)

• **Transport Aircraft System OPTimization – electric (TASOPTe)**
  • Simultaneous optimization of airframe, propulsor, operations for given mission
  • Uses first-principles methods

• **Design Constraints**
  • Takeoff length limited to 2.4 km (8,000 ft)
  • 4.5° climb angle; top-of-climb gradient \( \geq 1.5\% \)
  • Battery specific energy: 1,500 Wh/kg, 20% reserve
  • A320 geometry; 2-6 propulsors
  • Design range: 900 nm (1,667 km)

• **Additional Inputs**
  • Cruise Mach number/altitude
  • Allowable material stresses
  • Non-structural weight fractions
  • Basic aircraft dimensions
Electric Aircraft Characteristics (MIT)

- Outputs
  - Optimized aircraft design
  - Component weights
  - Propulsor dimensions
  - Mission energy use
  - Complete flight profile & performance

Avg. power requirement: 20 MW
Avg. energy intensity: 177 Wh/RPK (0.64 MJ_{el}/RPK)
Noise Study (Southampton)

- Determine community noise contours of A320el vs. A320neo
- Parametric study to evaluate noise vs.
  - Number of propulsors
  - Battery energy density
  - Battery charging strategies
  - Mission length
- Conclusions
  - Noise benefits could be substantial on short missions
  - Noise highly dependent on all operational constraints and procedures, i.e., flight profiles and recharging strategies
  - Approach noise can be higher than conventional A/C and is subject to less variation with other parameters
  - Directivity effects may be significant

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Noise Contour Area (84dB(A)-SEL)*</th>
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<tbody>
<tr>
<td>A320-232</td>
<td>7.4 km² (+102%)</td>
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<tr>
<td>A320neo</td>
<td>3.7 km²</td>
</tr>
<tr>
<td>e-A320</td>
<td>2.8 km² (-23%)</td>
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* Relative to A320neo
Operations Study (UCL)

• UK electric grid implications
  • Electrifying 80% of SA Classes 3-5 (440,000 electric aircraft departures) requires an additional 12 TWh (~ 4% of UK total): equivalent to 1,000 – 1,500 wind turbines (@ 3 MW each)
  • Daily departure profile and electricity load similar: opportunities for load levelling through night charging

• 2015 CO₂ emissions intensity based on UK grid: stage length = 830 km
  • \(332 \text{ gCO}_2/\text{kWh}_{\text{el}} \times 0.18 \text{ kWh}_{\text{el}}/\text{RPK} \approx 73.3 \text{ gCO}_2/\text{MJ} \times 0.9 \text{ MJ/RPK}

\[
\begin{align*}
60 \text{ gCO}_2/\text{RPK} \; \text{(BEA)} & \quad & 66 \text{ gCO}_2/\text{RPK} \; \text{(A320NEO)}
\end{align*}
\]
  • However, gCO₂/kWh_{el} projected to decline strongly in future

• Turnaround strategies
Turnaround / Battery Management Strategies

830 km Trip Length (22 MWh)

- 46 MWh
- 32% charge
- 40 min
- 80% charge
- 51% charge
- 25 min
- 32% charge
- Etc.

1,260 km Trip Length (30 MWh)

- 46 MWh
- 24% charge
- 40 min
- 35% charge
- 90% charge
- 25 min
- 35% charge
- or:

- 60 min
- < 40 min

20% reserve battery charge required
Direct Operating Cost Study (UCL)

• Estimate DOC of battery electric aircraft
• Electrification affects 75% of DOC (capital costs, maintenance, energy, en-route / airport charges)
• Cost-effectiveness depends mainly on battery performance and costs, jet fuel and electricity price → feasible economic window seems to exist
Fleet Impacts of Battery Electric Aircraft

Open Source Aviation Integrated Model

Aircraft Technology & Cost

Aircraft Movement

Aircraft Movement

Global Climate

Global Environment Impacts

Local Environment Impacts

Local/National Economic Impacts

Air Transport Demand

Airline & Airport Activity

Air Quality & Noise

Regional Economics

Air Transport Demand

Aircraft Technology & Cost

Open Source Aviation Integrated Model

www.ATSlab.org
• Sample model inputs, starting from IPCC AR5 scenarios
• These runs assume:
  - Mid-range values (SSP1-3)
  - No carbon price
  - 3%/year decrease in future carbon intensity of electricity generation
  - Electricity price tends to $0.05/kWh by 2100, all countries

[Data: IEA, 2017; IPCC, 2015; DECC, 2015]
Projected Electric Aircraft Network (2050)
Electric Aircraft “Grand Challenge”

• Key “Systems” Questions
  • Fundamental technology requirements for different markets
  • Optimum deployment under airline competition → network impacts
  • Early markets for BEA / HEA adoption → new business models?
  • Impact on airport operations (incl. capacity), electric grid, and transportation system
  • Impact on airline and airport economics
  • Lifecycle emissions and noise

• Key Enabling Studies
  • Key performance parameters of optimized BEA / HEA
  • Optimized BEA / HEA noise assessment
  • Optimized BEA direct operating costs
  • Optimized battery management & airport / grid infrastructure

• Systems model required to account for interdependencies
Example: Noise Research in Detail

• Baseline Aircraft Noise Sources: Investigate and model any novel sources: e.g. BL ingestion, novel airframe and DP installation effects

• Baseline Aircraft NPD Curves
  • Determine baseline NPD curves – likely to involve understanding how to deal with fully 3-d noise emissions as current lateral directivity procedures will be inadequate
  • Determine scaling laws for aircraft noise source levels with both technology and operation changes (e.g., mass changes due to energy density, discharge levels => noise changes)
  • Extend tool for determining variation in NPDs due to aircraft and operational changes to allow for parametric studies

• Extension of Airport Noise Tool: Extend current contour noise tool to allow for novel directivity and lateral attenuation characteristics

• Public Acceptability
  • Operational characteristics and noise signatures will differ markedly from conventional aircraft
  • Better understand human response to EA noise and develop metrics for assessing noise impact
Nota bene: Transitions can materialize very quickly

US Steam to Diesel-electric Locomotive Transition

Winners

Losers

Source: Schäfer and Sweeney (2016)