Electric and Hybrid-Electric Aircraft: A pragmatic view
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A glimpse into the future of transportation
An Episode of Mythbusters
Focus Topic: Electric Aviation
Agenda

I. (Hybrid-)electric flight (in a nutshell)

II. Mythbusters: Particular Topics

III. Should we invest into (hybrid-)electric?
Siemens eAircraft flight test history

2011
Maiden flights of the DA36 e-Star, world’s first hybrid-electric aircraft, and improved eStar 2, with Airbus and Diamond Aircraft

2013

2016
¼ Megawatt
Maiden flight of the record propulsion system SP260D in the Extra 330LE

2018
Maiden flight of the world’s first two engined serial-hybrid propulsion system
Why do we want to fly electrically?

ACARE 2050 goals can only be achieved with disruptive concepts

- Potential by further development of current technologies
- Potential with disruptive technologies (e.g. eAircraft)

→ “Flight-path 2050” of EU requires 90% reduction of NOx/CO2 emissions and 75% noise emissions

Total cost of ownership (Bsp.: Boeing 737-800)

- 51% Fuel
- 20% Purchase
- 15% Crew
- 14% Maintance, Insurance, etc.

→ Fuel is a main cost driver

* IATA technology roadmap, June 2013
** eAir: Market studies
Challenge One – Battery

Energy Density of Various Energy Sources in kWh/kg

- Kerosine
- Li-Ion
- Li-Air
- Al-Air ST
- Al-Air LT
- LH2

5 years outlook on battery cell level development

Data source: Sion Power
Hybrid Electric Propulsion System

1) E-machines are capable to fulfill “power generation” and/or “propulsion” depending on e.g. mission profile, requirements and/or mode of operation, 2) Battery Management System (BMS), 3) Internal Combustion Engine (ICE)
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Myth 1: “A hybrid-electric A320 is a good airplane”

Keep A320 Design + “Replace turbine with hybrid-electric drive train” = “Not a good concept”


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Hybrid Electric Propulsion System vs. Conventional

**Hybrid Electric Propulsion System (HEPS)**

- **Turbine / ICE**
- **Generator\(^1\)**
- **Power Distribution**
- **Motor\(^1\)**
- **Energy Storage**
  - Battery Packs
  - Converter
  - BMS\(^2\)

**Conventional**

- **Turbine / ICE**

\[ \eta \approx 40\% \]
\[ \eta \approx 99\% \]
\[ \eta \approx 98\% \]
\[ \eta \approx 99\% \]

**Efficiency Calculations**

HEPS:

\[ \eta_T \cdot \eta_G \cdot \eta_P \cdot \prod_{\text{e}} \eta_e < \eta_T \cdot \eta_G \cdot \eta_P \]

Conventional:

\[ m_T + m_G + m_P + \sum e m_e > m_T + m_G + m_P \]

\[ \eta \approx 99\% \]
Myth 2:
“We can have on optimized turbine operation point”

ICE for cars

Gas turbine for aircraft

*Images taken from M. Ekwonu et al.: „Modelling and Simulation of Gas Engines Using Aspen HYSYS“ and x-engineer.com

Turbine Design Point:
- “One Engine Off”
- “Cruise”
- “Take-Off”
Myth 3: “Efficiency of gas turbines cannot be substantially improved”

"We took something so old and simple as a one-stage gear box and that resulted in a fuel burn reduction of 16 %.”

*Images taken from J. Sieber: „Aero Engine Roadmap 2050”*
Myth 3: “Efficiency of gas turbines cannot be substantially improved”


**Images taken from S. Kaiser et al.: “A Composite Cycle Engine Concept for Year 2050”

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Optimized GTF</th>
<th>CCE</th>
<th>CCE large</th>
<th>CCE IC</th>
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<tbody>
<tr>
<td>TSFC_{T0C} [g/kN/s]</td>
<td>13.73</td>
<td>12.38</td>
<td>12.09</td>
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<td>11.23</td>
<td>11.45</td>
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<td>TSFC_{TO} [g/kN/s]</td>
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<tr>
<td>$d_{Fan}$ [m]</td>
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<td>$m_{Fan}$ [kg]</td>
<td>5161.3</td>
<td>7283.2</td>
<td>7665.5</td>
<td>6009.5</td>
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<tr>
<td>$\Delta FB$ vs Y2050 GTF [%]</td>
<td>-1.5</td>
<td>-9.6</td>
<td>-11.9</td>
<td>-12.5</td>
</tr>
<tr>
<td>$\Delta FB$ vs Y2000 [%]</td>
<td>-45.8</td>
<td>-50.3</td>
<td>-51.5</td>
<td>-51.9</td>
</tr>
</tbody>
</table>

Improvements of 8 % to 10 % in fuel burn

However:
CO2 and NOx emissions increase significantly
Myth 3: “Efficiency of gas turbines cannot be substantially improved”

60% NOx reduction

*Images taken from H. Kayadelen: "Thermoenvironmonic evaluation of simple, intercooled, STIG, and ISTIG cycles"
Distributed electric propulsion:
Increasing $\frac{C_L}{C_D}$ by utilizing the scale behavior of electric motors

*Images taken from M. Hepperle (2016)
** Data source: G. Atanasov (2018)
A consequence of VTOLs: New operation concepts

*Images taken Uber Elevate*
Myth 4: “Urban air mobility will solve urban congestion problems”

Example: Munich Metropolitan Area
4.5 million inhabitants → 8.7 million trips/d

1% of trips with UAM: 87,000 trips/d
10% of trips with UAM: 870,000 trips/d

Comparison:
MUC: 1,000 aircraft moves/d

*Following the Keynote of P. Plötner: „Future Perspectives of Aviation for Urban and Regional Mobility” (2019)
Myth 4: “Urban air mobility will solve urban congestion problems”

Capacity:
- > 1000 landings/h (12 pads, 23 s/landing)
- > 150 landings/h (4 pads, 96 s/landing)
- > 24 landings/h per pad (60 s/landing)

Example: Munich
Operating hours (06:00 – 23:00)
1 % of trips with UAM:
- > 61 large vertiports
- > 126 medium vertiports
- > 213 small vertiports

10 % of trips with UAM:
- > 614 large vertiports
- > 1365 medium vertiports
- > 2132 small vertiports

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Public transport in Munich:
> 100 underground stations
> 150 suburban stations
> 173 tram stations
> 1006 bus stops

Share:
> 24 % in Munich City
> 11 % in Munich Suburbs

*Following the Keynote of P. Plötner: „Future Perspectives of Aviation for Urban and Regional Mobility“ (2019)
Myth 5: “Electric aircraft is silent”

*Following the Keynote of J. Delfs: “E2Flight = silent ?” (2019)*

- FFT analysis of EXTRA330 overflight reveals that the electric version has significantly lower noise emissions.
- Probably due to less torque ripple than ICE.
Myth 5: “Electric aircraft is silent”

*Following the Keynote of J. Delfs: „E2Flight = silent ?“ (2019)

- **Take-off:**
  - engine noise
    - jet
    - fan tonal (+ broadband)
    - (compressor)

- **Approach:**
  - engine noise
    - jet
    - fan broadband (+ tonal)
    - (combustion + turbine)
  - airframe noise
    - high lift devices
    - landing gears
    - parasitic sources
Myth 5: “Electric aircraft is silent”

*Following the Keynote of J. Delfs: „E2Flight = silent ?“ (2019)

- Many additional noise sources beyond the propulsion unit
- Solely replacing the gas-turbine of a turbo-fan with an electric motor will not have a hearable effect since other noise sources prevail

*Following the Keynote of J. Delfs: „E2Flight = silent ?“ (2019)
Myth 5: “Electric aircraft is silent”

The aircraft design space that is available due to hybrid-electric propulsion could be used to build low noise emission aircraft

*Following the Keynote of J. Delfs: „E2Flight = silent ?“ (2019)
*Image courtesy of NASA and Airbus Group
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A comparison of designs based on electric propulsion

Mission distance: ~ 800 nm

*Taken from M. Strack: „Conceptual Design Assessment of Advanced Hybrid Electric Turboprop Aircraft Configurations“ (2018)
Advantages of (hybrid) electric propulsion:

Mission Profile

Design Range of PHA2

Typical mission profile

Distribution of Commercial Flight Distances

Number of Flights

Distance (miles)

A320/B737 Design Range

A320/B737 Flight Usage

Plot taken from hastydata.wordpress.com

Battery Powered

ηₖ ~ 95 %

Turbine Powered

η₆ ~ 40 %

Data from: https://openflights.org/data.html
Do we need superconductivity for that?

Breguet-Formula (Turbo-Electric):

\[ R = \frac{v}{g \cdot SFC} \left( \frac{m_{\text{fuel}} + m_{\text{empt}}}{m_{\text{empt}}} \right) \ln C_L \]

Educated guess on power density (incl. heat exchangers):

<table>
<thead>
<tr>
<th>Component</th>
<th>Warm</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Machines</td>
<td>10 kW/kg</td>
<td>25 kW/kg</td>
</tr>
<tr>
<td>Power Electronics</td>
<td>30 kW/kg</td>
<td>60 kW/kg</td>
</tr>
<tr>
<td>Cables</td>
<td>40 kW/kg</td>
<td>100 kW/kg</td>
</tr>
</tbody>
</table>

~ 3 kW/kg warm: ~7 kW/kg cold:

~ 10% Extra Range

~ 10% less SFC
Myth 6: Superconductivity is an extraordinary complex technology

Siemens eAir
10 MW HTS Design

Brushless-DC Motor

Aircraft Turbo-Fan Propulsor

Combustion Chamber @ 1600 degC

Airgap 2 mm clearance on 2 m diameter

Multi shaft design

Complex fuel pipes and injection control
Last Slides – Key Messages: We don’t have to wait long

We will have empirical evidence soon!
Invest in Lithium, because the future of flight is electric!
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