E2Flight Presentation:
Potential Propulsion Architecture for a Reduced Climate Impact of Civil Aviation

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Introduction

Aviation global CO₂ contribution (2018) ~2%
Aviation global temperature impact contribution (2018) ~5%

Goal: Reduced Impact of Aviation.

Possible means:

- Non-fossil fuels with renewable energy sources:
  - mainly CO₂ impact mitigation (~1/3)
  - NOₓ?, Contrails?, H₂0?

- Alternative propulsion systems aiming:
  - reducing the fuel consumption of the aircraft fleet
  - Reduction of the non-CO₂ emissions

Focus of the presentation:

- Hybrid-electric architecture with the battery as the main power provider.

Source: Grewe et al (2019)
Motivation for Batteries

* Based on the UN GEO-4 socio-economic scenario Sustainability First. Expected APD number is obtained from the APD forecasting model on city level – D-Cast.

A significant portion of the air traffic takes place at distances, attainable by battery powered aircraft.
Battery-Driven Aircraft Design

Main challenge: Low energy density
Limited aircraft range!

Aircraft Assumptions:
• L/D = 20
• $m_{\text{BAT}} / m_{\text{TOM}} = 0.3$
• 85% propulsive efficiency

Aircraft Allowances (Taxi, Takeoff, etc.) included: ~4 Wh per kg aircraft mass

Flight Distance* ~ 300km

State-of-the-Art Batteries

*5% Contingency included.
Range Extender for Increased Electric Range

Main Mission

Airport-to-Airport: ~300km
(state-of-the-art)

Battery for the main mission

m_{BAT} / m_{TOM} = 0.3

Reserves

Diversion: 100-200km

Kerosene for reserves

m_{Fuel} / m_{TOM} = 0.02

Loiter: 45 min

m_{Fuel} / m_{TOM} = 0.01

Total Flight Distance ~ 300km

Airport-to-Airport: ~300km
(state-of-the-art)
Battery + Range Extender

**E-Motors:**
- Sized for fully electric operation (incl. takeoff).

**Range extenders & fuel tank:**
- In parallel with e-motors, via a gear / clutch.
- For full mission reserves with kerosene.
- For range flexibility with kerosene.
- Sized for diversion speeds.

**Batteries:**
- Sized for all-electric operation.
- No need to consider mission reserves.

\[ \text{~10\% of Power Train Mass} \]

\[ \text{~80\% of Power Train Mass} \]
19-Seater Electric Aircraft with a Range Extender

- E19 (CoCoRe Project)
  - CS 23 (8.6t limit)
  - 0.23 m_{BAT} / m_{TOM}
  - Conventional 19-Seater Airframe & Gas Turbines (80s Technology)
  - State-of-the-Art Electric Propulsion

88% of Missions

19PAX global fleet data (2018), Grimme, et al
19-Seater Electric Aircraft with a Range Extender

Grimme, et al

19PAX global fleet fuel burn profile. Assumptions.
• comprised only of Do228
• operated at efficient cruise speed

Same airframe and gas turbine technology for both aircraft

>70% global fuel saving potential

E19 fleet instead of Do228

Mission Block Fuel [kg]

Mission Distance [km]

Do228 @ Efficient Cruise Speed

E19

Fully Electric Flight

Mission Distance [km]
**State-of-the-Art Perspective**

**Production & Logistics:**
~60g eq. CO₂ / kWh

**Combustion:**
~260g CO₂ / kWh

**German Mix (2018):**
~474g**
CO₂ / kWh

**2000 cycles**

**160 Wh/kg**

**Life Cycle:**
~ +50g***
CO₂ / kWh

**Gas Turbine**
Do228 size
Efficiency: ~25%

**Battery**
~90%

**eMotor**
~94%

**Total Eff** ~85%

**~ 4 kWh Kerosene:**
- 1280 g CO₂
- + Impact from NOₓ and H₂O

**~ 1.2 kWh e-Power**
- 600 g CO₂

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* EU Commission - Report EUR 26237 EN
** Umweltbundesamt (2018a/b)
*** Calculated using data from Fraunhofer StudypFHG-SK: ISE-PUBLI
E19 Potential Impact

- 19PAX fleet composed of Do228 operated at efficient cruise speed
- 70% NO\textsubscript{x} and H\textsubscript{2}O impact reduction
- >70% global fuel saving potential

- 19PAX fleet composed of E19

- 50% CO\textsubscript{2} reduction

19PAX fleet composed of Do228 operated at efficient cruise speed

Mission Distance [km]

Fleet Fuel Burn

CO2 Emissions
Aircraft Class Impact Breakdown

Flight distance for average global fleet fuel burn (2014 Data – Grimme et al)

<table>
<thead>
<tr>
<th>Seats</th>
<th>Flight Distance [km]</th>
<th>Impact</th>
<th>Global Fleet Fuel Burn 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-19</td>
<td>200 km</td>
<td>~0%</td>
<td>~0%</td>
</tr>
<tr>
<td>20-50</td>
<td>576 km</td>
<td>~9%</td>
<td>0.2%</td>
</tr>
<tr>
<td>51-70</td>
<td>349 km</td>
<td>~9%</td>
<td>0.4%</td>
</tr>
<tr>
<td>71-85</td>
<td>663 km</td>
<td>~9%</td>
<td>2.9%</td>
</tr>
<tr>
<td>86-100</td>
<td>596 km</td>
<td>~9%</td>
<td>2.1%</td>
</tr>
<tr>
<td>101-125</td>
<td>864 km</td>
<td>~9%</td>
<td>3.1%</td>
</tr>
<tr>
<td>126-150</td>
<td>1225 km</td>
<td>~44%</td>
<td>14.9%</td>
</tr>
<tr>
<td>151-175</td>
<td>1310 km</td>
<td>~44%</td>
<td>21.2%</td>
</tr>
<tr>
<td>176-210</td>
<td>1627 km</td>
<td>~44%</td>
<td>7.9%</td>
</tr>
<tr>
<td>211-300</td>
<td>3917 km</td>
<td>~37%</td>
<td>20.2%</td>
</tr>
<tr>
<td>301-400</td>
<td>5283 km</td>
<td>~37%</td>
<td>18.6%</td>
</tr>
<tr>
<td>401-500</td>
<td>5779 km</td>
<td>~37%</td>
<td>4.8%</td>
</tr>
<tr>
<td>501+</td>
<td>7117 km</td>
<td>~37%</td>
<td>3.6%</td>
</tr>
</tbody>
</table>

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Fuel Impact Mitigation EIS2030 – Baseline Conventional Turboprop Aircraft

Mission distance for average fuel burn

- 501+: 7117 km
- 401-500: 5779 km
- 301-400: 5283 km
- 211-300: 3917 km
- 176-210: 1627 km
- 151-175: 1310 km
- 126-150: 1225 km
- 101-125: 864 km
- 86-100: 596 km
- 71-85: 663 km
- 51-70: 349 km
- 20-50: 576 km
- 1-19: 200 km

Generic Advanced Turboprop Design (EIS 2030) for the Lower Seat Categories (Mostly Regional Flights)

Top-Level Aircraft Requirements (TLARS):
- Mach = 0.5
- SPP Range = 1200 nm
- Cruise ALT 29000 ft
- Takeoff Field Length = 1300 m
- Approach Speed = 120 kCAS

Technology Assumptions:
- CFRP Wing & Fuselage
- Fly-by-Wire
- Gas Turbine (EIS 2030) Eff = 35%

Performance Characteristics:
- \( \frac{m_{\text{Payload}}}{m_{\text{TOM}}} = 0.3 \)
- L/D (cruise) = 19
- Propeller Eff = 87%
EIS2030+ Szenario

Conventional

- Same TLARS
- Const. Aspect Ratio
- Const. Wing Loading
- Complete Snowball Effects

Battery + Range Extender

EIS 2030+ Assumptions:
- $m_{\text{Payload}} / m_{\text{TOM}} = 0.3$
- $m_{\text{OEM}} / m_{\text{TOM}} = 0.4$
- $m_{\text{Fuel}} / m_{\text{TOM}} = 0.15$
- $L/D \text{ (cruise)} = 19$

- $m_{\text{BAT}} / m_{\text{TOM}} = 0.27$
- $m_{\text{TOM}} \text{ increase: } +86\%$
- $L/D \text{ (cruise)} = 22$
  (big wing for same fuselage)

Battery + Range Extender applied on Lower-Seat-Cathegories

Global Fleet Fuel Burn 2014

Fleet Fuel Burn

Conventional Fleet

BAT + RE Fleet

0 1000 2000 3000
Flight Distance [km]

-45%
Fuel

-55%
Fuel

-64%
Fuel

0 1000 2000 3000
Flight Distance [km]

-45%
Fuel

-55%
Fuel

-64%
Fuel

Potential Global Climate Impact Reduction: ~5%

Only the smaller aircraft cathegories!
Global Potential of Battery + Range Extender Concept (EIS2030+ Technology)

Conventional

-100% Fuel
-60% Fuel
-25% Fuel
-6% Fuel

BAT + RE

Block Fuel

0 500 1000 1500 2000 2500

Flight Distance [km]

Conventional

BAT + RE

ICCT Data (2018)

~ 18% Potential Global Climate Impact Reduction of Aviation

Significant potential for global emissions reduction already for near-term battery development expectations.
Battery Technology Level Effect on Global Potential

Diagram based on ICCT 2018 global fleet data. Needs to be improved with market growth expectations.

* Potential as defined in the previous slide
Concluding Remarks

- Specific power needed for propeller-driven aircraft, assuming $m_{BAT} / m_{TOM} = 0.3$ is around 0.5kW/kg
  → Specific power of high-energy battery cells is not a potential showstopper.

- The validity of the presented results can be expected to hold for mach numbers of up to 0.65, after which a counter-rotating propeller or a turbofan architecture would be required, which would offset the overall result.

- The presented results are on a conceptual level and do not include an aircraft configuration optimisation for the new power train.
Thank you for your attention!