Electric Commuter Transport Concept Enabled by Combustion Engine Range Extender

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Outlines

Background and Objectives.

Conceptual-Level Aircraft Sizing of a Hybrid-Electric 19-Seater

Results and Assessment

Conclusions and Outlook
Background and Objectives

A collaborative project between the DLR and Bauhaus Luftfahrt:

→ Re-introduction of small regional aircraft with up to 19 passengers.

Approach:

→ 19-seater market analysis
→ 19-seater aircraft data base for support
→ Assessment of feasible concepts

Objectives of this study:

→ A conceptual aircraft design that answers the market analysis results
Design Goals

Market research data:

- Extremely short utilization distances of 19-seater aircraft

→ Market suitable for fully electric flight

Design aim:

- 19-seater aircraft with fully electric flight capability.
- State-of-the-art electric components at prototype level.
- Certification under CS 23
- Competitive payload-range characteristics
Propulsion Architecture

- Classical twin propeller configuration:
  - Low-risk, dependable conceptual-level results.

- E-Motors:
  - Sized for take-off & all-electric operation.

- Range extender:
  - In parallel to e-motors, with a coupling / decoupling device.
  - For full IFR mission reserves with kerosene.
  - For range flexibility with kerosene.
  - Sized for loiter speeds @ 10000ft.

- Batteries:
  - Sized for all-electric operation.
  - Must not consider mission reserves.
Configurational Aspects

Pressurized cabin complementing the e-motors’ lack of power lapse.

Landing gear to wing root due to space allocation.

Propulsion mass directly supported by the landing gear.

Favourable mass distribution for the wing in flight.
Conceptual Design Model Calibration

Aircraft Sizing Model Based on Do228

- Refined throughout previous studies
- Dependable for similar configurations
- Used as a base for this study

Model Validation and Calibration on Similar to E19 Configurations

- B1900D
- B1900D ref. data
- BAe JS31
- Bae JS31 ref. data

Uncertainty: E19 configuration is different

Range [km]

Payload [kg]
Top-Level Aircraft Requirements (TLARs) & Assumptions

<table>
<thead>
<tr>
<th>TLAR</th>
<th>Value</th>
<th>Unit</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTOM Limit</td>
<td>8618</td>
<td>Kg</td>
<td>CS23 Limit</td>
</tr>
<tr>
<td>Max Payload</td>
<td>1805</td>
<td>Kg</td>
<td>Same as BAe JS31</td>
</tr>
<tr>
<td>Min Cruise Altitude</td>
<td>10000</td>
<td>Ft</td>
<td></td>
</tr>
<tr>
<td>Ceiling Altitude</td>
<td>25000</td>
<td>Ft</td>
<td>Same as BAe JS31</td>
</tr>
<tr>
<td>Diversion Mission</td>
<td>100</td>
<td>Nm</td>
<td>For IFR flight rules</td>
</tr>
<tr>
<td>Approach Speed</td>
<td>109</td>
<td>Kts</td>
<td>Similar to BAe JS31</td>
</tr>
<tr>
<td>Takeoff Field Length</td>
<td>1440</td>
<td>m</td>
<td>Same as BAe JS31</td>
</tr>
</tbody>
</table>

Same technology as the Bae JS31:
- Airframe structure
- Systems
- Gas turbine
- Furnishings & Operator Items

Allowances

<table>
<thead>
<tr>
<th>Segment</th>
<th>Time [min]</th>
<th>Energy [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi out</td>
<td>3.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Take-off</td>
<td>1.1</td>
<td>24.7</td>
</tr>
<tr>
<td>Approach &amp; Landing</td>
<td>2.0</td>
<td>6.1</td>
</tr>
<tr>
<td>Taxi in</td>
<td>3.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Total</td>
<td>9.1</td>
<td>32.4</td>
</tr>
</tbody>
</table>
## Sizing Results

<table>
<thead>
<tr>
<th>Sizing Model Results</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Takeoff Mass (MTOM)</td>
<td>8618</td>
<td>kg</td>
</tr>
<tr>
<td>Design Fuel (IFR Reserves Only)</td>
<td>192</td>
<td>kg</td>
</tr>
<tr>
<td>Max. Zero-Fuel Mass</td>
<td>8426</td>
<td>kg</td>
</tr>
<tr>
<td>Max. Payload</td>
<td>1805</td>
<td>kg</td>
</tr>
<tr>
<td>Operating Empty Mass (OEM)</td>
<td>6621</td>
<td>kg</td>
</tr>
<tr>
<td>Operator's Items</td>
<td>475</td>
<td>kg</td>
</tr>
<tr>
<td>Manufacturer's Empty Mass</td>
<td>6146</td>
<td>kg</td>
</tr>
<tr>
<td>Furnishings</td>
<td>270</td>
<td>kg</td>
</tr>
<tr>
<td>Systems</td>
<td>650</td>
<td>kg</td>
</tr>
<tr>
<td>Propellers + Range Ext. (incl Systems)</td>
<td>388</td>
<td>kg</td>
</tr>
<tr>
<td>Airframe Structure</td>
<td>2446</td>
<td>kg</td>
</tr>
<tr>
<td><strong>El. Power Train Budget</strong></td>
<td>2329</td>
<td>kg</td>
</tr>
</tbody>
</table>

### State of the Art Technology Assumptions @ Prototype Level

- **El. Power Train**
  - **E-Motors**
    - Tot. Mass: 253 kg
    - Tot. Power: 1251 kW
    - Eff.: 95.0%
  - **Controllers**
    - Tot. Mass: 12 kg
    - Tot. Power: 1321 kW
    - Eff.: 98.0%
  - **Cooling**
    - Tot. Mass: 44 kg
    - Tot. Power: 89 kW
    - Eff.: -
  - **Power Distr.**
    - Tot. Mass: 66 kg
    - Tot. Power: 1321 kW
    - Eff.: 99.7%
  - **Battery**
    - Tot. Mass: 2018 kg
    - Tot. Power: 1352 kW
    - Eff.: -

### Battery Pack
- 230 Wh/kg
- 690 W/kg
- 90% State of Charge (start of Mission)
- 20% State of Charge (end of Mission)
- Effective: 160 Wh/kg
## E19 Geometry Overview

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Wing</th>
<th>HTP</th>
<th>VTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area [m²]</td>
<td>33.2</td>
<td>8.2</td>
<td>6.1</td>
</tr>
<tr>
<td>Aspect Ratio [-]</td>
<td>12.0</td>
<td>5.2</td>
<td>1.5</td>
</tr>
<tr>
<td>MAC [m]</td>
<td>1.77</td>
<td>1.27</td>
<td>2.17</td>
</tr>
<tr>
<td>¼-Chord Sweep [°]</td>
<td>1.8</td>
<td>3.0</td>
<td>36.0</td>
</tr>
<tr>
<td>Rel. thickness [-]</td>
<td>16% / 12%</td>
<td>13% / 12%</td>
<td>13% / 12%</td>
</tr>
</tbody>
</table>
E19 Payload-Range Characteristics

- Mostly electric operation in the typical utilization range
- Extended range capability for airline flexibility
E19 Power Profile

**Electric Mission (190km)**
- Battery Power
- Altitude

**Hybrid Mission (340km)**
- GT* + E-Mot Power
- E-Motor Power
- Altitude

- 10000ft cruise – too short for higher altitude.
- No pressurization offtakes at this altitude.
- Climbs higher and faster to improve time performance at the bigger distances
Payload-Range Comparison

![Graph showing range vs payload for different aircraft models.]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Do228</th>
<th>BAe JS31</th>
<th>B1900D</th>
<th>E19</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTOM</td>
<td>kg</td>
<td>6400</td>
<td>6950</td>
<td>7766</td>
<td>8618</td>
</tr>
<tr>
<td>Sref</td>
<td>m²</td>
<td>32</td>
<td>25.2</td>
<td>28.8</td>
<td>33</td>
</tr>
<tr>
<td>Span</td>
<td>m</td>
<td>17</td>
<td>15.9</td>
<td>17.75</td>
<td>20</td>
</tr>
<tr>
<td>$c_{L,cruise}$</td>
<td>-</td>
<td>0.3</td>
<td>0.55</td>
<td>0.45</td>
<td>0.75</td>
</tr>
<tr>
<td>$L/D_{cruise}$</td>
<td>-</td>
<td>10.0</td>
<td>14.6</td>
<td>12.1</td>
<td>19.4</td>
</tr>
<tr>
<td>$psfc_{GT,cruise}$</td>
<td>kg/kWh</td>
<td>0.34</td>
<td>0.32</td>
<td>0.33</td>
<td>0.35</td>
</tr>
</tbody>
</table>

→ High MTOM is mitigated by improved L/D
Mission Performance

- E19 → velocity traded for efficiency.
- Penalty most prominent at the longer missions.
- Less affected at the typical utilization range.
Sizing Requirements for the Hybrid Chain

- With renewable energy for recharging, ~70% emissions reduction potential at the 19-seater market
- If current electric mix in Germany is used → a potential of ~45% emissions reduction remains
Conclusions

The conceptual design study conclusions:

- State-of-the-art electric power technology is potentially suitable for the 19-seater market.
- > 70% fuel savings on average are potentially feasible on this market.
- > 40% CO2 emission reduction possible, if battery charging with the German electric mix of today is assumed.

Further efforts needed:

- Operational assessment, including charging during turnaround and life-cycle assessment.
Outlook

- New battery technology could improve performance without redesigning the aircraft.
- The approach is scalable to bigger aircraft for similar range performance.
Thank you for your attention!