A general approach to conceptual design of hybrid-electric aircraft

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Toulouse 24th October 2018
Outline

1) Introduction
   • Hybrid architectures
   • Future trends

2) Sizing Approach
   • Preliminary aircraft sizing
   • Working assumptions
   • Motors and Battery sizing

3) Numerical Implementation
   • Hyperion program procedure
   • Simulation strategies
   • Program validation

4) Results
   • General aviation case study
   • Micro feeder case study

5) Conclusions
Introduction: hybrid architectures

Available architectures

- All Electric
- Series Hybrid
- Parallel Hybrid
- Series/parallel Hybrid

Introduction: future trends

Trend of applications

- Non propulsive energy
- Electrically assisted gas turbines
- Parallel hybrid propulsion
- Series hybrid or Turboelectric
- Full-Electric

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Sizing Approach: aircraft preliminary sizing

Airplane conceptual design

- Computation of aircraft takeoff, empty and payload mass
- Estimation of aircraft aerodynamic characteristics and performance
- Determination of required power and mission energy
- Computation of motor and generator power and fuel and battery mass

Flight profile definition

Engines Regression

- Thermal
- Electric
- Data
Sizing Approach: working assumptions

Power-train
- Use of propellers driven by electric motors
- Power provided by batteries
- Motor power not depending on altitude
- Windmilling allowed in descent phase
- Generator: turboshaft or reciprocating engine with alternator

Generator model
- Simulation of the thermodynamic cycle at every altitude with estimation of real efficiency through experimental parameters
- Fuel flow rate obtained from needed power from flight mechanics
- Selection of a transition altitude for generator operation

Source: hypstair.eu
Sizing Approach: motors and battery sizing

- Aircraft empty mass and aerodynamic characteristics from statistical regression
- Analysis of needed power, estimated duration and overall energy for each phase
- Motor and Generator sizing based on maximum and cruise power respectively
- Battery and fuel mass from required energy and power needs
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Numerical Implementation: **Hyperion program**

Hyperion: HYbrid PERformance simulatION

- Program **initialization** through input file
- Simulation **settings** selected by user
- Preliminary aircraft sizing
- **Step-by-step** simulation of each flight phase
- Check on final **fuel** and **SoC levels**
- Battery/Fuel mass correction and **re-iteration** until convergence
- Visual **postprocess** and file writing
Numerical Implementation: simulation strategies

Battery charging Strategy

- Based on battery state of charge, returns generator throttle for subsequent time step
- Evolution through PID controller: more realistic throttle characteristics
- Generator turned off during takeoff and first climb segment
- Divided in steady charging and cyclic charging strategies

![Steady charging strategy](image)

![Cyclic charging strategy](image)
Numerical Implementation: program validation

- Validation on **general aviation**, **micro feeder**, **commuter** and **regional** aircraft classes
- Validation based on aircraft **weight breakdown** and **installed power**
- Conventional airplanes simulated as **turboelectric**
- Validation on **Panthera Hybrid** (internal ring)

### General Aviation – Power

<table>
<thead>
<tr>
<th></th>
<th>Motor [kW]</th>
<th>Generator [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panthera Hybrid</td>
<td>200</td>
<td>178</td>
</tr>
<tr>
<td>Simulated General Aviation</td>
<td>110</td>
<td>105</td>
</tr>
</tbody>
</table>

### General Aviation Weight Breakdown

- **Empty [kg]**: 868
- **Fuel [kg]**: 830
- **Payload [kg]**: 53
- **Battery [kg]**: 61

- **Motor [kW]**: 312 (22.9%)
- **Generator [kW]**: 121 (8.9%)
- **Simulated General Aviation**
  - Empty [kg]: 868 (63.1%)
  - Battery [kg]: 61 (4.5%)
  - Motor [kW]: 312 (23.7%)
  - Generator [kW]: 53 (4.0%)
Numerical Implementation: program validation

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>MTOM [kg]</th>
<th>ME [kg]</th>
<th>MF [kg]</th>
<th>Sw [m²]</th>
<th>PM [kW]</th>
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</thead>
<tbody>
<tr>
<td>Micro feeder</td>
<td>Real</td>
<td>3600</td>
<td>2250</td>
<td>275</td>
<td>25.4</td>
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<tr>
<td>Tecnam P2012</td>
<td>Simulated</td>
<td>3327</td>
<td>1927</td>
<td>304</td>
<td>24.0</td>
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<tr>
<td>Commuter</td>
<td>Real</td>
<td>7764</td>
<td>4732</td>
<td>894</td>
<td>28.8</td>
</tr>
<tr>
<td>Beechcraft Beech-1900D</td>
<td>Simulated</td>
<td>7659</td>
<td>4707</td>
<td>814</td>
<td>28.2</td>
</tr>
<tr>
<td>Large regional</td>
<td>Real</td>
<td>23000</td>
<td>13500</td>
<td>2000</td>
<td>61.0</td>
</tr>
<tr>
<td>ATR 72-600</td>
<td>Simulated</td>
<td>22990</td>
<td>13450</td>
<td>1920</td>
<td>61.8</td>
</tr>
</tbody>
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Results: general aviation case study

- Study on a single-engine, 4-seater general aviation aircraft with range of 300 km
- Comparison of an All-Electric (internal ring) and Hybrid-Electric (external ring)
- Battery with 1000 W kg\(^{-1}\) and 500 Wh kg\(^{-1}\) of specific power and energy
- Final state of charge (SoC) of 25% and 10% fuel reserve

### Aircraft Results

- MTOM [kg]: 1775
- Motor Power [kW]: 1328
- Battery [kg]: 185
- Fuel [kg]: 145

### Weight Breakdown

- Empty [kg]: 985 (63.3%)
- Fuel [kg]: 312 (17.6%)
- Payload [kg]: 478 (26.9%)
- Battery [kg]: 312 (55.5%)
- Motor Power [kW]: 841 (23.5%)
Results: micro feeder case study

- Study on a twin-engine, 8-seater micro feeder aircraft with range of 250 km All-Electric and 600 km Hybrid-Electric
- Comparison of an All-Electric (internal ring) and Hybrid-Electric (external ring)
- Battery with 1000 W kg\(^{-1}\) and 500 Wh kg\(^{-1}\) of specific power and energy
- Final state of charge (SoC) of 25% and 10% fuel reserve

**Aircraft Results**

<table>
<thead>
<tr>
<th>MTOM [kg]</th>
<th>Power [kW]</th>
<th>Range [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3615</td>
<td>400</td>
<td>250</td>
</tr>
<tr>
<td>3609</td>
<td>400</td>
<td>600</td>
</tr>
</tbody>
</table>

**Weight Breakdown**

- Empty [kg]: 2123 (58.8%)
- Fuel [kg]: 653 (18.1%)
- Payload [kg]: 166 (4.6%)
- Battery [kg]: 913 (25.3%)

- 407 (11.3%) of specific power and energy
- 2049 (56.7%) of specific power and energy
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Conclusion

• Developed a general procedure for All-Electric and serial Hybrid-Electric aircraft conceptual design using turboshift or reciprocating generator
• Conducted validation on available hybrid aircraft and simulated conventional limit case
• Conceptual design of All-Electric and Hybrid-Electric 4-seater general aviation aircraft and 8-seater micro feeder aircraft
Acknowledgements

• Research partially funded by the EU’s Horizon 2020 research and innovation programme under Grant Agreement N. 723368

• **Develop hybrid electric serial powertrains** to enable cleaner, **quieter** and **more efficient** aircraft propulsion

• Deliver **optimized propulsion components** with increased reliability suitable for **commercial deployment** to small aircraft
Thank you for your attention!