ARPA-E Electric Motor Workshop
Hybrid Electric Aircraft Design Space, Feasibility and Technical Challenges

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Electrified Propulsion (EP) System Architectures

4 basic configurations

**Parallel Gas-Electric Hybrid**
- All thrust from main fans, fan power from liquid fuel through GT and battery through LS motor

**Full Series Turboelectric Hybrid**
- GT creates electric power from liquid fuel, electric power distributed to multiple electric fans for thrust, battery used for load leveling

**Partial Series Turboelectric Hybrid**
- Full Series Turboelectric Hybrid, with addition of thrust from GT LS fan

**All Electric (not a Hybrid)**
- Electric power from battery distributed to multiple electric fans for thrust

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United Technologies Research Center

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Electrified Aircraft Propulsion (EAP) Concepts

Example EP implementations

Parallel Gas-Electric Hybrid

Credit: Boeing/NASA

Full Series Turboelectric Hybrid

Credit: Zunum

Partial Series Turboelectric Hybrid

Credit: NASA

Electric

Credit: NASA

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Why Hybrid Electric

Enables New Missions

Enables New Business Models

Enables Fuel Burn & CO2 Reduction
Hybrid Electric Aircraft Design Space

Point studies done in the design space
EAP Drive Train

- Turbine Engine
- Generator
- AC to DC Conversion
- Distribution
- Motor Drive
- Motor
- Battery
- Propulsor
- Turbine Engine

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# Drive Train Challenges

<table>
<thead>
<tr>
<th>Component</th>
<th>TODAY</th>
<th>Power Train</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generator</strong></td>
<td>90 %</td>
<td>96%</td>
</tr>
<tr>
<td><strong>AC to DC Conversion</strong></td>
<td>96 %</td>
<td>98.5%</td>
</tr>
<tr>
<td><strong>Distribution Wiring &amp; Switch Gear</strong></td>
<td>50 KW/Kg</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Motor Drive</strong></td>
<td>96 %</td>
<td>92%</td>
</tr>
<tr>
<td><strong>Motor</strong></td>
<td>92%</td>
<td></td>
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</tbody>
</table>

- **Turbine Engine**: 2 KW/Kg
- **AC to DC Conversion**: 10 KW/Kg
- **Distribution Wiring & Switch Gear**: 50 KW/Kg
- **Motor Drive**: 10 KW/Kg
- **Motor**: 5 KW/Kg

**Battery**: 150 Wh/Kg

**Low emissions energy storage**

**Medium to Low Quality Waste Heat**

- **Weight**: Heat Exchangers, Ducts, Plumbing
- **Ram Drag**: Battery cooling
- **Power**: Pumps, Fans, VCS?

**Power Train**

- **Weight**: EM Machines, PE & Distribution
- **High voltage**: switches and protection
- **Power**: Losses increase power and energy requirement, create heat

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Series Turboelectric Hybrid

Series hybrids include an electric drive that must buy its way on the system.

**Series turbo-electric hybrid**

![Graph showing Electric Drive Efficiency vs. Electric Drive Specific Power](image1)

**Partial series turbo-electric hybrid**

![Graph showing Electric Drive Efficiency vs. Electric Drive Specific Power](image2)

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**Electric Drive System**

- Fan
- Motor
- MD
- Inv
- Gen
- LPC
- HPC
- Core
- HPT
- LPT
- Battery
- TMS
- Liquid Fuel

**Propulsion Airframe Integration (PAI) Benefit**

- Minimum
- Median
- Maximum


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Electric Drive Train (EDT) Performance

Current development progressing toward 2.1 kW/kg @ 86%

<table>
<thead>
<tr>
<th>Components</th>
<th>Efficiency</th>
<th>Power Density</th>
<th>Efficiency</th>
<th>Power Density</th>
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<td>94.0%</td>
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<td>Rectifier</td>
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<td>50</td>
<td>99.0%</td>
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<td>98.0%</td>
<td>20</td>
<td>99.0%</td>
<td>40</td>
</tr>
<tr>
<td>Motor</td>
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<tr>
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<tr>
<td>Total</td>
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<td>0.9</td>
<td>86%</td>
<td>2.1</td>
<td>91%</td>
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</tbody>
</table>

Today 0.9 kW/kg, 75%
Current Progress 2.1 kW/kg, 86%
Future Targets 8.4 kW/kg, 91%
Benefit of Improved EDT Performance

Future EDT improvements can enable PAI benefit

Series turbo-electric hybrid

Partial series turbo-electric hybrid


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