Visions of the Future: Hybrid Electric Aircraft Propulsion

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Outline

• NASA’s Motivation for Electrified Aircraft Propulsion Investment
• Strategic Thrust 4: Transition to Low Carbon Propulsion
• Hybrid and Electric Aircraft Propulsion Terminology
• NASA’s Approach to Electrified Aircraft Propulsion
• Convergent Aeronautics Solutions: for High Risk and High Payoff
• SCEPTOR/X-57: Near Term Flight Demonstration
• Advanced Air Transport Technology: Long Term Aircraft Investment for Electrified Propulsion
• Summary
Electrified Aircraft Propulsion: Motivation

NASA Aeronautics Research Mission Directorate

Mega Drivers

Global

Sustainable

Strategic Thrusts

6 Strategic Thrusts

Safe, Efficient Growth in Global Operations
Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft
Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles
Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion
Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance
Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation
Develop high impact aviation autonomy applications
Electrified Aircraft Propulsion: Motivation

Strategic Thrusts Guide Investment Targets

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>2015</td>
<td>Introduction of Low-Carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems</td>
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<tr>
<td>2025</td>
<td>Initial Introduction of Alternative Propulsion Systems</td>
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<tr>
<td>2035</td>
<td>Introduction of Alternative Propulsion Systems to Aircraft of All Sizes</td>
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The Low Carbon Challenge is to enable carbon-neutral growth in aircraft operations:

![CO₂ Emissions Chart]

- Forecasts Carbon Emissions Growth (Without improvements)
- Technology Development—Ongoing Fleet Renewal
- Operational Improvements—ATC/NextGen
- Additional Technology Advancement and Low Carbon Fuels
- Carbon neutral growth
- Baseline reduced by 50%
Electrified Aircraft Propulsion Terminology

• **Electrified Propulsion refers to the use of electric power for aircraft propulsion**
  – Could be all or partially electric propulsion
  – Other aircraft development programs use the terms “More electric” or “All electric” as the use of electric power for secondary systems on aircraft such as control surfaces and wing de-icing

• **Hybrid Electric has two meanings in aircraft context**
  – One meaning is the use of two power sources, such as turbine engine and electric motor, to drive the fan (or propeller) on an aircraft—hybrid electric powertrain
  – Another meaning is the combination of more than one propulsive sources such as engines, turboelectric energy generation, fuel cells energy generation, or battery energy storage—hybrid electric propulsion

• **Turboelectric Propulsion refers to on-air generated electric power for aircraft propulsion**
  – Turboelectric generation already provides electric power for secondary systems on aircraft
  – Fully turboelectric propulsion means that all turbine power goes to electricity
  – Partially turboelectric propulsion means a turbofan engine with some fraction of generated electric power going to propulsion
Electrified Propulsion Vehicle Trade Space

Baseline Aircraft with Podded Turbo-Fan

VEHICLE CONFIGURATION EXAMPLES

- SCEPTOR 4 PAX X-Plane
- SUGAR VOLT 150 PAX Study
- AATT 50 PAX STUDIES
- Current NRA 150 PAX Studies
- STARC-ABL 150 PAX Study
- ECO-150 150 PAX Studies
- N3-X 300 PAX Turbo-Electric
Electrified Propulsion: NASA’s Approach

Build, Test, Mature Enabling Technologies and Knowledge Bases

- **2020**: Test Beds, Component Improvements, and Modeling
- **2030**: Build, learn, demonstrate
- **2040**: Certify, Operate and Work toward full PAI and HEP

Prove Out Transformational Potential:
- Explore and demonstrate vehicle integration synergies enabled by hybrid electric propulsion

Environmental Benefit:
- Increasingly electric aircraft propulsion with minimal change to aircraft outer mold lines

Knowledge through Integration & Demonstration
### Electrified Propulsion Development

**Goal:** Enable the paradigm shift to electric, hybrid electric, and turboelectric propulsion for reductions in energy consumption, emissions, and noise.

**Path:**
- Identify promising propulsion / vehicle configurations
- Buy-down risk for crucial technologies in
  - Flight Control: new knobs in vehicle and subsystems
  - Power Conversion: electric machines & electronics
  - Power Control: vehicle electric grid management
  - Fundamental Enablers: materials and analysis
- Demonstrate results in purpose-built flight demonstration
Multiple Paths to Carbon Reduction

All Electric, Hybrid Electric, Distributed Propulsion

- On Demand Mobility Focus
- Small Plane Focused

Enable New Aero Efficiencies
Power Sharing
Distributed Thrust Control
Certification Trailblazing

Energy & Cost Efficient, Short Range Aviation

Turbo Electric, Distributed Propulsion

- Low Carbon Propulsion
- Transport Class Focused

Enable New Aero Efficiencies
High Efficiency Power Distribution
Power Rich Optimization
Non-flight Critical First Application

Energy & Cost Efficient, Transport Aviation
Convergent Aeronautics Solutions Project
Aircraft Hybrid/Electric Propulsion Activities

• **M-SHELLS – Multifunctional Structures for High Energy Lightweight Load-bearing Storage**
  – Integrates hybrid battery/supercaps into aircraft structure to increase effective specific power & specific energy
  – Converges advanced electrochemistries, microstructures, manufacturing, and nano-technologies

• **LION – Integrated Computational-Experimental Development of Li-Air Batteries for Electric Aircraft**
  – Investigates “electrolyte engineering” concepts to enable Li-Air batteries with high practical energy densities, rechargeability and safety
  – Converges advances in predictive computation, material science, and fundamental chemistry

• **HVHEP – High Voltage Hybrid Electric Propulsion**
  – Variable-frequency AC, kV, power distribution with DFIM machines for multi-MWe DEP applications
  – Minimizes constituent weights of power electronics, TMS, and fault protection

• **Compact High Power Density Machine Enabled by Additive Manufacturing**
  – 2 to 3x increase in specific power of electric machines for DEP enabled by additive manufacturing
  – Compact, lightweight motor designs/topologies, integrated cooling, and multi-material systems/components

• **DELIVER – Design Environment for Novel Vertical Lift Vehicles – cryo-cooling HEP task**
  – Maximizing efficiency and power density of electronic components by cryogenic LNG-fuel cooling
  – Longer-range hybrid/electric UAS with reduced fuel-burn and emissions (CO2, sulfur, particulates)

• **FUELEAP – Fostering Ultra-Efficient, Low-Emitting Aviation Power**
  – GA aircraft / early-adopter application of JP-fueled SOFC power plant for clean, hybrid/electric architecture
  – Zero NOx electric power production at ~2x typical combustion efficiencies

• **SCEPTOR – Scalable Convergent Electric Propulsion Technology and Operations Research**
  – Seeks 5x reduction in cruise-energy-use by aerodynamic benefits of DEP & batteries in place of engines
  – DEP enables high efficiency wing & high performance wingtip motors for cruise
SCEPTOR X-57 Research Objectives

NASA SCEPTOR Primary Objective

- Goal: 5x Lower Energy Use (Comparative to Retrofit GA Baseline @ 150 knots)
  - Motor/controller/battery conversion efficiency from 28% to 92% (3.3x)
  - Integration benefits of ~1.5x (2.0x likely achievable with non-retrofit)

NASA SCEPTOR Derivative Objectives

- ~30% Lower Total Operating Cost (Comparative to Retrofit GA Baseline)
- Zero In-flight Carbon Emissions

NASA SCEPTOR Secondary Objectives

- 15 dB Lower community noise (with even lower true community annoyance).
- Flight control redundancy, robustness, reliability, with improved ride quality.
- Certification basis for DEP technologies.
Adv. Air Transport Technology Project Investment

- Highly Efficient Turbine Engines
- Efficient, Low Noise Propulsors
- Boundary-Layer Ingestion Systems
- Power Systems Architectures
- Advanced Electrical Components
- Integrated Vehicles and Concepts Evaluation
**Objective**
Key performance parameters and threshold level requirements for gas turbine aircraft augmented with electrical powertrain

**Propulsion System Conceptual Design**
– Concepts for system interaction exploration

**Integrated Subsystems**
– Flight control methodology for distributed propulsion

**High Efficiency/Power Density Electric Machines**
– Step change in component performance

**Flight-weight Power System and Electronics**
– High voltage power electronics, transmission, protection, and management

**Enabling Materials**
– Insulation, Conductors, Magnetic Materials
NASA Electrified Propulsion Takeaways

• NASA Aeronautics Strategic Thrust 4 - Transition to Low-Carbon Propulsion is supporting investment in alternative aircraft propulsion including electrified aircraft propulsion

• The NASA vision includes transforming aviation via new propulsion technologies integrated with airframes to
  – increase aircraft functionality
  – reduce carbon emissions
  – improve operational efficiency and reduce noise

• There are many possible Electrified Aircraft configurations

• NASA investment includes vehicle concepts and technology to support aircraft for
  – Small to midsize aircraft to increase mobility provide a new paradigm
  – Commercial transport aircraft to impact the current large carbon producing market segment
## Timeline of Machine Power Relevant to Aircraft Class

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<tr>
<th>Non-cryogenic</th>
<th>Largest Electrical Machine on Aircraft</th>
<th>Superconducting</th>
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<tbody>
<tr>
<td>100 kW</td>
<td>1 MW</td>
<td>30 MW</td>
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<tr>
<td></td>
<td>3 MW</td>
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<tr>
<td></td>
<td>10 MW</td>
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<tr>
<td></td>
<td>30 MW</td>
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### 9 Seat
- 0.5 MW Total Propulsive Power
- 50-250 kW Electric Machines

### 19 Seat
- 2 MW Total Propulsive Power
- 1-1 MW Electric Machines

### 50 Seat Turboprop
- 3 MW Total Propulsive Power
- 0.3-6 MW Electric Machines

### 50 Seat Jet
- 12 MW Total Propulsive Power
- 0.3-6 MW Electric Machines

### 150 Seat
- 22 MW Total Propulsive Power
- 1-11 MW Electric Machines

### 300 Seat
- 60 MW Total Propulsive
- 3-30 MW Electric Machines