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

Transformative

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
The Low Carbon Challenge is to enable carbon-neutral growth in aircraft operations:
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

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

Work toward full PAI and HEP
- Increasingly electric aircraft propulsion with minimal change to aircraft outer mold lines

Certify, Operate
- Single Aisle Transport

Build, learn, demonstrate
- Small Aircraft

Modeling
- Explore Architectures
- Test Beds
- Component Improvements

Environmental Benefit

Knowledge through Integration & Demonstration

Gain experience through integration and demonstration on progressively larger platforms
**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
- Integrated Vehicles and Concepts Evaluation
- Advanced Electrical Components

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Adv. Air Transport Technology Project Investment

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

Scrutinizing tube & wing architectures

Revolutionary system testing

Superconducting and ambient machines

Transitioning materials from lab to component
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

<table>
<thead>
<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></td>
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<tr>
<td></td>
<td>3 MW</td>
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<tr>
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<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
  - 3-6 MW Electric Machines

- **50 Seat Jet**
  - 12 MW Total Propulsive Power
  - 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