NASA Investments in Electric Propulsion Technologies for Large Commercial Aircraft

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U.S. leadership for a new era of flight
Strategic Thrust 3: Ultra Efficient Commercial Vehicles

2015-2025
- Aircraft on defined path to fleet-level carbon neutral growth relative to 2005 levels

2025-2035
- Aircraft improvements to achieve fleet-level carbon neutral growth relative to 2005 levels

2035+
- Aircraft enabling a 50% fleet-level carbon reduction reduction from 2005 levels

Evolutionary

Revolutionary

Transformational

Strategic Thrust 4: Transition to Low Carbon Propulsion

2015-2025
- Low-carbon fuels for conventional engines and exploration of alternative propulsion systems

2025-2035
- Initial introduction of alternative propulsion systems

2035+
- Introduction of alternative propulsion systems for aircraft of all sizes
**NASA Perspective on Electrified Aircraft Propulsion**

*Explore alternative propulsion systems that can reduce carbon, noise, and emissions from commercial aviation*

Cleaner, quieter systems  
Potential for vehicle system efficiency gains (use less energy)  
Leverage advances in other transportation and energy sectors  
Address aviation-unique challenges (e.g. weight, altitude)  
Recognize potential for early learning and impact on smaller or shorter range aircraft

**Address Key Challenges**

- Electrical system weight  
- Energy storage capabilities  
- Thermal management  
- Flight controls  
- Safety  
- Certification

Laying the foundation for a future of sustainable aviation through wind tunnel testing of aircraft and engines and a renewed emphasis on flight testing

Green Aviation investments in
- Alternative Fuels
- New Configurations
- Emissions and Noise Reductions

Potential X-Planes
- Truss-braced wing
- Over-the-Wing Nacelle
- Boundary Layer Ingestion
- Blended Wing Body
- Turbo- and Hybrid-Electric Propulsion

First Demonstrators
- Maxwell X-57
- QuESST
NASA New Aviation Horizons Flight Demo Plan

“Purpose-Built” Ultra-Efficient Subsonic Transport (UEST) Demonstrators

- Hybrid Electric Propulsion (HEP) Demonstrators
  - Transport Scale
  - Ground Test Risk Reduction
  - Preliminary Design
  - Design & Build
  - Flight Test

- “Small Scale “Build, Fly, Learn”
  - Ground Test Risk Reduction
  - Preliminary Design
  - Design & Build
  - Flight Test

- Fully integrated UEST Demonstrator
  - Preliminary Design
  - Design & Build
  - Flight Test

- Life Cycle Cost Est: $430M

Validated ability for U.S. industry to build transformative aircraft that use 50% less energy and contain noise within the airport boundary.

Validated HEP concepts, technologies and integration for U.S. industry to lead the Clean Propulsion Revolution.

Enable Low Boom Regulatory Standard and validated ability for industry to produce and operate commercial low-noise supersonic aircraft.
Electrified Aircraft Design Space

• Electric, hybrid-electric, and turboelectric propulsion offers many new degrees of freedom

• Point designs help explore the potential

• Mission profiling, airport infrastructure, and nontraditional airspace operations additional considerations
NASA N3-X (Fully Turboelectric/Distributed/BLI)

Baseline is B777-200LR/GE90-115B

Wing-tip mounted superconducting turbogenerators

Power distributed electrically from turbine-driven generators to superconducting motors driving electric fans in a continuous nacelle

Fuel burn benefits relative to 2000 baseline
• 70% / 72% with cryocooler / LH2 (relative to 2000 technology baseline)
• 18% / 20% with cryocooler / LH2 (relative to N+3 HWB with UHB turbofans)

N3-X w/ MgB2 + LH2
Passengers: 300
Range: 7500 nm
Cruise Speed: Mach 0.84
Generators: 2x30 MW
Motors: 14x4.3 MW

**Boeing SUGAR Volt (Parallel Hybrid)**

750 Wh/kg battery energy density assumed

1.3 MW reduces fuel consumption to meet NASA N+3 goal at the same energy consumption as SUGAR High

5.3 MW reduces fuel consumption further at the price of increased energy consumption compared to SUGAR High

TRL of 4-6 possible by 2025

Ref: Boeing N+3 Subsonic Ultra Green Aircraft Research (SUGAR) Final Report
Parallel Hybrids with Expanded Mission Optimization

Parallel hybrids (podded configurations) may allow fleet retro-fit or earlier entry into service

Three independent studies show interesting results

• Boeing SUGAR VOLT concept with hybrid propulsion during cruise
• UTRC concept with hybrid propulsion during take-off and climb
• Rolls-Royce (RR) concept using fleet-optimized hybrid architecture

Each study made independent assumptions for future baseline vehicle to identify benefits resulting from hybridization

• 6-24% fuel burn savings for 900 nm mission
• 0% energy savings for Boeing; 2.5-7% energy savings for UTRC and RR concepts
• 6-24% emissions reductions also achievable
• Noise benefits low for Boeing and UTRC concepts (same fan, smaller core); moderate for RR concept (smaller fan and core)

Important Note: These studies were performed with very different assumptions. Result comparisons are provided for reference only.
Fuel burn and CO2 reductions without improvements in battery technology

- 154 PAX, M=0.7 Concept
- Downsized engines provide 80% of takeoff and 55% of cruise thrust
- Electrically power aft propulsor provides 20% of takeoff and 45% of cruise thrust
- 2x1.4 MW Generators, 2.6 MW Motor
- Configuration meets speed and range requirement of baseline aircraft
- Uses existing airport infrastructure
- 7-12% fuel (and energy) savings relative to baseline advanced technology aircraft for 900-3500 nm mission

Electrical Machine Specific Power and Efficiency Sensitivities

Motor sensitivity analysis by J. Felder
ESAero ECO-150—Fully Turboelectric / Distributed

150 PAX, M=0.8, 3500 nm range, concept

"Split-wing" turboelectric system with 2 turbogenerators and 16 motor driven fans embedded in wing

Initial studies considered superconducting motors and generators

Recent studies focused on conventional (ambient temp) non-superconducting systems

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>CO2 Reduction from Current Baseline</th>
<th>TRL 4-6</th>
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<tbody>
<tr>
<td>ECO-150</td>
<td>44%</td>
<td>2020</td>
</tr>
<tr>
<td>STARC-ABL</td>
<td>59%</td>
<td>2025</td>
</tr>
<tr>
<td>SUGAR Volt</td>
<td>59%</td>
<td>2025</td>
</tr>
<tr>
<td>SUGAR Freeze</td>
<td>68%</td>
<td>2030</td>
</tr>
<tr>
<td>N3-X (Twin-Aisle)</td>
<td>70%-75%</td>
<td>2030</td>
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</table>
Technology development targeted toward large commercial aircraft

- Propulsion System Conceptual Design
- High Efficiency/Specific Power Electric Machines
- Flight-weight Power Systems and Electronics
- Integrated Flight Simulations and Testing
- Enabling Materials for Machines and Electronics
- Turbine/Generator Integration and Controls

Powertrain, Controls and Flight Simulation Testbeds and Advanced CFD

Exploring tube-and-wing architectures

Advanced Materials and Novel Designs for Flightweight Power

Superconducting and Ambient Motor Designs
Enable increasingly electrified aircraft propulsion systems with minimal change to aircraft outer mold lines

Explore and demonstrate vehicle integration synergies enabled by electrified aircraft propulsion

Gain experience through integration and demonstration on progressively larger platforms

Knowledge through Integration & Demonstration

Environmental Benefit

Modeling
Architecture Exploration
Test Beds
Component Improvements

Work toward full PAI and HEP

Certify, Operate

Build, learn, demonstrate

Single Aisle Transport

Small Aircraft