NASA Aeronautics Vision for Aviation in the 21st Century

U.S. leadership for a new era of flight
Global Growth in Aviation

Tremendous opportunities
• Huge demand
• $5.9T market over next 20 years
• Need for speed

But stakes are high
• Competitiveness
• Environment
• Mobility
• Safety

Over 39,000 New Aircraft required (replacement and growth) over the next 20 year period ($5.9T)

Growth in Airline passenger traffic at annual rate of 4.8%, and Air Cargo traffic at 4.2% over the next 20 years
The Aviation Grand Challenge: Cutting Carbon

- Improve fleet fuel efficiency by 1.5% per year from now until 2020
- Beginning in 2020, cap net emissions through carbon-neutral growth
- By 2050, net aviation carbon emissions will be half what they were in 2025.

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

Promise of 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
aircraft

Address Key Challenges
Electrical system weight
Energy storage capabilities
Thermal management
Flight controls
Safety
Certification
Four Cardinal Electric Propulsion Architectures

**All Electric**
- Battery
- Motor(s)
- Electric Bus
- 1 to Many Fans

**Turboelectric**
- Turboshaft
- Electric Bus
- Generator
- Motor
- Distributed Fans

**Parallel Hybrid**
- Electric Bus
- Turbofan
- Motor
- Battery
- Fan

**Series Hybrid**
- Turboshaft
- Electric Bus
- Generator
- Distributed Fans
- Battery
- Motor
- Fuel
Electrified Propulsion Enables Exciting Configuration Options

**Boundary Layer Ingestion:** Allows propulsion systems to energize boundary layers without distorted flow entering turbine core

**Wing Tip Propulsors:** Allows energization of wing tip vortices without penalty of small turbomachinery

**Distributed Propulsion:** Allows effective increase in fan bypass ratio through distributed propulsors

**Common Technology Requirement:** Increased efficiency and specific power in electric drive systems, thermal management systems, power extraction, and/or energy storage

**Lower Carbon Designs:** Reduces combustion-based propulsive power (and emissions) using electric motors and/or on-board “clean” energy storage
Potential Future Aircraft Concepts

Boeing Sugar Volt

ESAero ECO-150

NASA N3X

NASA STARC-ABL

Airbus/Rolls-Royce eThrust
Timeline of Machine Power with Application to Aircraft Class

<table>
<thead>
<tr>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
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<tbody>
<tr>
<td><strong>Non-cryogenic</strong></td>
<td>100 kW</td>
<td></td>
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<tr>
<td><strong>Largest Electrical Machine on Aircraft</strong></td>
<td>1 MW</td>
<td>3 MW</td>
<td>10 MW</td>
<td>30 MW Superconducting</td>
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<tr>
<td>9 Seat</td>
<td>0.5 MW Total Propulsive Power</td>
<td>50-250 kW Electric Machines</td>
<td>1 MW Electric Machines identified as a key initial research focus</td>
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<tr>
<td>19 Seat</td>
<td>2 MW Total Propulsive Power</td>
<td>1-1 MW Electric Machines</td>
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<td></td>
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<tr>
<td>50 Seat Turboprop</td>
<td>3 MW Total Propulsive Power</td>
<td>0.3-6 MW Electric Machines</td>
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</tr>
<tr>
<td>50 Seat Jet</td>
<td>12 MW Total Propulsive Power</td>
<td>0.3-6 MW Electric Machines</td>
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<tr>
<td>150 Seat</td>
<td>22 MW Total Propulsive Power</td>
<td>1-11 MW Electric Machines</td>
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<tr>
<td>300 Seat</td>
<td>60 MW Total Propulsive Power</td>
<td>3-30 MW Electric Machines</td>
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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
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
High Efficiency, High Specific Power Electric Machines

- Develop both conventional (near-term) and cryogenic, superconducting (long-term) motors
- Design and test scalable high efficiency and power density (96%, 8 hp/lb) 1 MW non-cryogenic motor for aircraft propulsion in collaboration with
  - Ohio State U
  - U of Illinois, UTRC, Automated Dynamics
- Reduce AC losses and enable thermal management for SC machines: models and measurement techniques, SC wires, flight-weight cryo-coolers
- Design and test fully superconducting electric machine test at 1 MW design level in FY17-18
  - Collaboration with Navy, Air Force, Creare, HyperTech, Advanced Magnet Lab, U of FL
  - Detailed concept design completed of 12MW fully superconducting machine achieving 25 hp/lb
- Develop materials and manufacturing technologies
Flight-Weight Power Management and Electronics

- Multi-KV, Multi-MW power system architecture for aircraft applications
- Power management, distribution and control at MW and subscale (kW) levels
- Integrated thermal management and motor control schemes
- Flightweight conductors, advanced magnetic materials, and insulators
- Collaborations with GE Global Research, Boeing, U of Illinois on flight-weight 1 MW inverters

Superconducting transmission line

Lightweight power transmission

Integrated motor with high power density power electronics

Lightweight Cryocooler

Distributed propulsion control and power systems architectures

Lightweight power electronics

National Aeronautics and Space Administration
Integrated System Testing

- Study steady-state and transient component operation and interactions
- Validate power system benefit predictions
- Develop flight control methodology for distributed propulsion
- Integrate power, controls, and thermal management into system testing

**Software/Hardware emulation**

**hardware-in-the-loop electrical grid**

**Flight Simulator – Flight Dynamics**

**NEAT 2MW Configurable Power Testbed**

**HEIST 200kW Ironbird Flight Simulation Hardware in the Loop**
Other Related NASA HEP R&T Investments

• Scalable Convergent Electric Propulsion Technology Operations Research (SCEPTOR)
• Multifunctional Structures for High Energy Lightweight Load-Bearing Storage (M-SHELLS)
• High Voltage Hybrid Electric Propulsion
• Heavy Fuel Hybrid-Electric SOFC for Airborne Applications
The Path Forward…

- Focus on future single-aisle twin engine and large regional jets
- Viable concepts with net reduction in energy use
- Core technology development: turbine-coupled motors, generators, power system architectures, power electronics, thermal management, flight controls
- Modeling/Simulation tools for propulsion, vehicle, electrical, and flight control systems
- Technology demonstrations of components, subsystems, and systems

Exciting times ahead!
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