Green Propulsion Technologies for Advanced Air Transports

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Green Propulsion Technologies for Advanced Air Transports

- Importance of aviation in the global economy
- NASA Aeronautics and subsonic transport research
- Why hybrid-electric propulsion?
- Enabling hybrid-electric propulsion for commercial transport aircraft – A NASA perspective
- NASA technologies for hybrid-electric propulsion
- Looking toward the future
We have come a long ways, but we can go much further...
Remembering the Past
What do emerging global trends reveal?

New realities challenge traditional approaches to strategic planning.

China and India are growing economically at unprecedented rates.

Asia-Pacific will have the largest middle class.

Source: National Intelligence Council
What do emerging global trends reveal?
New realities challenge traditional approaches to strategic planning.

The world will be predominantly urban

Revolutionary technology development and adoption are accelerating

Source: National Intelligence Council
Why are these trends important?

- They drive global demand for air travel…
- They drive expanding competition for high-tech manufacturing…
- They drive “leapfrog” adoption of new technology and infrastructure…
- They drive resource use, costs, constraints, and impacts…
- They drive the need for alternative energy technologies…
Three mega-drivers emerge:

1. Traditional measures of global demand for mobility—economic development and urbanization—are growing rapidly.
2. Technology convergence—revolutions in automation, information and communication technologies enable enormous affordability and safety-critical autonomous systems.
3. Severe energy and climate issues create sustainability challenges.

**Emissions reduction roadmap**

- "Frozen technology" emissions
- Known technology, operations and infrastructure measures
- Biofuels and additional technology
- Carbon-neutral growth 2020
- Gross emissions trajectory
- Economic measures

**Scenarios:**

- **No action**
- CNG 2020

*CO2 emissions over time (schematic)*

- 2005
- 2010
- 2020
- 2030
- 2040
- 2050

*50% by 2050*
NASA Aeronautics Vision for the 21st Century

TRANSFORMATIVE

On Demand

SUSTAINABLE

Fast

Intelligent

Low Carbon

GLOBAL

Safety, NextGen

Efficiency, Environment

A revolution in sustainable global air mobility
NASA Is Responding With Its Aeronautics Mission

NASA Aeronautics focuses on six strategic R&T 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
NASA Aeronautics Programs

- Advanced Air Vehicles Program
- Integrated Aviation Systems Program
- Airspace Operations and Safety Program
- Transformative Aeronautics Concept Program
Advanced Air Vehicles Program

Cutting-edge research that will generate innovative concepts, technologies, capabilities & knowledge to enable revolutionary advances for a wide range of air vehicles

**Advanced Air Transport Technology Project (AATT)**
Conducts fundamental research to improve aircraft performance and minimize environmental impacts from subsonic air vehicles.

**Revolutionary Vertical Lift Technology Project (RVLT)**
Develops and validates tools, technologies & concepts to overcome key barriers, including noise, efficiency, & safety for vertical lift vehicles.

**Advanced Composites Project (ACP)**
Conducts research to reduce the timeline for certification of composite structures for aviation.

**Commercial Supersonics Technology Project (CST)**
Explores theoretical research for potential advanced capabilities & configurations for low boom supersonic aircraft.

**Aeronautical Evaluation & Test Capabilities Project (AETC)**
Ensures the strategic availability, accessibility, & capability of a critical suite of aeronautics ground test facilities to meet Agency & national aeronautics testing needs.
Advanced Air Transport Technology Project

Explore and Develop Technologies and Concepts for Improved Energy Efficiency and Environmental Compatibility for Fixed Wing Subsonic Transports

Vision
" Early-stage exploration and initial development of game-changing technology and concepts for fixed wing vehicles and propulsion systems

Scope
" Subsonic commercial transport vehicles (passengers, cargo, dual-use military)
" Technologies and concepts to improve vehicle and propulsion system energy efficiency and environmental compatibility without adversely impacting safety
" Development of tools as enablers for specific technologies and concepts

Evolution of Subsonic Transports

1903 1930s 1950s 2000s

1903  DC-3  B-707  B-787
### NASA Subsonic Transport System-Level Metrics

#### Strategic Thrusts

1. **Energy Efficiency**
2. **Environmental Compatibility**

#### Technology Benefits

<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS*</th>
<th>TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)</th>
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<tbody>
<tr>
<td>Noise (cum margin rel. to Stage 4)</td>
<td>-32 dB</td>
</tr>
<tr>
<td>LTO NOx Emissions (rel. to CAEP 6)</td>
<td>-60%</td>
</tr>
<tr>
<td>Cruise NOx Emissions (rel. to 2005 best in class)</td>
<td>-55%</td>
</tr>
<tr>
<td>Aircraft Fuel/Energy Consumption† (rel. to 2005 best in class)</td>
<td>-33%</td>
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* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines
** ERA’s time-phased approach includes advancing “long-pole” technologies to TRL 6 by 2015
† CO2 emission benefits dependent on life-cycle CO2e per MJ for fuel and/or energy source used

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Research addressing revolutionary far-term goals with opportunities for near-term impact
Trends:
• Tailored/multifunctional structures
• High aspect ratio/laminar/active structural control
• Highly integrated propulsion systems
• Ultra-high bypass ratio (20+ with small cores)
• Alternative fuels and emerging hybrid electric concepts
• Noise reduction by component, configuration, and operations improvements

Advances required on multiple fronts…
## AATT Project Research Themes

<table>
<thead>
<tr>
<th>Goals</th>
<th>Noise</th>
<th>Emissions (LTO)</th>
<th>Emissions (cruise)</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metrics (N+3)</td>
<td>Stage 4 – 52 dB cum</td>
<td>CAEP6 – 80%</td>
<td>2005 best – 80%</td>
<td>2005 best – 60%</td>
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<tr>
<td><strong>Goal-Driven Advanced Concepts (N+3)</strong></td>
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<tr>
<td><strong>Concepts (N+3)</strong></td>
<td>Lighter Weight Fuselage and Wings</td>
<td>Noise Reduction Technologies</td>
<td>Hybrid Gas Electric Propulsion</td>
<td>Alternative Fuels Characterization</td>
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<tr>
<td></td>
<td>Compact Higher Bypass Propulsion</td>
<td>Propulsion Airframe Integration</td>
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Electric Propulsion for Large Commercial Aircraft

• Why electric?
  – Fewer emissions (cleaner skies)
  – Less atmospheric heat release (less global warming)
  – Quieter flight (community and passenger comfort)
  – Better energy conservation (less dependence on fossil fuels)
  – More reliable systems (more efficiency and fewer delays)

• Considerable success in development of “all-electric” light GA aircraft and UAVs

• Creative ideas and technology advances needed to exploit full potential

• NASA can help accelerate key technologies in collaboration with OGAs, industry, and academia
Aircraft Hybrid-Electric Propulsion

Projected Timeframe for Achieving Technology Readiness Level (TRL) 6

Technologies benefit more electric and all-electric aircraft architectures:
- High-power density electric motors replacing hydraulic actuation
- Electrical component and transmission system weight reduction

Power Level for Electrical Propulsion

- kW class
  - All-electric and hybrid-electric general aviation (limited range)

- 1 to 2 MW class
  - Hybrid electric 50 PAX regional
  - Turboelectric distributed propulsion 100 PAX regional
  - All-electric, full-range general aviation

- 2 to 5 MW class
  - Hybrid electric 100 PAX regional
  - Turboelectric distributed propulsion 150 PAX
  - All electric 50 PAX regional (500 mile range)

- 5 to 10 MW
  - Hybrid electric 150 PAX
  - Turboelectric 150 PAX

- >10 MW
  - Turbo/hybrid electric distributed propulsion 300 PAX

Timeline:
- Today
- 10 Year
- 20 Year
- 30 Year
- 40 Year
Both concepts can use either non-cryogenic motors or cryogenic superconducting motors.
Estimated Benefits From Systems Studies

**SUGAR** (baseline Boeing 737–800)
- ~60% fuel burn reduction
- ~53% energy use reduction
- 77 to 87% reduction in NOx
- 24-31 EPNdB cum noise reduction

**N3–X** (baseline Boeing 777–200)
- ~63% energy use reduction
- ~90% NOx reduction
- 32-64 EPNdB cum noise reduction

**LEAPTech Wing Technology for GA** (baseline Cirrus)
- 5 to 9x lower energy use/cost and emission
- 25 dB lower community noise
- Propulsion redundancy, improved ride quality, and control robustness
Technologies for Hybrid-Electric Aircraft
Highly Efficient Gas Generators

- 1500 °F capable disks, coatings, and non-contacting seals
- 2700 °F capable CMC turbine blades
- Low NOx fuel-flexible combustion
- Characterization of alternative fuels emissions
- Minimize losses due to large tip and hub seal cavity gaps of small size core
- Minimize cooling/leakage losses
- Assess system benefits and evaluate “smaller core” technology concepts for high-speed compressor demonstration

Smaller Core Size Research

Compressor exit corrected flow $W \sqrt{q/d}$

6.0 lbm/s vs. 2.0 lbm/s core size

Low NOx, fuel flexible combustor

Tip/endwall aerodynamic loss mitigation

1500 F, bonded hybrid disk concept

Technologies for Hybrid-Electric Aircraft
Flight-weight Power Management and Electronics

- Multi-KV multi-MW aircraft propulsion power system architectures and associated control systems
- Power management, distribution and control at MW and subscale (kW) levels
- Integrated thermal management and motor control schemes
- Enabling materials and manufacturing technologies

- 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
High-Power Density Electrical Motors

- Cryogenic, superconducting motors for long term
- Normal conductor motors for near and intermediate term
- High power to weight ratio is enabling
- Materials and manufacturing technologies advances required
- Design and test 1-MW noncryogenic electric motor starting in FY2015

Normal conductor 1-MW rim-driven motor/fan
Technologies for Hybrid-Electric Aircraft
Understanding Boundary Layer Ingesting Systems

- Assess net system-level benefits of propulsion-airframe integration concepts relative to podded engines.
- Measure boundary layer ingestion benefits of integrated propulsion airframe configuration relative to podded engine.
- Design highly coupled inlet/fan tolerant to continuous operation in distorted inflow.
- Test performance of highly coupled inlet/fan design required to achieve net system level benefits.

Distortion tolerance required for net vehicle system benefit

Reduced velocity in the boundary layer reduces inlet diffusion drag, but highly distorts inlet flow
Efficient, Low Noise Propulsor Systems

- Conceive and explore advanced propulsor architectures and technologies that alter the trajectory of noise and fuel burn trends for fans and open rotors to achieve future performance targets.

- Enhance analysis capabilities and acquire verification data to model nontraditional propulsion technologies and configurations.

- Maintain experimental facilities and capability to allow cutting-edge exploration of unique fan and open rotor system performance and associated physics.
Enabling System Testing and Validation

- Develop MW-class power system testbed and modeling capability
- Demonstrate technology at appropriate scale for best research value
- Identify system-level issues early
- Integrate power, controls, and thermal management into system testing
- Develop validated tools and data that industry and future government projects can use for further development

Integrated thermal management system

- GTE
- Rectifier
- Engine controls
- Gen. controls
- Electrical distribution
- Research Testbed
- Energy storage
- VF motor/inverter
- Motor controls
- Load simulator
- FD&C simulator
- Integrated controls

Propulsion Electric Grid Simulator—hardware-in-the-loop electrical grid

Fully cryogenic motor testing Glenn/SMIRF

Eventual flight simulation testing at NASA Armstrong Flight Research Center
Integrated Vehicles and Concept Evaluations

- Determine design requirements and trade space for hybrid electric propulsion vehicles
- Identify near-term technologies that can benefit aircraft non-propulsive electric power
- Enhance analysis capabilities to model non-traditional vehicle configurations with HE systems
- Establish vehicle conceptual designs that span power requirements from GA (<1 MW) to regional jets (1-2 MW) to single-aisle transports (5-10 MW)
Looking to the Future...

- Exciting challenges for an industry that was deemed “mature”
- Conceptual designs and trade studies for electric-based concepts
- Tech development and demonstration for N+3 MW class aircraft
- Development of core technologies - turbine coupled motors, propulsion systems modeling, power architecture, power electronics, thermal management, and flight controls
- Multiplatform technology testbeds
- Development of multi-scale modeling and simulations tools
- Focus on future large regional jets and single aisle twin-engine aircraft for greatest impact