Propulsion Technologies for Future Commercial Aircraft

Gregory J. Follen
Deputy Director, Aeronautics Research Office
NASA Glenn Research Center
Outline of Talk

- Introduction
- Future Challenges for Commercial Aviation
- NASA Aeronautics Research and Subsonic Transport Metrics
- Future Propulsion Technologies
  - NASA ERA Advance Vehicles Concepts (N+2)
  - NASA Fixed Wing Gen N+3 Advanced Vehicle Concept Studies
  - Towards Electric Propulsion
- Summary
NASA Aeronautics Programs

Fundamental Aeronautics Program
Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to enable revolutionary changes for vehicles that fly in all speed regimes.

Aviation Safety Program
Conduct cutting-edge research that will produce innovative concepts, tools, and technologies to improve the intrinsic safety attributes of current and future aircraft.

Airspace Systems Program
Directly address the fundamental ATM research needs for NextGen by developing revolutionary concepts, capabilities, and technologies that will enable significant increases in the capacity, efficiency and flexibility of the NAS.

Aeronautics Test Program
Preserve and promote the testing capabilities of one of the United States’ largest, most versatile and comprehensive set of flight and ground-based research facilities.
Major Challenges for Commercial Aviation

By 2050, substantially reduce emissions of carbon and oxides of nitrogen and contain objectionable noise within the airport boundary.

Carbon neutral growth
Baseline reduced by 50%
Carbon overlap
Baseline

Forecasted Carbon Emissions Growth (Without improvements)

Technology Development—Ongoing Fleet Renewal
Operational Improvements—ATC/NextGen/
Additional Technology Advancement and Low Carbon Fuels

Source: IATA, 2010
NASA Subsonic Transport System Level Metrics

Strategic Thrusts

1. Energy Efficiency
2. Environmental Compatibility

<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS</th>
<th>TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)</th>
</tr>
</thead>
<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>
</tr>
</tbody>
</table>

* 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 CO2eq per MJ for fuel and/or energy source used.

Research addressing revolutionary future goals with opportunities for near term impact.
The Fixed Wing Project conducts research to improve prediction methods and technologies that will produce lower noise, lower emissions, and higher performing subsonic aircraft for the Next Generation Air Transportation System.

The Integrated Systems Research Program (ISRP) focuses on maturing and integrating NextGen technologies into major vehicle/operational systems and subsystems that will address these national challenges.
Program Goal:
Pursue innovative solutions to high priority aeronautical needs and accelerate implementation by the aviation community through integrated system level research on promising concepts and technologies, demonstrated in a relevant environment.

Environmentally Responsible Aviation (ERA) Project
Mature technologies and study vehicle concepts that together can simultaneously meet the NASA Subsonic Transport System Level Metrics for noise, emissions and fuel burn in the N+2 timeframe.

Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project
Capitalizing on NASA’s unique capabilities, the project will utilize integrated system level tests in a relevant environment to eliminate or reduce critical technical barriers of integrating Unmanned Aircraft Systems into the National Airspace System

By focusing on technologies that have already proven their merit at the fundamental research level, this program helps transition them more quickly to the aviation community, as well as inform future fundamental research needs.
Traceability from National R&D Plan to ERA Project Technical Challenges

<table>
<thead>
<tr>
<th>National R&amp;D Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and Environment</td>
</tr>
<tr>
<td>Enhance Mobility</td>
</tr>
<tr>
<td>National Security</td>
</tr>
</tbody>
</table>

**Lead** development of vehicle concepts that enable simultaneous reduction of fuel burn, noise and emissions

- **-75% LTO & -70% Cruise NOx Emissions below CAEP6**
- **-42dB below Stage 4 Community Noise**
- **-50% Aircraft Fuel/ Energy Consumption**

**Technical Focus Areas**

*Accelerate* technology maturation through integrated system research

ERA Phase I Investigations
Reduce Mission Fuel Burn and Community Noise

**DRAG REDUCTION - Via Laminar Flow**

**SFC/NOISE REDUCTION**
Advanced Cores and Development of Integration of Advanced UHB Engines

**WEIGHT REDUCTION**
PRSEUS – Pultruded Rod Stitched Efficient Unitized Structure

ERA Phase I Investigations
Reduce LTO and Cruise NOX

**CMC COMBUSTOR LINER**
For higher engine temps

**INSTABILITY CONTROL**
Suppress combustor instabilities

**LOW NOX, FUEL**
FLEXIBLE DESIGN/TEST

ERA Phase I Investigations
Reduce Mission Fuel Burn and Community Noise

**AIRFRAME NOISE**
High-lift Systems and Landing Gear

**PROPULSION NOISE**
Fan, Core and Jet Noise

**AIRFRAME AEROACUSTICS**
Airframe/Propulsion Interaction & Shielding
Environmentally Responsible Aviation
Advanced Vehicle Concepts

• Task 1 - Define / Development Future Scenario
• Task 2 - Develop a conceptual design of a 2025 EIS subsonic transport – passenger and/or cargo
• Task 3 - Develop associated tech maturation plans
• Task 4 - FY 2013 – 2015 Critical Technology Demonstrations
• Task 5 - Conceptual Design of a Subscale Testbed Vehicle
The NASA Fixed Wing Project

Explore and Develop Tools, Technologies, and Concepts for Improved Energy Efficiency and Environmental Compatibility for Sustained Growth of Commercial Aviation

Objectives
- Prediction and analysis tools for reduced uncertainty
- Concepts and technologies for dramatic improvements in noise, emissions and performance

Relevance
- Address daunting energy and environmental challenges for aviation
- Enable growth in mobility/aviation/transportation
- Subsonic air transportation vital to our economy and quality of life

Evolution of Subsonic Transports

1903 1930s 1950s 2000s
Fixed Wing Project Research Themes
based on Goal-Driven Advanced Concept Studies

<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 – 71 dB cum</td>
<td>CAEP6 – 80%</td>
<td>2005 best – 80%</td>
<td>2005 best – 60%</td>
</tr>
<tr>
<td>Goal-Driven Advanced Concepts</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N+3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Research Themes                |               |                 |                    |                    |
| Unconventional Propulsion      | Lighter-weight Lower Drag Fuselage | Higher Aspect Ratio Optimal Wing | Quieter Low-Speed Performance | Cleaner, Compact Higher BPR Propulsion |
| Airframe Integration           |               |                 |                    |                    |
| Alternative Fuel Emissions     | SX/PX Rim 1500F PM Bore 1300F |                    | Systems Analysis and Integration | Hybrid Gas-Electric Propulsion |
| Systems Analysis and Integration |           |                 |                    |                    |
| Systems Analysis and Integration |           |                 |                    |                    |
Gen N+3 Propulsion Technologies
NASA Gen N+3 Advanced Vehicle Concept Studies

Summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 EIS

Boeing, GE, GA Tech

NG, RR, Tufts, Sensis, Spirit

GE, Cessna, GA Tech

MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT

Trends:
- Tailored/Multifunctional Structures
- High AR/Active Structural Control
- Highly Integrated Propulsion Systems
- Ultra-high BPR (20+ w/ small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements

Advances required on multiple fronts…
Northrop Grumman/Rolls Royce SELECT

Three-Shaft Turbofan
- High BPR (~18) = propulsive efficiency
- High OPR (~50) = thermal efficiency
  - Low noise
  - Low weight

Technology Suite
- Three-shaft Turbofan Engine
- Ultra-High Bypass Ratio of ~18
- CMC Turbine Blades
- Lean-Burn CMC Combustor
- Intercooled Compressor Stages
- Swept Fan Outlet Guide Vanes
- Fan Blade Sweep Design
- Lightweight Fan/Fan Cowl
- Compressor Flow Control
- Active Compressor Clearance Control
- Variable Geometry Nozzles

- Open rotor had best sea level static fuel consumption
- Open rotor potential noise not quantified in time to be included

NASA-CR-2010-216798
MIT/Pratt & Whitney D Series

Novel configuration plus suite of airframe and propulsion technologies, and operations modifications

- Reduced Secondary Structure weight
- Active Load Alleviation
- Natural Laminar Flow on Wing Bottom
- Health and Usage Monitoring
- Lifting Body
- Advanced Structural Materials
- Faired Undercarriage
- High Bypass Ratio Engines (BPR 20) with High-Efficiency Small Cores
- Boundary Layer Ingestion
- Distortion Tolerant Fans
- Tt4 Materials and advanced cooling
- Variable Area Nozzle
- LDI Advanced Combustor
- Advanced Engine Materials

NASA-CR-2010-216794 Vol. 1 & 2
Boeing/General Electric SUGAR “Volt”

Subsonic Ultra Green Aircraft Research (SUGAR)

High Aspect Ratio Truss Braced Wing

Hybrid Electric (Batteries) Propulsion Systems
Propulsors ingest boundary layer & fill center-body wake.

Low velocity core exhaust reduces noise.

Forward and aft fan noise shielding by airframe.

Electric power from generators distributed to multiple motor-driven propulsors.

Many small fans give a large total fan area and very high effective bypass ratio.

Large efficient engines with freestream inlets drive superconducting generators.
Toward Large Electric Aircraft Propulsion

• Hybrid-electric and turboelectric aircraft offer cleaner skies and fuel savings
• Hybrid electrics use battery power for short-range cruise, fuel and turbine engine for long-range
• Battery-powered cruise emits little or no CO₂ and water vapor on short flights (Boeing SUGAR Volt study)
• Turboelectric distributed propulsion offers up to 20% fuel savings on Blended Wing Body aircraft
• Distributed and/or more-electric propulsion critical to meeting NASA N+3 fuel burn, noise, and emissions metrics
Summary

- NASA’s ARMD research Portfolio includes System Level technologies targeted at the N+2 timeframe and Fundamental Research targeted at the N+3 timeframe.

<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS*</th>
<th>TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)</th>
</tr>
</thead>
<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>
</tr>
</tbody>
</table>

* 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 dependant on life-cycle CO₂/MJ for fuel and/or energy source used

ERA Technical Focus Areas:
- Innovative Flow Control Concepts for Drag reduction
- Advanced Composites for Weight reduction
- Advanced UHB Engine Designs for Specific Fuel Consumption and Noise reduction
- Advanced Combustor Designs for Oxides of Nitrogen Reduction
- Airframe and Engine Integration Concepts for Community Noise and Fuel Burn Reduction

FAP/Fixed Wing

- Tailored/Multifunctional Structures
- High AR/Active Structural Control
- Highly Integrated Propulsion Systems
- Ultra-high BPR (20+ w/ small cores)
- Alternative fuels and emerging hybrid electric concepts
- Noise reduction by component, configuration, and operations improvements