Propulsion Technologies for Future Commercial Aircraft

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

Canada-Ohio Aerospace Summit 2013
February 25-26, 2013
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.

**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.

**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.

**Integrated Systems Research Program**
Conduct research at an integrated system-level on promising concepts and technologies and explore/assess/demonstrate the benefits in a relevant environment.
Major Challenges for Commercial Aviation

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

Source: IATA, 2010
### 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>
</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 CO₂ 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.
Integrated Systems Research Program Overview

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>
<th>Enhance Mobility</th>
<th>National Security</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy and Environment</td>
<td></td>
<td></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 1 Investigations

**ERA Phase I Investigations**
Reduce Mission Fuel Burn and Community Noise

- **TFA1** DRAG REDUCTION - Via Laminar Flow
- **TFA2** WEIGHT REDUCTION
  - PRSEUS – Pultruded Rod Stitched Efficient Unitized Structure
- **TFA3** SFC/NOISE REDUCTION
  - Advanced Cores and Development of Integration of Advanced UHB Engines

**ERA Phase I Investigations**
Reduce LTO and Cruise NOX

- **TFA4** CMC COMBUSTOR LINER
  - For higher engine temps
  - SIC CMC Concepts
  - CMC combustor liner
- **TFA5** INSTABILITY CONTROL
  - Suppress combustor instabilities
  - High Temperature SiC electronics circuits and dynamic pressure sensors
  - Fuel Modulation for high frequency fuel delivery systems

**ERA Phase I Investigations**
Reduce Mission Fuel Burn and Community Noise

- **TFA5** AIRFRAME NOISE
  - High-lift Systems and Landing Gear
- **TFA5** PROPULSION NOISE
  - Fan, Core and Jet Noise
- **TFA5** PROPULSION AIRFRAME AEROCUSTICS
  - Airframe/Propulsion Interaction & Shielding

**ERA Phase I Investigations**
Reduce LTO and Cruise NOX

- **TFA4** LOW NOX, FUEL FLEXIBLE DESIGN/TEST
  - Innovative Injector Concept
  - ASCR Combustion Rig
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 - DC-3 - B-707 - B-787 - 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>
</tbody>
</table>

**Goal-Driven Advanced Concepts**

<table>
<thead>
<tr>
<th>(N+3)</th>
</tr>
</thead>
</table>

**Lighter-weight**
- Lower Drag
- Fuselage

**Higher Aspect Ratio Optimal Wing**

**Quieter Low-Speed Performance**

**Cleaner, Compact Higher BPR Propulsion**

**Hybrid Gas-Electric Propulsion**

**Unconventional Propulsion Airframe Integration**

**Alternative Fuel Emissions**

**Research Themes**

**Cleaner, Compact Higher BPR Propulsion**

**Systems Analysis and Integration**
Gen N+3 Propulsion Technologies
Boeing, GE, GA Tech

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

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

MIT, Aurora, P&W, Aerodyne

NASA, VA Tech, GT

NASA Gen N+3 Advanced Vehicle Concept Studies
Summary

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
MIT/Pratt & Whitney D Series

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

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

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

Forward and aft fan noise shielding by airframe.

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

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.

FAP/Fixed Wing

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

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