Propulsion Technologies for Future Commercial Aircraft

Dr. Rubén Del Rosario
Project Manager
Subsonic Fixed Wing Project
NASA Fundamental Aeronautics Program

Panel Discussion on Challenges for Future Commercial Aircraft Propulsion
48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit
Atlanta, GA
July 30- August 1, 2012

www.nasa.gov
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 Gen N+3 Advanced Vehicle Concept Studies
  - Towards Electric Propulsion

Concluding Remarks
Major Challenges for Commercial Aviation

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

- Baseline reduced by 50%
- Low Carbon Fuels
- Operational Improvements—ATC/NextGen/
- Additional Technology Advancement
- Technology Development—Ongoing Fleet Renewal

Source: IATA, 2010
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.

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.

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.
Traceability from National R&D Plan to ERA Project Technical Challenges

**National R&D Plan**

| Energy and Environment | Enhance Mobility | National Security |

**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

**Reduce Mission Fuel Burn and Community Noise**

**TFA1** DRAG REDUCTION - Via Laminar Flow

**TFA3** SFC/NOISE REDUCTION
- Advanced Cores and Development of Integration of Advanced UHB Engines

**TFA2** WEIGHT REDUCTION
- PRSEUS – Pultruded Rod Stitched Efficient Unitized Structure

**ERA Phase I Investigations**

**Reduce LTO and Cruise NOX**

**TFA4** CMC COMBUSTOR LINER
- For higher engine temps
  - SIC CMC Concepts
  - CMC combustor liner

**TFA5** AIRFRAME NOISE
- High-lift Systems and Landing Gear

**TFA5** PROPULSION NOISE
- Fan, Core and Jet Noise

**TFA5** PROPULSION AIRFRAME AEROACUSTICS
- Airframe/Propulsion Interaction & Shielding

**TFA4** INSTABILITY CONTROL
- Suppress combustor instabilities
  - High Temperature SiC electronics circuits and dynamic pressure sensors
  - Fuel Modulation for high frequency fuel delivery systems

**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
Advanced Vehicle Concept Study
Summary Results

Vehicle Performance

Key Technologies Identified

- Laminar flow control
- Advanced unitized composite structures
- Advanced UHB Engines

Performance vs. ERA Goals

- Noise
- Emissions
- Fuel Burn

Boeing, LM, NGC
### Strategic Thrusts

1. **Energy Efficiency**

2. **Environmental Compatibility**

### NASA Subsonic Transport System Level Metrics

#### TECHNOLOGY BENEFITS*

<table>
<thead>
<tr>
<th></th>
<th>TECHNOLOGY GENERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Technology Readiness Level = 4-6)</td>
</tr>
<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 NASA Subsonic 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
- **1930s**: B-707
- **1950s**: B-787
- **2000s**: Advanced Concepts
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

NASA


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…
Diversified Portfolio Addressing N+3 Goals
Broadly applicable subsystems technical challenges

N+3 Vehicle Concepts

Research Themes

Reduce Drag, Weight, TSEC, Emissions and Noise

Tailored Fuselage

High AR Elastic Wing

Quiet, Simplified High-Lift

High Eff. Gas Generator

Lightweight Hybrid Electric Propulsion

Propulsion Airframe Integration

Tools

Alternative Fuels

Technical Challenges
Gen N+3 Propulsion Technologies
**Northrop Grumman/Rolls Royce SELECT**

### Technology Suite

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

**Three-Shaft Turbofan**

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

- Open rotor had best sea level static fuel consumption
- Open rotor potential noise not quantified in time to be included
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
- Advanced Structural Materials
- Lifting Body
- High Bypass Ratio Engines (BPR 20) with High-Efficiency Small Cores
- Health and Usage Monitoring
- Faired Undercarriage
- Boundary Layer Ingestion
- Distortion Tolerant Fans
- Tt4 Materials and advanced cooling
- Variable Area Nozzle
- LDI Advanced Combustor
- Advanced Engine Materials

MIT/Pratt & Whitney D Series

NASA-CR-2010-216794 Vol. 1 & 2

Fundamental Aeronautics Program
Subsonic Fixed Wing Project
Boeing/General Electric SUGAR “Volt”

High Aspect Ratio Truss Braced Wing
Hybrid Electric (Batteries) Propulsion Systems
- With a 750 Wh/kg battery, increasing aircraft weight to accommodate higher battery capacity reduces fuel burn and total energy.

- >500 WH/kg battery technology needed to meet NASA fuel burn goal.

- 85-90% fuel burn reduction is max. achievable for SUGAR hybrid architecture and assumptions.
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 CO$_2$ 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
Propulsion Related Research Elements

versatile core applicable to variety of propulsion systems/installations

- ducted fan
- open fan
- hybrid system

materials, aerodynamics, acoustics, and control

distortion tolerance

boundary-layer ingesting concepts, thrust vectoring

adaptive fan blades

Jet/surface interaction acoustics

multi-point lean direct injection

Alternative Aviation Fuel Experiment

Superconducting-motor-driven fans in a continuous nacelle