Fixed Wing Project: Technologies for Advanced Air Transports

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www.nasa.gov
The Fixed Wing 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
- Development of tools as enablers for specific technologies and concepts

**Evolution of Subsonic Transports**

- 1903
- 1930s: DC-3
- 1950s: B-707
- 2000s: B-787
### NASA Subsonic Transport System Level Metrics

#### Strategic Thrusts

<table>
<thead>
<tr>
<th>1. Energy Efficiency</th>
<th>2. Environmental Compatibility</th>
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<table>
<thead>
<tr>
<th>TECHNOLOGY BENEFITS*</th>
<th>TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-32 dB</td>
<td>-42 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 CO2e per MJ for fuel and/or energy source used.

Research addressing revolutionary far-term goals with opportunities for near-term impact.
N+3 Advanced Vehicle Concept Studies Summary

Advanced concept studies for commercial subsonic transport aircraft for 2030-35 Entry into Service (EIS)

Technology 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...
Fixed Wing Project Research Themes
Based on Goal-Driven Advanced Concept Studies

<table>
<thead>
<tr>
<th>Goals Metrics (N+3)</th>
<th>Noise</th>
<th>Emissions (LTO)</th>
<th>Emissions (cruise)</th>
<th>Energy Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 4 – 52 dB cum</td>
<td></td>
<td>CAEP6 – 80%</td>
<td>2005 best – 80%</td>
<td>2005 best – 60%</td>
</tr>
</tbody>
</table>

Goal-Driven Advanced Concepts (N+3)

1. Lighter-Weight Lower Drag Fuselage
2. Higher Aspect Ratio Optimal Wing
3. Quieter Low-Speed Performance
4. Cleaner, Compact Higher BPR Propulsion
5. Hybrid Gas-Electric Propulsion
6. Unconventional Propulsion Airframe Integration
7. Alternative Fuel Emissions

Research Themes with Investments in both Near-Term Tech Challenges and Long-Term (2030) Vision
**Objective**
Explore and develop aerodynamic, structural, and control technologies to expand the optimal wing system drag vs. weight design trade space for reduced energy consumption.

**Technical Areas and Approaches**

**Tailored Load Path Structure**
- Passive aeroelastic tailored structures

**Active Structural Control**
- Distributed control effectors, robust control laws
- Actuator/sensor structural integration

**Aerodynamic Shaping**
- Low interference external bracing
- Passive wave drag reduction concepts

**Active Flow Control**
- Transonic drag reduction; mechanically simple high-lift

**Adaptive Aeroelastic Shape Control**
- Continuous control effector(s) for mission-adaptive optimization

**Benefit/Pay-off**
- 20% wing structural weight reduction
- Wave drag benefits tradable for weight or other parameters
- Concepts to control and exploit structural flexibility
- Optimal AR increase up to 50% for cantilever wings, 100% for braced wings
Truss-Braced Wing: Wing Weight Uncertainty
(Boeing SUGAR N+3 Phase 2 NRA)

Objective
Refine the SUGAR High configuration and reduce the uncertainty in estimates of the potential benefits of TBW technology with specific focus on reducing wing weight uncertainty.

Approach
Create a detailed finite element model (FEM) of SUGAR High configuration to provide a higher fidelity weight estimate of the concept and validate the FEM via a transonic aeroservoelastic test in the LaRC/Transonic Dynamics Tunnel (TDT).

Status
• FEM completed to provide the desired higher fidelity wing weight estimates. 1) SUGAR High fuel burn significantly improves, 2) SUGAR High fuel burn over Refined SUGAR gets better, and 3) Unducted fan variant of SUGAR High may approach the N+3 goal.
• Wind tunnel testing of 15% scale model completed. Flutter boundaries identified with successful demonstration of flutter suppression for this model. Additional new control laws were also tested at more aggressive conditions.

POCs: Marty Bradley (Boeing), Erik Olson (LaRC)
Truss-Braced Wing: Testing
(Boeing SUGAR N+3 Phase 2 NRA)

TEST  644
RUN    52
POINT  2714

H   296.5
P   212.4
M   0.779
Q   72.1

Fixed Wing Project
Fundamental Aeronautics Program

POCs: Marty Bradley (Boeing), Erik Olson (LaRC)
Objective
Explore and develop technologies to directly enable efficient, clean-burning, fuel-flexible combustors compatible with high OPR (50+) gas-turbine generators

Technical Areas and Approaches
Fuel-Flexible Combustion
- Injection, mixing, stability

Benefit/Pay-off
- Low emissions: NOx reduction of 80% at cruise and 80% below CAEP6 at LTO and reduced particulates
- Compatible with thermally efficient, high OPR (50+) gas generators
- Compatible for gas-only and hybrid gas-electric architectures
- Compatible with ducted or unducted propulsors
Cleaner, Compact, Higher Bypass Ratio Propulsion
Compact, High OPR Gas Generator

Objective
Explore and develop material, aerodynamic, and control technologies to enable compact gas-turbine generators with high thermal efficiency to directly reduce fuel consumption

Technical Areas and Approaches

Hot Section Materials
- 1500F disk & coatings
- 1500F capable non-contacting seal

Tip/Endwall Aerodynamics
- Minimize losses due to short blades/vanes
- Minimize cooling/leakage losses

Benefit/Pay-off
- Advanced compact gas-generator core architecture and component technologies enabling BPR 20+ growth by minimizing core size
- Thermally efficient, high OPR (50+) engines

Wu et al., Exp. Fluids, 2010. 1011
Compressor Tip Clearance/Endwall Flow Research (Johns Hopkins U. & Purdue U.)

**Objective**
Gain physical insights into loss mechanisms associated with large compressor tip clearance gaps by experiments and simulations of loss mitigation concepts.

**Approach**
Obtain detailed data and CFD simulations for tight and increased tip clearance gaps to measure performance impact and loss mechanisms. Johns Hopkins University (JHU) rig made of acrylic operating in Sodium Iodide (NaI) mixture renders casing and blades optically transparent. This is a unique capability.

**Status**
JHU: Obtaining unsteady 3-D tip clearance flow data at low speed compressor test rig. Tomographic PIV validated.

Purdue: Stall inception testing and compressor stability characterization completed. PIV measurement progressing well.

**Research team:** Prof. Nicole Key (Purdue), Mark Celestina (GRC), Prof. Joe Katz (JHU), Chunill Hah (GRC)
Turbine Tip Clearance/Endwall Flow Research (Honeywell, Pratt & Whitney, Naval Academy)

Objective
Gain physics insight into large tip clearance gap leakage flow losses and hub seal cavity hot-gas re-ingestion to minimize loss and cooling flow requirements.

Approach
Obtain detailed data and CFD simulations with increasing tip clearance gaps and novel tip treatments to measure performance impact and loss mechanisms. Understand impact of seal cavity design parameters on minimizing hot gas re-ingestion and cooling requirements.

Status
P&W: Testing at PSU in low-speed cascade facility underway. Axial Flow Turbine Rig will also be used for measuring blade exit relative total pressure.

USNA: Passive flow control to reduce tip leakage with winglets, with and without gaps, measured. Tip vortex reduced but losses not affected.

Honeywell: CFD simulations and test article fabrication completed. Testing at U of Notre Dame underway.

Research team: J. Christophel (P&W), Ashlie McVetta (GRC), M. Malak (Honeywell), Phil Poinsatte (GRC), R. Volino (Naval Academy), David Ashpis (GRC)
**Objective**
Explore and develop electric system materials and increase the power density of an electric motor contributing to game-changing hybrid gas-electric propulsion

**Technical Areas and Approaches:**

**Electric System Materials**
- Low ac loss superconducting materials
- Multifunctional structures integrating power system

**Electric Components**
- High power density superconducting motor
- High power density non-cryogenic motor

**Benefit/Pay-off:**
- Will help enable the paradigm shift from gas to hybrid gas-electric propulsion
- Hybrid gas-electric propulsion will help reduce energy consumption, emissions, and noise
Unconventional Propulsion Airframe Integration
Integrated BLI Systems

**Objective**
Explore and develop technologies to enable highly coupled, propulsion-airframe integration that provides a net vehicle system-level energy efficiency benefit

**Technical Areas and Approaches**

**Aerodynamic Configuration**
- Novel configurations and installations

**Distortion-Tolerant Fan**
- Integrated inlet/fan design robust to unsteady and non-uniform inflow

**Benefit/Pay-off**
- Demonstrates a net system-level benefit for BLI propulsion system integration; applicable and beneficial to a variety of advanced vehicle concepts
- Distortion-tolerant fan technology and acoustics characterization relevant to near-term, conventional short-duct installations
Objective
Experimentally assess the benefits of boundary layer ingestion (BLI) for the D8 configuration.

Approach
Obtain experimental data at simulated cruise conditions for the podded and integrated configurations and conduct complementary numerical simulations.

Status
• Collected force and moment data, rake surveys of the engine inlet and exit, surface pressures, and surface tuft visualization. Results indicate a 20-25 drag count reduction for the integrated configuration relative to the podded configuration. This translates to an electrical power savings on the fans of about 5-8%.

• Results are aligned with design assumptions of D8 configuration.

Research Team: MIT/PW/Aurora Team; Greg Gatlin (LaRC)
Shishir Pandya (ARC)

Aviation Week Article
September 30, 2013
Alternative Fuel Emissions at Cruise

Objectives
Explore the potential of alternative fuels to reduce the impact of aviation on air quality and climate, and their impact on performance

Technical Areas & Approaches
Emission & Performance Characterization
- Flight tests
- Ground tests
- Laboratory tests

Benefit/Pay-off
- Will dramatically reduce the impact of aviation on the environment (gaseous, particulates, and contrails)
- Will support standard-setting organizations by providing important and timely data
ACCESS 2 flight test campaign on-going (May 5-30, 2014)

- Establish effects of alternative fuels on engine emissions and thrust at cruise and examine the impact of aerosols on contrail formation

- In partnership with DLR (Germany), NRC (Canada), FAA (USA)
**ACCESS: Multi-Platform, Multi-Fuels Sampling**

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<thead>
<tr>
<th>Test</th>
<th>JP-8</th>
<th>JP-8 Hi S</th>
<th>Blend</th>
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<tbody>
<tr>
<td>Sulfur (ppm)</td>
<td>&lt;10 ppm</td>
<td>1000 ppm</td>
<td>&lt;5 ppm</td>
</tr>
<tr>
<td>Aromatics (%vol)</td>
<td>18</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>Density (kg/L)</td>
<td>0.81</td>
<td>0.81</td>
<td>0.79</td>
</tr>
<tr>
<td>End Point (degC)</td>
<td>275</td>
<td>275</td>
<td>279</td>
</tr>
</tbody>
</table>

LaRC HU-25 Falcon  
NRC CT-133  
DLR Falcon 20
Preliminary Results from ACCESS II Flight Campaign

HEFA Blend Reduces Black Carbon Number and Mass Emissions by 30 to 60% at Cruise

![Graphs showing the reduction in nonvolatile aerosol and black carbon emissions with different fuel types at cruise](image-url)
HEFA Blend Reduces Black Carbon Number and Mass Emissions by 30 to 80% during Ground Ops
Concluding Remarks

- Addressing the environmental challenges and improving the performance of subsonic aircraft
- Undertaking and solving the enduring and pervasive challenges of subsonic flight
- Understanding and assessing the game changers of the future
- Nurturing strong foundational research in partnership with industry, academia, and other Government agencies

Technologies, Concepts, and Knowledge
Fixed Wing Project

Fundamental Aeronautics Program