AN OVERVIEW OF THE NASA FUNDAMENTAL AERONAUTICS PROGRAM SUBSONIC FIXED WING PROJECT AND ULTRA HIGH BYPASS PARTNERSHIP RESEARCH GOALS

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Abstract

An overview of the NASA Fundamental Aeronautics Program (FAP) mission and goals is presented. One of the subprograms under the FAP, the Subsonic Fixed Wing Project (SFW), is the focus of the presentation. The SFW system environmental metrics are discussed, along with highlights of planned, systematic approach to research to reduce the environmental impact of commercial aircraft in the areas of acoustics, fuel burn and emissions. The presentation then focuses on collaborative research being conducted with U.S. Industry on the Ultra High Bypass (UHB) engine cycle, the propulsion cycle selected by the SFW to meet the system goals. The partnerships with General Electric Aviation to investigate Open Rotor propulsion concepts and with Pratt & Whitney to investigate the Geared Turbofan UHB engine are highlighted, including current and planned future collaborative research activities with NASA and each organization.
An Overview of the NASA Fundamental Aeronautics Program Subsonic Fixed Wing Project and Ultra High Bypass Partnership Research Goals

Chris Hughes
Manager, Ultra High Bypass Partnership Element

15th AIAA/CEAS Aeroacoustics Conference
(30th AIAA Aeroacoustics Conference)
11-13 May 2009
Miami, Florida
• Policy
  - Executive Order signed December 2006
  - Outlines 7 basic principles to follow in order for the U.S. to “maintain its technological leadership across the aeronautics enterprise”
  - Mobility, national security, aviation safety, security, workforce, energy & efficiency, and environment

• Plan (including Related Infrastructure)
  - Plan signed by Pres. Bush December 2007
  - Goals and Objectives for all basic principles (except Workforce, being worked under a separate doc)
  - Summary of challenges in each area and the facilities needed to support related R&D
  - Specific quantitative targets where appropriate
  - More detailed document/version to follow later in 2008

  Executive Order, Policy, Plan, and Goals & Objectives all available on the web

  For more information visit: http://www.ostp.gov/cs/nstc/documents_reports
• **Objectives**

(1a) Development of prediction and analysis tools for reduced uncertainty in design process

(1b) Development of concepts/technologies for enabling dramatic improvements in noise, emissions and performance characteristics of subsonic/transonic aircraft

• **Relevance**

– Direct impact on future designs of a wide range of subsonic aircraft relevant to industry, DoD, and OGA

– Direct impact on JPDO & NextGen operational and environmental goals and objectives
Organization of SFW Project

Principal Investigator
Fay Collier

Project Scientist
Jim Heidmann, Acting

Combustion
Dan Bulzan, API
Mary Wadel, APM

Acoustics
Ed Envia, API
Mary Wadel, APM

Aerothermodynamics
Nateri Madavan, API
Kevin Walsh, APM

SADO
Bill Haller, API
Mary Wadel, APM

System-Level Partnerships and Plans
MDAO - Cynthia Naiman
BWB - Dan Vicroy
CESTOL - Craig Hange
Quiet Technology - Charlotte Whitfield
UHB Engines Tech - Chris Hughes
Aero Efficiency - Dave Voracek
JPDO/CLEEN - Fay Collier et al
Green Prop. Initiative - Mike Nathal

Component and Discipline
NRAs and Foundational Research Plans

Aerodynamics
Mike Rogers, API
Craig Hange, APM

Materials and Structures
Karen Taminger, API
Rubén Del Rosario, APM

Aeroelasticity
Jennifer Heeg, API
Kevin Walsh, APM

Controls and Dynamics
Diana Acosta, API
Craig Hange, APM

Balanced, Integrated Plans & Associated Resources & Schedule

Technology Integration Manager - Anna McGowan
NRA Manager - Kim Pham
Lead Resource Analyst - Sarah Samples
Lead Scheduler - Mandy Eberwine
**System Level Metrics**

... technology for dramatically improving noise, emissions, & performance

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Noise</td>
<td>- 32 dB (cum below Stage 4)</td>
<td>- 42 dB (cum below Stage 4)</td>
<td>- 71 dB (cum below Stage 4)</td>
</tr>
<tr>
<td>LTO NOx Emissions (below CAEP 6)</td>
<td>-60%</td>
<td>-75%</td>
<td>better than -75%</td>
</tr>
<tr>
<td>Performance: Aircraft Fuel Burn</td>
<td>-33%**</td>
<td>-40%**</td>
<td>better than -70%</td>
</tr>
<tr>
<td>Performance: Field Length</td>
<td>-33%</td>
<td>-50%</td>
<td>exploit metro-plex* concepts</td>
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**Approach**

- Enable Major Changes in Engine Cycle/Airframe Configurations
- Reduce Uncertainty in Multi-Disciplinary Design and Analysis Tools and Processes
- Develop/Test/Analyze Advanced Multi-Discipline Based Concepts and Technologies
- Conduct Discipline-based Foundational Research

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**Footnotes:**

**An additional reduction of 10 percent may be possible through improved operational capability**

* Concepts that enable optimal use of runways at multiple airports within the metropolitan areas

--- EIS = Entry Into Service; IOC = Initial Operating Capability
Change in noise “footprint” area based on SFW goals for single landing and takeoff

Current Noise Rule (Stage 4): Stage 3 – 10 dB CUM
Area: ~55% of Baseline

Current Generation of Quietest Aircraft (Gen. N): Stage 4 – 11 dB CUM
Area: ~29% of Baseline

SFW Next Generation N+1 Goal: Stage 4 – 32 dB CUM
Area: ~8.4% of Baseline

SFW Generation N+2: Stage 4 – 42 dB CUM
Area: ~4.6% of Baseline

SFW Generation N+3: Stage 4 – 71 CUM dB
Area: ~0.8% of Baseline

NOTES

• Relative ground noise contour areas for notional SFW N+1, N+2, and N+3 generation aircraft
  ─ Independent of aircraft type/weight
  ─ Independent of baseline noise level

• Noise reduction assumed to be evenly distributed between the three certification points

• Simplified Model: Effects of source directivity, wind, etc. not included
“N + 1” Conventional Small Twin
• 32 EPNdB cumulative below Stage 4
• Target Next Generation Single Aisle (NGSA)
• Ultra-High Bypass (UHB) engines
• Noise Reduction (NR) technologies for fans, landing gear, propulsion airframe aeroacoustics
• Light weight acoustic treatment in multifunctional structures
Conventional Small Twin: N+1

- 60% LTO NOx reduction below CAEP6
- Target Next Generation Single Aisle (NGSA)
- Annular combustor TAPS (GE)
  - Improved fuel/air mixers
- TALONX (P&amp;W)
  - Optimized quench section for improved mixing
  - Improved fuel/air mixing in rich zone
“N + 1” Conventional Small Twin

- 162 pax, 2940 nm mission baseline
- Ultra high bypass ratio engines, geared
- Key technology targets:
  - +1 point increase in turbomachinery efficiencies
  - 25% reduction in turbine cooling flow enabled by: improved cooling effectiveness and advanced materials
  - +50 deg. F compressor temps (T3)
  - +100 deg. F turbine rotor inlet temps
  - -15% airframe structure weight
  - -1% total vehicle drag
  - -15% hydraulic system weight

“N + 1” Advanced Small Twin

- All technologies listed above plus:
  Hybrid Laminar Flow Control
  - 67% upper wing,
  - 50% lower wing,
  - tail, nacelle

  Result = -17% total vehicle drag

Performance - Fuel Burn
Detailed System Analysis

Fuel Burn = 39,300 lbs
1998 EIS Technology

Advanced Propulsion
Δ Fuel Burn = - 15%

Advanced Materials and Structures
Δ Fuel Burn = - 5%

Aerodynamic Improvements
Δ Fuel Burn = - 1.5%

Subsystem Improvements
Δ Fuel Burn < 0.5%

Fuel Burn = 30,900 lbs

Fuel Burn = 39,300 lbs
1998 EIS Technology

Advanced Propulsion
Δ Fuel Burn = - 13.4%

Advanced Materials and Structures
Δ Fuel Burn = - 4.4%

Advanced Aerodynamic Technology
Δ Fuel Burn = - 15.4%

Subsystem Improvements
Δ Fuel Burn < 0.5%

Fuel Burn = 26,200 lbs

Fundamental Aeronautics Program
Subsonic Fixed Wing Project
Objective

• Develop noise reduction, emission reduction and performance improvement technologies for the Ultra High Bypass engine cycle, then demonstrate and validate their potential in full scale applications

Meeting SFW Goals Requires Evaluating Game-Changing Architectures

NASA has a strong and successful history of developing aircraft propulsion improvement technologies with Industry/OGA/Academia partners
Technology Challenges

- **Geared Turbofan (P&W)**
  - *Small, high density engine core* – required to achieve higher fan bypass ratio without significantly increasing fan diameter
  - *Aerodynamic performance* – larger fan diameter means larger nacelle and higher drag
  - *Installation* – increasingly larger diameter engines means limited application for current, low wing aircraft designs

- **Open Rotor (GE)**
  - *Noise* – rotor blade noise radiates unobstructed to the environment, well above current aircraft noise regulation limits
  - *Installation* – very large blade diameters mean significant aircraft installation problems, perhaps requiring all new aircraft design
  - *Power* – slow, counter-rotating rotors requires novel turbine power distribution designs to optimize turbomachinery efficiency
Meeting SFW Goals Requires Evaluating Game-Changing Architectures

- CR Prop EIS 2018-20
  - BPR ~ 40-80

- NASA N+1

- GTF/2 EIS ~ 2018-20
  - BPR ~ 15-20

- GTF EIS ~ 2013
  - BPR ~ 9-12

- Current 737/A320
  - BPR ~ 5
Meeting SFW Goals Requires Evaluating Game-Changing Architectures

- Turbofan
- GTF
- Adv GTF ~ 2018

Fuel Burn vs. Noise vs. Weight & Drag

(Higher FPR) vs. (Lower FPR)

Increasing Fan Diameter
NASA Partnership Areas on Pratt & Whitney Geared TurboFan (GTF™)

Fan Drive Gear System
- 5 Planets
- Gear Ratio ~ 3

Low PR Fan
- Low Tip Speed
- BPR ~ 9 - 12

High-Speed Low Spool
- Compact LPC, LPT

Low-Emissions Combustor

NASA / P&W UHB Partnership Research

Fundamental Aeronautics Program
Subsonic Fixed Wing Project
Pratt & Whitney Geared Turbofan

**22” Subscale Rig Test**
- Successful demonstration of UHB fan technology
- Fan efficiency exceeded expectations
- Overall advantage of low PR, low tip speed fan demonstrated
- Test data used to define fan aerodynamics for full scale demonstrator engine

**Nacelle/Wing Interaction Test**
- Highly successful collaboration between Industry Partner and three NASA centers
- Test data provided design confidence for nacelle-wing integration at BPR = 12
Pratt & Whitney Geared Turbofan

- **Geared Turbofan Demonstrator Engine**
  - Successful ground demonstration of Geared Turbofan concept completed May 2008
    - Predicted fan performance verified
    - Acoustic characteristics within expectations

- **Future Collaboration**
  - Space Act Agreement negotiations initiated continued research collaboration into next generation Geared Turbofan
    - System analysis and design studies in 2009
    - 22” rig test at NASA Glenn 9’x15’ wind tunnel in 2011
    - Powered nacelle integration test on half span model in Ames 11’ in 2012

GTF Demonstrator Engine ground test
Geared TurboFan (GTF™)
Balanced Design Solution for Reduced Fuel Burn – Noise – Emissions

Projected Based on Demonstrated Technology

NOISE
(cum margin to Ch4) -20 EPNdB

LTO NOX
(below CAEP 6) -60%

FUEL BURN
(relative to 737/CFM56) -15%

MAINTAINANCE COST
Significant Reduction
NASA / GE UHB Partnership Research
Meeting SFW Goals Requires Evaluating Game-Changing Architectures

- Open Rotor Technology has potential for significant performance improvement, but with noise goal challenges

![Graph showing advanced turbofan vs. open rotor technology performance compared to today's standard.](image-url)
Extensive 1980s collaborative testing experience of counter-rotation, open rotor concepts by NASA and GE, resulting in substantial experimental database to guide new activity

Improved Computational Aeroacoustics developed by NASA/GE/Universities to evaluate new open rotor concepts

Improved design and system analysis tools to screen potential candidates and minimize scale model test configurations

Utilize proven NASA test facilities, improved diagnostic testing techniques and existing scale model test articles

Build on GE expertise in composite construction and advanced core technology to achieve full Open Rotor potential
General Electric Open Rotor

- **Space Act Agreement**
  - Signed August 2008
  - Initiates collaborative research on Open Rotor propulsion concepts in NASA Glenn 9’x15’ and 8’x6’ wind tunnels in 3Q 2009

**Test Objectives**

- Investigate performance and noise
- Produce shareable open rotor fan design
- Generate shareable database of test results

**Plan**

- NASA refurbish and update 1980s counter-rotation propfan drive rig
- GE will design, fabricate and test 1980s technology based open rotor fan as Historical Baseline
NASA Glenn Open Rotor Propulsion Rig

- Two independently controlled, counter-rotating shafts
- Each shaft capable of delivering up to 750 shp at maximum speed of 10,000 rpm
- Two-component rotating force balances measure up to 400 lbs thrust / 500 ft-lbs torque per rotor
- State-of-the-art digital telemetry units transmit data from each rotor to base system for transfer and storage on facility data system
- Up to 12 strain gages per rotor available for monitoring fan blade dynamics
- All subsystems (speed control, lubrication, air supply) are new, state-of-the-art designs
Future of Partnerships

- Though the challenges are big, exploiting partnerships and collaborative research opportunities can leverage their experience, expertise, facilities and resources to conduct research on Ultra High Bypass Propulsion concepts for the next generation of advanced aircraft designs, and investigate their viability as a new, game-changing aircraft propulsion technology in a changing, environmentally-conscious world.