Collaborative Research on the Ultra High Bypass Ratio Engine Cycle to Reduce Noise, Emissions, and Fuel Consumption

Presentation Abstract

A pictorial history of NASA development of advanced engine technologies for reducing environmental emissions and increasing performance from the 1970s to present is presented. The goals of the Subsonic Fixed Wing Program portion of the NASA Fundamental Aeronautics Program are addressed, along with the areas of investigation currently being pursued by the Ultra High Bypass Partnership Element of the Subsonic Fixed Wing Program to meet the goals. Ultra High Bypass cycle research collaboration successes with Pratt & Whitney are presented.
Collaborative Research on the Ultra High Bypass Ratio Engine Cycle to Reduce Noise, Emissions, and Fuel Consumption

Chris Hughes
Manager, Ultra High Bypass Engine Technology Maturation and Integration Validation Partnership Element, 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.

NASA has a strong history of aircraft propulsion improvement technology development with Industry Partners.
Strong History of Technology Development

1970s

- Single Rotation Propfans (Hamilton Standard/UTRC)
  - Significant fuel burn improvement over then current turbofans

SR-5 Fan in NASA Glenn 8’x6’ Wind Tunnel

Large Advanced Propeller Full Scale Static Test

Propeller Test Assessment Aircraft Demo
1980s

- Counter Rotation Propfans (GE)
  - Reduced installation effects, improved efficiency
Strong History of Technology Development

1990s

• Ultra High Bypass Engine Cycle (P&W)
  - Reduced noise and fuel burn with conventional appearance

17” Advanced Ducted Propulsor in NASA Glenn 8’x6’ Wind Tunnel

22” Advanced Ducted Propulsor in NASA Glenn 9’x15’ Wind Tunnel
1990s

- Advanced noise reduction technologies for turbofans
  - Fan blade tip flow management (P&W)
  - Active/passive liners (Northup Grumman)
  - Active noise control (NASA)
1990s

- Advanced noise reduction technologies for turbofans
  - Increased rotor-stator spacing (Allison)
  - Reduced fan tip speed (P&W)
  - Swept and/or Leaned stator vanes (Allison, Honeywell)
Strong History of Technology Development

1990s

- Advanced combustors for turbofans
2000s

- Advanced noise reduction technologies for turbofans
  - Chevrons (GE, P&W, Boeing)

First commercial delivery on Boeing 777

Advanced Chevron Test in NASA Glenn AeroAcoustic Propulsion Lab (AAPL)

Boeing Quiet Technology Demonstrator 2 Test Bed

Boeing 787 Test Flight
Strong History of Technology Development

2000s

- Advanced noise reduction technologies for turbofans
  - Highly forward swept fan blade (Honeywell)
  - Variable Area Fan Nozzle (NASA)
Strong History of Technology Development

2000s

- Advanced noise reduction technologies for turbofans
  - Fan trailing edge blowing (NASA)
Today’s Challenges

- Refining and improving on previous noise reduction and performance improvement technologies and demonstrating their combined effectiveness is necessary to meet the aggressive SFW goals for “N + 1” aircraft
  - Noise: -42 cum below Stage 3
  - Emissions: -70% LTO NOx below CAEP/2
  - Performance: -33% Fuel Burn below B737/CFM56

- However, goals trading may be possible in certain applications

<table>
<thead>
<tr>
<th>Noise</th>
<th>Current SOA (N)</th>
<th>N + 1 Optimized for Performance</th>
<th>N + 1 Optimized for Noise</th>
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</thead>
<tbody>
<tr>
<td>Cum below Stage 3</td>
<td>-14 dB</td>
<td>-30 dB</td>
<td>-42 dB</td>
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<table>
<thead>
<tr>
<th>Emissions</th>
<th>Current SOA (N)</th>
<th>N + 1 Optimized for Performance</th>
<th>N + 1 Optimized for Noise</th>
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</thead>
<tbody>
<tr>
<td>LTO NOx below CAEP/2</td>
<td>-25%</td>
<td>-60%</td>
<td>-70%</td>
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<table>
<thead>
<tr>
<th>Performance</th>
<th>Current SOA (N)</th>
<th>N + 1 Optimized for Performance</th>
<th>N + 1 Optimized for Noise</th>
</tr>
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<tbody>
<tr>
<td>Aircraft Fuel Burn relative to 737/CFM56</td>
<td>Ref.</td>
<td>-15%</td>
<td>-33%</td>
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SFW Project Organization

APIs for
- Combustion
- Acoustics
- Aerothermodynamics
- Systems Analysis, Design and Optimization

System-Level Partnerships and Plans
- MDAO
- Blended Wing Body
- Extreme STOL
- Long Endurance
- Quiet Aircraft Technology
- UHB Engine Technology
- Adaptive Structures
- Component and Discipline Partnerships and Plans
- NRAs and Foundational Research Plans

Aerosystems
- Aerodynamics
- Materials and Structures
- Aeroelasticity
- Controls & Dynamics
- Experimental Capabilities

Balanced, Integrated Plans & Associated Resources & Schedule

TIM, APMs, Partnership Leads, NRA Manager, Program Analysts, Scheduler
Current Areas of Investigation Under SFW UHB

Performance

- Nacelle/Airframe Integration Aerodynamics
- Counter Rotation Fans (Bypass Ratio >30)
  - NASA Glenn drive rig being refurbished now

Approach/Takeoff Testing in NASA Glenn 9’x15’ Wind Tunnel

Propulsion/Airframe Integration Aerodynamics Test in NASA Ames 11’ Wind Tunnel

NASA Open Rotor Propulsion Rig, Aft Pusher Configuration

Climb/Cruise Testing in NASA Glenn 8’x6’ Wind Tunnel
Noise Reduction

- Acoustically Treated Fan Casing ("Over-The-Rotor")
  - Foam metal behind porous rub strip
- Acoustically Treated Stator Vanes ("Soft Vanes")
Current Areas of Investigation Under SFW UHB

➢ Emissions
  • Alternative Fuels
  • Advanced Emissions Measurement Instrumentation Technology

Probes Mounted on Learjet Exhaust Flange
UnCooled Particle Probe
Water Cooled Gas Probe
Water Cooled Particle Probe

Gas & Particulate Probe Design Testing

Probe Sample Line Evaluation

Advanced Particulate Probe Design
While the challenges are big, establishing partnerships with Industry/OGA/Universities to exploit collaborative research opportunities will insure that the noise, emissions and performance goals of the SFW Project are successfully achieved.
An Overview of Recent Collaboration Research with NASA in Ultra High Bypass Engine Technology

Original Presentation at the Fundamental Aeronautics 2007 Annual Meeting

by

Jeff Schweitzer
Manager, Pratt & Whitney Advanced Commercial Engine Programs
Ultra High Bypass Enables a Step-Change in Propulsion

Evolution in By-Pass Ratio

- Lower fuel consumption
- Lower noise
- Lower greenhouse gases

TURBOJET

TURBOFAN
Low by-pass

TURBOFAN
High by-pass

Ultra high by-pass

Pratt & Whitney Developing the GTF™

Geared Turbofan (GTF) Engine is Optimized Implementation of UHB

Gear Box
Fundamental Propulsion System Characteristic

**GTF allows Paradigm Shift to Reduce Fuel Burn AND Noise**

- **Problem:** Increasing weight of Low-RPM LPT contributes to increasing fuel burn

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**Fuel Burn**

- **Low Bypass Ratio (Higher FPR)**
  - **Noise Reduction**
  - **Advanced Components**

- **High Bypass Ratio (Lower FPR)**
  - **EPNdB Noise Reduction**
  - **Paradigm Shift**

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**INCREASING FAN DIAMETER**

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**State-of-The-Art**

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**Pratt & Whitney**

A United Technologies Company
NASA-P&W History of Technology Development

Some Technology Highlights from NASA-P&W Programs

Fan Drive Gear System – NASA UEET

System Optimization – NASA EVNERT

Talon II RQL – NASA AST

Talon X RQL – NASA UEET

Low PR Fan Optimization – NASA AST and QAT
Subscale Rig Demonstrated UHB Fan Performance

Collaborative Test in NASA 9’ x 15’ Acoustic Wind Tunnel

22” Subscale Rig Demonstrated:
- Noise reduction benefits of an advanced (UHB) cycle fan
- Fan efficiency that exceeded predictions
  - Overall performance advantage of a low PR, low tip speed fan
  - High efficiency fan design translates into decreased noise

Rig test data used to define fan aerodynamics for GTF Engine Demo Test
Geared Turbofan™ Demonstrator Runs in 2007


On Track For 2007 Demonstration Testing

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<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
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Ground Test

Flight Test
Intersection of NASA-P&W Goals

**UHB Partnership Objectives from GTF Engine Demo Test**

- Evaluate alternative fuels
  - Fischer-Tropsch fuel (50/50 blend)
  - Confirm reduced emissions (particulates)
  - Confirm specific fuel consumption
- Use data to confirm scalability to subscale model fan results. Validate:
  - NASA codes and systems
  - Reduced noise, higher efficiency

**Collaborative Alternative Fuels test successfully completed**

*February 2008 at P&W Florida facility*
UHB Propulsion Integration Study

Wing Interaction Study for UHB Engine Installation

- Large diameter UHB nacelle
- Realistic HB engine simulation
- Drag minimization
- Low PR fan/nozzle installation aerodynamics
- NASA Multi-Disciplinary Analysis and Optimization verification

Collaborative model test planned for May 2008 at NASA Ames 11’ Wind Tunnel
P&W Transitioning Technologies Today

Products with a Step Change in Environmental Performance
Summary

GTF Activities at P&W Align with many NASA UHB Goals

- NASA-P&W: Tradition of technology successes
- EVNERT and 22” GTF Fan Rig Test demonstrated UHB concepts
- UHB Partnership collaboration opportunities for 2008 and beyond identified
- Anticipate continued collaboration with NASA on research challenges in aeronautics
Questions