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
1980s

- Counter Rotation Propfans (GE)
  - Reduced installation effects, improved efficiency

Counter Rotation Propeller in NASA Glenn 8’x6’ Wind Tunnel

GE Unducted Fan / Boeing 727 Flight Demo
Strong History of Technology Development

1990s

- Ultra High Bypass Engine Cycle (P&W)
  - Reduced noise and fuel burn with conventional appearance
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)
1990s

- Advanced combustors for turbofans

**TALON (Technology for Advanced Low NOₓ)**

- Original Standard
- Conventional
- PW4090
- PW4098
- PW4158
- PW4168
- PW6000
- CAEP/2
- CAEP/4
- CAEP/6
- TALON I
- TALON II
- TALON X
- Engine Demo 2003 (Characteristic Level Estimates)
- Rig Demo (Characteristic Level Estimates, TRL 4 & 5)
- Potential?

**Rich Burn Quick Quench Lean Burn Combustor Concept**

- Rich Primary Zone
- Optimized Quench
- Lean Combustion Zone

**Annular Combustor Test Rig**
2000s

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

First commercial delivery on Boeing 777

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)
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></th>
<th>Current SOA (N)</th>
<th>N + 1 Optimized for Performance</th>
<th>N + 1 Optimized for Noise</th>
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<tbody>
<tr>
<td><strong>Noise</strong></td>
<td></td>
<td></td>
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<tr>
<td>Cum below Stage 3</td>
<td>-14 dB</td>
<td>-30 dB</td>
<td>-42 dB</td>
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<tr>
<td><strong>Emissions</strong></td>
<td></td>
<td></td>
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<tr>
<td>LTO NOx below CAEP/2</td>
<td>-25%</td>
<td>-60%</td>
<td>-70%</td>
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<tr>
<td><strong>Performance</strong></td>
<td></td>
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<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

Program Director

Principal Investigator

Project Scientist

Project Manager

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

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”)

Over-The-Rotor and Soft Vanes designs in 22” Advanced Ducted Propulsor model

Over-The-Rotor Fan Casing Treatment Test in NASA Glenn Active Noise Control Facility (ANCF)
Current Areas of Investigation Under SFW UHB

Emissions

- Alternative Fuels
- Advanced Emissions Measurement Instrumentation Technology

Probes Mounted on Learjet Exhaust Flange

UnCooled Particle Probe

UnCooled Gas 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 insur 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

Pratt & Whitney
A United Technologies Company
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

Fuel Burn

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

Noise

State-of-The-Art

Advanced Components

EPNdB Noise Reduction

Paradigm Shift

INCREASING FAN DIAMETER

Low Bypass Ratio (Higher FPR)

High Bypass Ratio (Lower FPR)
Some Technology Highlights from NASA-P&W Programs

- System Optimization – NASA EVNERT
- Fan Drive Gear System – NASA UEET
- 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

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

**Ground Test 2007-2008, Flight Test in 2008**

<table>
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<tr>
<th>Year</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
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On Track For 2007 Demonstration Testing

- **Ground Test**
- **Flight Test**

Pratt & Whitney
A United Technologies Company
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