Technologies for Turbofan Noise Reduction

Dennis Huff
NASA Glenn Research Center

ABSTRACT

An overview presentation of NASA’s engine noise research since 1992 is given for subsonic commercial aircraft applications. Highlights are included from the Advanced Subsonic Technology (AST) Noise Reduction Program and the Quiet Aircraft Technology (QAT) project with emphasis on engine source noise reduction. Noise reduction goals for 10 EPNdB by 2007 and 20 EPNdB by 2022 are reviewed. Fan and jet noise technologies are highlighted from the AST program including higher bypass ratio propulsion, scarf inlets, forward-swept fans, swept/leaned stators, chevron nozzles, noise prediction methods, and active noise control for fans. Source diagnostic tests for fans and jets that have been completed over the past few years are presented showing how new flow measurement methods such as Particle Image Velocimetry (PIV) have played a key role in understanding turbulence, the noise generation process, and how to improve noise prediction methods. Tests focused on source decomposition have helped identify which engine components need further noise reduction. The role of Computational AeroAcoustics (CAA) for fan noise prediction is presented. Advanced noise reduction methods such as Herschel-Quincke tubes and trailing edge blowing for fan noise that are currently being pursued in the QAT program are also presented. Highlights are shown from engine validation and flight demonstrations that were done in the late 1990’s with Pratt & Whitney on their PW4098 engine and Honeywell on their TFE-731-60 engine. Finally, future propulsion configurations currently being studied that show promise towards meeting NASA’s long term goal of 20 dB noise reduction are shown including a Dual Fan Engine concept on a Blended Wing Body aircraft.
Technologies for Turbofan Noise Reduction

Dennis Huff
NASA Glenn Research Center
Cleveland, Ohio
U.S.A.

Special thanks to Edmane Envia, James Bridges and Mike Jones

presented at
10th AIAA/CEAS Aeroacoustics Conference
Manchester, United Kingdom
May 11, 2004
New Technology Enables Aircraft To Meet Future Requirements

- History: JT3D, JT8D, JT9D, CF6, CFM56
- Current: JT8D-200, PW2000, PW4000, V2500, GE90, PW6000
- Future Goals: quiet aircraft technology (QAT) program goal (additional 5 dB)
- Advanced subsonic technology (AST) noise reduction program goal of 5 dB

Average noise level relative to Stage 3 (EPNdB)

Year of Certification

- 1960
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
Aircraft Fleet Noise Reduction Needed For 55 LDN Noise Contours Within Airport Boundaries

According to a document from the U.S. Environmental Protection Agency (EPA) published in the 1970’s, 55 LDN is the outdoor noise exposure level “requisite to protect the public health and welfare with an adequate margin of safety”. The phrase “health and welfare” is defined as “complete physical, mental and social well-being and not merely the absence of disease and infirmity”.

Analysis by Don Garber, NASA Langley, using NoiseMap
Pratt & Whitney's PW8000 Turbofan Engine (Conceptual)
Engine Noise Reduction Technologies

- Swept/Leaned Stators
- Active Noise Control
- Forward-Swept Fans
- Noise Prediction
- Scarf Inlets
- Higher Bypass Ratio
- Chevron Nozzles
OUTLINE

- Source Diagnostics Tests
- Fan Noise
- Jet Noise
- Static Engine Tests & Flight Validation
- Future Directions
Jet Noise Baseline Data For CFD/CAA Validation

- Provide reliable data base for experimental and analytical comparisons
- Cover wide range of subsonic and supersonic conditions (Tanna data)
Jet Noise Baseline Data For CFD/CAA Validation

- Objective: Turbulent flow statistics

Bridges & Wernet (AIAA Paper 2002-2484)
Fan Source Diagnostics Test (SDT)

**Approach**

- Comprehensive Aero-Acoustic Testing
- Advanced Diagnostics
- Source Separation
  - Inlet vs. exhaust
  - stage vs. rotor-alone

Top View Schematic of NASA’s 9’ x 15’ Low-Speed Wind Tunnel
Fan Source Diagnostics Test Summary

- Shock Location Surveys (LDV)
- Turbulence Surveys (PIV)
- Unsteady Pressure Surveys
- Inlet BL Surveys (HW)
- Tip Flow Surveys (LDV)
- Nozzle Exit Surveys (LDV)
- Wake Surveys (LDV)
- 2-Point Correlation Surveys (HW)
- Duct Wall Pressure Surveys
- Rotating Rake Microphone Surveys
- Traversing Microphone Farfield Surveys

Tested 2 Fans, 3 Outlet Guide Vanes and Rotor-Alone Configurations at Multiple Fan Tip Speeds
## Fan Source Diagnostics Test - References

<table>
<thead>
<tr>
<th>Results Type</th>
<th>Contributors</th>
<th>Paper Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor Alone Aerodynamic Performance Results</td>
<td>Hughes et. al</td>
<td>AIAA Paper 2002-2426</td>
</tr>
<tr>
<td>Farfield Acoustic Results</td>
<td>Woodward et. al</td>
<td>AIAA Paper 2002-2427</td>
</tr>
<tr>
<td>Tone Modal Structure Results</td>
<td>Heidelberg</td>
<td>AIAA Paper 2002-2428</td>
</tr>
<tr>
<td>Wall Measured Circumferential Array Mode Results</td>
<td>Premo &amp; Joppa</td>
<td>AIAA Paper 2002-2429</td>
</tr>
<tr>
<td>Vane Unsteady Pressure Results</td>
<td>Envia</td>
<td>AIAA Paper 2002-2430</td>
</tr>
<tr>
<td>LDV Measured Flow Field Results</td>
<td>Podboy et. al</td>
<td>AIAA Paper 2002-2431</td>
</tr>
<tr>
<td>Computation of Rotor Wake Turbulence Noise</td>
<td>Nallasamy et. al</td>
<td>AIAA Paper 2002-2489</td>
</tr>
</tbody>
</table>
Fan Tone Noise Prediction (Frequency Domain)

- **Methodology**
  - Fan Wake Description: Steady RANS
  - OGV Acoustic Response: Linearized Euler

Verdon et al. (NASA/CR-2001-210713)

Exhaust Tone Levels: Prediction

<table>
<thead>
<tr>
<th>Cut-Off Stator (2xBPF)</th>
<th>Cut-On Stator (1xBPF)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode: (m,n)</strong></td>
<td><strong>Power (dB)</strong></td>
</tr>
<tr>
<td>(-10,0)</td>
<td>113</td>
</tr>
<tr>
<td>(-10,1)</td>
<td>100</td>
</tr>
<tr>
<td>(-10,2)</td>
<td>101</td>
</tr>
<tr>
<td>(-10,3)</td>
<td>102</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>114</td>
</tr>
</tbody>
</table>

*Data includes a recently discovered 3 dB correction*
Computational Aeroacoustics for Fan Noise Prediction (Time-Domain)

- **Methodology**
  - Time-Accurate, Non-linear & Inviscid Simulation
  - Validated in 2D. Extension to 3D is Underway

- **Harmonic content of unsteady pressure (only 9 passages shown)**
Fan Broadband Noise Prediction

- **Methodology**
  - Fan Wake Turbulence Description: Steady RANS
  - OGV Acoustic Response: Strip-wise lift response (2D cascade)
    Classical duct acoustics (3D)

Inlet and Exhaust PWL at Approach Condition (Stator Contribution Only)
Data includes both coherent and broadband, theory only includes broadband

[Graphs showing inlet and exhaust PWL spectra with data and theory curves.]
Fan Noise Duct Propagation
CDUCT-LaRC Code

✓ Accounts for realistic geometries
✓ Uses CFD to achieve higher quality acoustic predictions
✓ Couples with source codes like LINFLUX or TFaNS
Fan Noise Reduction

- Low-Count Swept OGV
  - Low Count Reduces Broadband Noise
  - Sweep Minimizes BPF Tone Penalty

- Trailing Edge Blowing
  - Fill-in the Rotor Wake reduces tone noise
  - Blows internal passages


Woodward et al. (AIAA Paper 2002-2427)
Fan Noise Reduction

Virginia Polytechnic Institute Herschel-Quincke (HQ) Tubes
NASA Advanced Noise Control Fan (ANCF)
Fan Noise Reduction

NASA/BBN Active Noise Control Fan Test

[Image of a turbine with labels for Rotor Blade and Stator Vane]
Jet Noise Reduction – Flight Tests
Model Scale Versus Flight Tests
Chevron Benefit Comparison - Perceived Noise Level (PNL)

Model Scale Tests

Learjet Flight Data

Brown & Bridges (NASA TM 2003-212732)
Pratt & Whitney PW4098 Engine Test

- Active-Passive Liner
- Fan Blade # Change and Low Number/Cuton FEGV
- Scarf Inlet
- Treated Primary Nozzle
- Advanced PW Fan Case Treatment

Boeing
Honeywell Flight Demonstration of Noise Reduction Concepts

Scarf Inlet

Chevron Nozzle

Variable Nozzle
“Ultra-high-bypass-ratio engines [to] reduce fuel consumption, engine maintenance, and community noise. It might be possible to reduce community noise by 10 dB, thus making airplane noise a non-issue at airports.”
Dual-Fan Engine Concept On Blended Wing Body