Recent Progress in Aircraft Noise Research

ARMD Technical Seminar
October 16, 2007

Dr. Edmane Envia, NASA Glenn Research Center
Dr. Russell Thomas, NASA Langley Research Center
(on Behalf of NASA Acoustics Discipline Team)

An overview of the acoustics research at NASA under the Subsonic Fixed Wing project is given. The presentation describes the rationale behind the noise reduction goals of the project in the context of the next generation air transportation system, and the emphasis placed on achieving these goals through a combination of the in-house and collaborative efforts with industry, universities and other government agencies. The presentation also describes the in-house research plan which is focused on the development of advanced noise and flow diagnostic techniques, next generation noise prediction tools, and novel noise reduction techniques that are applicable across a wide range of aircraft.
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Presented by
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Presentation Outline

• **Motivation**
  - Background & Trends
  - Near- and-Long Term Technology Goals

• **Strategy**
  - Technology Paths
  - Partnerships and Collaborations

• **Research Approach**
  - Diagnostic Techniques
  - Prediction Methods
  - Noise Reduction Technology

• **Summary**
Motivation

• The Joint Planning and Development Office (JPDO) is designing the Next Generation Air Transportation System (NextGen) with the potential for a 3x increase in air traffic capacity by 2025.

• Reducing aircraft noise is critical for enabling this anticipated growth. Recent JPDO studies indicate that, without a significant influx of new noise reduction technology into the fleet, the number of people exposed to objectionable noise levels (>65 DNL) will grow significantly.
Aircraft Noise Metrics

- Populated Areas
- Approach
- Takeoff / Cutback
- Sideline

Noise Level, EPNdB
- Approach Sideline Cutback

<table>
<thead>
<tr>
<th></th>
<th>Engine</th>
<th>Airframe</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>dB Math</td>
<td>2x Source Acoustic Power = 3 dB Increase</td>
<td></td>
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<tr>
<td>dB Math</td>
<td>10x Source Acoustic Power = 10 dB Increase</td>
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Aircraft Noise Levels

- Approach
- Sideline
- Cutback

Noise Level, EPNdB
- 70
- 75
- 80
- 85
- 90
- 95
- 100

- Engine
- Airframe
- Total
The Challenge

Aircraft noise is a complex amalgam of sources, interactions, transmission, and propagation.
## Subsonic Fixed Wing Project Goals

### Comers of the Trade Space

<table>
<thead>
<tr>
<th></th>
<th>N+1 Generation</th>
<th>N+2 Generation</th>
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<tbody>
<tr>
<td><strong>Aircraft Fuel Burn</strong>&lt;br&gt;(relative to 737/CFM56)</td>
<td>-33%</td>
<td>-50%*</td>
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<tr>
<td><strong>Emissions (LTO NOx)</strong>&lt;br&gt;(below CAEP/2)</td>
<td>-70%</td>
<td>-80%</td>
</tr>
<tr>
<td><strong>Performance:</strong>&lt;br&gt;Aircraft Fuel Burn&lt;br&gt;(relative to 737/CFM56)</td>
<td>-33%</td>
<td>-50%*</td>
</tr>
<tr>
<td><strong>Performance:</strong>&lt;br&gt;Field Length&lt;br&gt;(relative to 737/CFM56)</td>
<td>-33%</td>
<td>-50%</td>
</tr>
<tr>
<td><strong>Noise</strong>&lt;br&gt;(cumulative below Stage 3)</td>
<td>-42 dB</td>
<td>-52 dB</td>
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</table>

*N+2 Generation* Fuel bum for N+2 being validated.
Step Change in Noise Trend

SFW Project Goals

Average Noise Level Relative to Stage 3 (EPNdB)

Year of Certification

Stage 2

Stage 3

Stage 4


-52 dB Goal (2018-2020)
### N+1 Aircraft Noise Margins

(All numbers relative to Stage 3 certification levels)

<table>
<thead>
<tr>
<th></th>
<th>Current SOA</th>
<th>N+1 w/o NR Techs</th>
<th>N+1</th>
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<tbody>
<tr>
<td>Approach</td>
<td></td>
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<tr>
<td>Cutback</td>
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<td>Sideline</td>
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<tr>
<td>Cumulative</td>
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<table>
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<tr>
<th>EPNdB</th>
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<tbody>
<tr>
<td>-50</td>
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<td>-10</td>
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<tr>
<td>-5</td>
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<td>0</td>
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</tbody>
</table>
N+2 Aircraft Noise Margins
(All numbers relative to Stage 3 certification levels)

- Approach
- Cutback
- Sideline
- Cumulative

Current SOA  N+2  SAX-40*

*SAX-40's weight is 332 klb.
N+1 Technology Path

Airframe Noise Reduction Technologies:
- Slat Cove Filler & Continuous Mold Line (CML) (for high-lift systems noise reduction)
- Toboggan Fairing (for landing gear noise reduction)

Engine Noise Reduction Technologies:
- Ultra High Bypass (UHB) Cycle (e.g., geared turbofan)
- Soft Vane Stator
- Over-The-Rotor Treatment (all for fan noise reduction)
Pratt & Whitney Partnership

• 9’x15’ Acoustic Wind Tunnel Fan Noise Reduction Validation Test:
  - UHB Cycle Noise Benefits (Test Completed in November ‘06 - Cycle Benefits Validated)
  - Over-The-Rotor & Soft Vane Fan NR Tech. Validation Test (Scheduled or September ‘08)

• 11’ Transonic Wind Tunnel Test:
  - Potential Aerodynamic Integration Study (Scheduled for April ‘08)

• Geared Turbofan (GTF) Static Engine Test
  - Potential for Sub-Scale/Full-Scale Fan Noise Data Comparison (Scheduled for Nov. ‘07)

P&W GTF Model Scale Fan in 9’x15’ WT

Fan Noise Reduction Technology Testbed in 9’x15’ WT
Gulfstream Partnership

FY07 Flight Test at Wallops Island Flight Facility

• Multi-Year, Comprehensive Project:
  - Component Flow & Noise Testing
  - Noise Prediction
  - Flight Testing

• Airframe Noise Source Investigation and Mitigation Study:
  - Landing Gear Noise
  - Flap Side Edge Noise

Nose Gear Test in BART
N+2 Technology Path
Hybrid Wing Body (HWB)

High-Lift
Low-Noise Airframe

Shielding of Engine Noise by the Airframe

Drooped Leading Edge & CML Trailing Edge

Notional N+2 Generation Aircraft: Hybrid Wing Body
Cambridge-MIT SAX-40 Conceptual Designs for 2025

• **Boeing Phantom Works NRA:**
  - Start with both SAX-40 Concepts (Embedded and Podded Engines)
  - Mature Design for both Concepts; NASA/MIT/UCI Team to Carry Out Noise Assessment
  - Technology and Validation Wind Tunnel Selection for Phase 2
Boeing/MIT/UCI Round 2 NRA (2/2)
(Acoustics, Aerodynamics, and SADO Disciplines)

Envisioned Phase 2 Large Scale, Aerodynamic and Acoustic Test ...

N+2 HWB Aircraft Model

~8 ft
Cal-Poly/Georgia Tech Round 2 NRA
(Aerodynamics and Acoustics Disciplines)

• Objective:
  - Develop & Validate Predictive Capabilities for Cruise Efficient, Short Take-Off and Landing (CESTOL) Subsonic Aircraft

• Technology Portfolio:
  - Upper Wing Surface Blowing
  - Externally Blown Flaps
  - Circulation Control Wings

• Approach in Year 1:
  - Determine Low-Speed Aerodynamics
  - Determine Acoustic Characteristics
  - Select and Refine CESTOL Concept

• Approach in Years 2 & 3:
  - Large Scale, High-Fidelity Wind Tunnel Validation Experiments
Additional HWB Technology Portfolio

• University of Florida NRA 2
  - Pulsed Circulation Control to Increase Lift at Reduced Mass Flow Rates

• University of Notre Dame NRA 2
  - Plasma Actuators to Provide Virtual Fairing for Landing Gear and High Lift Side Edges
NASAs In-House Research

- **Noise Diagnostics**
  - Understand Underlying Noise Generation Mechanisms

- **Noise Prediction**
  - Improve Existing Capabilities
  - Develop New Capabilities
  - MDAO Challenge: Developing a Multi-Fidelity MDAO Capability for both Detailed Component Analysis and Efficient System Level Assessment

- **Noise Reduction**
  - Develop Concepts and Technologies with Minimum Impact on Other Performance Aspects of Aircraft

MDAO: Multi-Disciplinary Analysis and Optimization
Noise & Flow Diagnostics

- Particle Image Velocimetry
- Acoustic Phased Arrays
- Curved Duct Test Rig
PIV & Phased Arrays

Mapping Jet Flowfield Using Particle Image Velocimetry

Main Wing

Flow

Flap

DAMAS Deconvolution

Flow

Main Wing

Conventional Beamforming

Mapping Noise Sources with Conventional and DAMAS Array Processing Techniques
Liner Diagnostic Techniques

Nacelle Length \downarrow \quad \rightarrow \quad \text{Liner Attenuation} \downarrow

Must Improve Understanding of Effects of Grazing Flow Over Liners and Propagation Through Curved Ducts

LinerPhysicsTech.mov
Noise Modeling & Prediction

- **Fan and Jet**
  - Rotor-Stator Interaction (R/S) Tone Noise
  - Jet Noise

- **Airframe**
  - Slat Noise
  - Landing Gear Noise

- **Propulsion Airframe Aeroacoustics**
  - Flow Interactions
  - Acoustic Scattering

- **Aircraft System Noise**
  - Aircraft Noise Prediction Program (ANOPP)
  - ANOPP II
R/S Tone Noise Prediction

Numerical Computation of Blade Passing Frequency Tones
Jet Noise Prediction

Physics-Based (Statistical) Jet Noise Prediction

Turbulence: Predicted vs. Measured

Jet Noise Spectra: Predicted vs. Measured
Slat Noise Prediction

- Two Dominant Noise Generation Mechanisms Identified via Computation
- Noise Reduction Concepts (e.g., Slat-Cove Filler) Under Development Have Shown Great Promise to Control These Noise Sources
Landing Gear Noise Prediction

- Low-Frequency Noise
  - Generated by the Wheels
- Mid-Frequency Noise
  - Generated by the Main Strut
- High-Frequency Noise
  - Generated by the Small LG Parts
Jet-Pylon Interaction Noise Prediction

Initial CFD Comparisons

CFD Turbulence Model Improvement

Installed Flowfield Computed

Noise source map computed


**Acoustic Scattering Prediction**

- Fast Scattering Code is Used to Compute the Scattering of Engine Noise Sources by the Airframe.
Aircraft System Noise

ANOPP & ANOPPP II

(Link to MDAO)
Aircraft Noise Prediction

ANOPP (Current)

- Aircraft Noise Sources Are Placed at a Single Point
- Effects of Engine Installation Are Added Based on Experience
- Effects of Atmosphere Are Primitive
- Cannot Venture Too Far Outside Experience Base
Aircraft Noise Prediction ANOPP II (Future)

- Aircraft Noise Sources Are at Their True Locations
- Effects of Engine Installation and Interactions Are Modeled
- Effects of Atmospheric Gradients and Winds Are Included
- Can (and Must) Venture Outside of Experience Base
Aircraft Noise Prediction Philosophy

Knowledge & Capabilities

Requirements & Needs

Increasing Scope
Increasing Fidelity

Aircraft Noise Software Hierarchy

System Design & Multi-Discipline Capabilities

Discipline Level Capabilities

Foundational Physics & Modeling

ANOPP-II

Research Codes

Optimizing concepts, configurations across disciplines

Aircraft system and component noise, low noise procedures, assessment

Noise physics, component noise generation and modeling
ANOPP II Framework

- All Aircraft (Fixed- & Rotary-Wing)
- NASA, OGAs & External Users
- Empirical to 1st Principles-Based Methods

Environment
Vehicle Condition

ANOPP
-PAS
-CTOL

ANOPP II Framework

Propagation
-RNM, RTP, PE
-Hybrid Methods

Installation
-Scattering (FSC)
-PAA

System Studies
Noise Impact of Technology
Noise Assessment

System Design & MDAO

EDS
JPDO/AEDT

Propulsion

Jet
-PAB3D/JET3D,
-JENO

Fan
-TFaNS
-LINFLUX
-RSI

Airframe
-BAF
-CFL3D, FUN3D
-FWH2D, FWH3D

Propeller
-ASSPIN

Nacelle
-CDUCT
-Liners

Rotorcraft
-CAMRADII
-OVERFLOW,
-FUN3D
-WOPWOP
-FWH-MID

Computational, Analytical and Theoretical Aeroacoustics
Aircraft Noise Prediction Demo

- Demonstration: ANOPP-RNM Aircraft Noise Footprint Prediction
- ANOPP Deck for 777 and GE90-85B (Using NPSS Engine Simulation)
- ANOPP Creates Noise Hemispheres for Full Power Condition
- RNM Propagates Aircraft Noise to Ground; Propagation Includes Atmospheric Absorption, Spherical Spreading, Terrain, but No Wind
Noise Reduction Technologies

• Engine
  - Soft Vane Stator

• Propulsion Airframe Aeroacoustic
  - Airframe Integrated PAA Chevrons

• Airframe
  - Continuous Mold Line Flaps
  - Landing Gear Fairings
Soft Vane

Prototype Soft Vane

Vane Cross-Section View

Liners

By-pass flow

Core flow

0.5<L/D<1.5

Attenuation, dB

Forward Arc

Aft Arc

Harmonic Order

Attenuation, dB

0 1 2 3

1 2 3 4 5 6

Hamonic Order

Forward Arc

Aft Arc
PAA Integrated Chevrons

NASA/Boeing/GE/Goodrich/FAA Extensive Exploration of Several PAA Concepts

Extensive CFD/Prediction Work within PAA and Liner Technology

PAA in Boeing LSAF

- PAA Asymmetric Chevrons
- Flapperon Treatment
- Passive Porosity Cowl

LSAF Instrumentation
- Farfield Acoustics
- Surface Kulites
- Infrared
- Phased Array

PAA on QTD2
- PAA Chevron
- Instrumentation for PAA Effects

PAA in Boeing LSAF
PAA Installation Effects and Noise Reduction Technologies Studied
- PAA Asymmetric Chevrons
- Flapperon Treatment
- Passive Porosity Cowl
Continuous Mold Line Link

Slat-Cove Filler

Original Wing
(Noise Source Strength Shown by Contours)

Modified Wing
(Noise Sources Reduced to Background Level)
Landing Gear Noise Reduction

Toboggan Fairing
Summary

• Aircraft noise is critical to the future growth of the air transportation system.

• NASA is working closely with the JPDO and FAA to enable future growth of the air transportation system.

• Three pronged in-house research approach involving diagnostics, prediction and noise reduction.

• Excellent industry partnerships already in place and many universities engaged through the NRA process.

• Subsonic Fixed Wing project has aggressive noise level targets for N+1 and N+2 generation aircraft.