NASA Jet Noise Research

Brenda Henderson and
NASA Glenn Research Center

Turbine Engine Technology Symposium
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www.nasa.gov
Outline

• NASA Program Overview

• NASA Jet Noise Facilities

• Highlights of current jet noise research
Six thrust areas

• Safe, efficient growth in global operations
• Innovation in commercial supersonic aircraft
• Ultra-efficient commercial vehicles
• Transition to low-carbon propulsion
• Real-time system safety assurance
• Assured autonomy for aviation transformation

Four programs to address these areas

• Advanced Air Vehicles Programs (AAVP)
• Airspace Operations and Safety Program (AOSP)
• Integrated Aviation Systems Program (IASP)
• Transformative Aeronautics Concepts Program (TACP)
Advanced Air Vehicles Program (AAVP)

Studies, evaluates, and develops technologies and capabilities that can be integrated into fixed wing and vertical lift aircraft as well as explores far-future concepts that hold revolutionary improvements to air travel.

Aeronautics Evaluation and Test Capabilities
- Ground test capabilities
- Subsonic, transonic, supersonic, hypersonic wind tunnels and propulsion test facilities
- Ames, Glenn, and Langley

Advanced Air Transport Technology Project
- Revolutionize energy efficiency and environmentally compatible fixed wing transport aircraft
  - Fan and High-lift Noise

Revolutionary Vertical Lift Technology Project

Advanced Composites Project

Commercial Supersonic Technology Project
- Low Noise Propulsion for Low Boom Aircraft
Commercial Supersonic Technology (CST) Project

Develop tools, technologies, and knowledge to help eliminate today’s technical barriers to practical commercial supersonic flight: sonic boom, fuel efficiency, airport community noise, high-altitude emissions, structural weight and flexibility, airspace operations, and the ability to design future vehicles in an integrated, multidisciplinary manner.

Technical Challenges (TCs)

<table>
<thead>
<tr>
<th>TC Title</th>
<th>TC Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC 1.1 Low Sonic Boom Design Tools</td>
<td>Tools and technologies enabling the design of supersonic aircraft that reduce sonic boom noise to 80 PLdB validated as ready for application in a flight demonstrator</td>
</tr>
<tr>
<td>TC 1.2 Sonic Boom Community Response Metric &amp; Methodology</td>
<td>Validated field study methodology, survey tools and test protocols to support community studies with a demonstrator aircraft</td>
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<tr>
<td>TC 2.2 Low Noise Propulsion for Low Boom Aircraft</td>
<td>Design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 EPNdB less than FAR 36 stage 4 (ICAO chapter 4) demonstrated in ground test</td>
</tr>
</tbody>
</table>

Concluding with new technical challenge beginning FY2017
Integrated Aviation Systems (IAS) Program

Conducts flight oriented, integrated, system-level research and technology development that supports the flight research needs across the ARMD strategic thrusts, the programs, and their projects

Environmentally Responsible Aviation Project
- Explores and assesses new vehicle concepts and enabling technologies through system-level experimentation to simultaneously reduce fuel burn, noise and emissions
- Research Challenges
  - Advanced UHB Engine Designs for Specific Fuel Consumption and Noise Reduction
  - Advanced Airframe and Engine Integration Concepts for Community Noise and Fuel Burn Reduction

Unmanned Aircraft Systems Integration in the National Air Space System

Flight Demonstrations and Capabilities Project
- Conducts complex and integrated small scale flight research demonstrations
- Operates, sustains, and enhances flight research test capabilities
NASA Jet Facilities
Aero-Acoustic Propulsion Lab (AAPL)

• 65’ radius anechoic dome
• Nozzle Acoustic Test Rig (NATR)
  – A three-stream jet-engine simulator (HFJER) with simulated forward flight
• Small Hot Jet Acoustic Rig (SHJAR)
  – Single-stream, specialty jet rig
• Far-field acoustics, phased arrays, flow rakes, hotwire, schlieren, PIV, IR, Rayleigh, Raman, PSP
Twin jet aeroacoustic test with nozzles near aft deck fuselage section of Hybrid Wing Body
NASA Aircraft Noise Prediction Program (ANOPP2)

Len Lopes: Leonard.V.Lopes@nasa.gov

- **Total aircraft noise prediction capability for subsonic and supersonic aircraft**
  - ANOPP2: mixed-fidelity prediction framework that includes ANOPP and high-fidelity, physics-based analyses
  - Predict aircraft source noise, propagation and impact at receiver in near or far-field

- **Specific Capabilities for Supersonic Aircraft Applications**
  - Coupling with Model Center for high speed aircraft noise optimizations
  - Comprehensive ability to predict high speed jet mixing & broadband shock noise (JeNo, MDOE)
  - Methodologies for mixer-ejector configurations

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**Propagation Effects**
- Spherical spreading
- Atmospheric absorption
- Ground absorption/reflection
- Refraction/scattering
  - Wind profile
  - Temperature profile
  - Atmospheric turbulence
- Terrain effects

**Recent focus on**
- Jet/surface interaction
- Jet/jet interaction
ANOPP2: Mixed-Fidelity System Noise Framework

POC: Len Lopes: Leonard.V.Lopes@nasa.gov
Subsonic Jet Noise Prediction with JENRE

Daniel Ingraham, daniel.j.ingraham@nasa.gov

- JENRE: Jet Engine Noise Reduction code from the Naval Research Lab
  - Monotonically Integrated Large-Eddy Simulation (MILES) code using the flux-corrected transport (FCT) method to combine low- and high-order finite element schemes on unstructured meshes
  - Proven capability predicting noise from realistic supersonic jets, including chevrons, multiple streams, pylons.
  - Current work at NASA Glenn: validate JENRE capability against Glenn’s considerable experimental database of subsonic jet experiments
  - Long-term plan: use JENRE to investigate flows of interest to NASA, (tone producing jets, jet-surface interaction, offset streams, etc.)
Subsonic Jet Noise Prediction with JENRE

Daniel Ingraham, daniel.j.ingraham@nasa.gov

- Preliminary test case: set point 3 from the Tanna Matrix
  - Axisymmetric nozzle, unheated jet, exit Ma = 0.513
  - Axial velocity statistics show good agreement with experiment, despite relatively coarse grids (15e6 and 27e6 nodes)
  - Noise predictions in process.
JSI - High Aspect Ratio Nozzle

Clifford Brown, clifford.a.brown@nasa.gov

- 16:1 aspect ratio nozzle
- Flush mounted surface – vary lengths
- Acquired:
  - Far-field noise
  - Phased array noise source localizations
  - In-flow total pressure
  - Static pressure on surface

JSI trailing edge noise combined with resonance

Resonance depends on geometry and jet condition

\[
\Theta = 90^\circ
\]

\[
\frac{X_E}{h} = 9.5
\]

\[
Sth PSD (dB)
\]

\[
\begin{array}{c}
100 \\
90 \\
80 \\
70 \\
60 \\
50 \\
\end{array}
\]

\[
\begin{array}{c}
10^{-1} \\
1 \\
10 \\
10^1 \\
10^2 \\
\end{array}
\]

\[
St_h
\]
Jet Surface Interaction Noise – Planar Exhaust

Abbas Khavaran, abbas.khavaran@nasa.gov

Interaction of exhaust noise with a nearby solid surface
▪ An acoustic analogy simulation approach
▪ Predict mixing (scrubbing) noise and Trailing Edge Noise (TEN)

Assumptions
▪ High aspect ratio rectangular exhaust
▪ Locally parallel mean flow
▪ Generalized Acoustic Analogy (GAA) to predict scrubbing noise
▪ Rapid Distortion Theory (RDT) to predict TEN

Approach
▪ Mean flow and turbulence – Steady RANS
▪ Map RANS solution to acoustic grid
▪ Source/GF volume integration for scrubbing noise
▪ Source/GF area integration at the plate tip for TEN
▪ Superimpose two component noise

Reference: AIAA-2016-2863
Jet Surface Interaction Noise – Planar Exhaust

Abbas Khavaran, abbas.khavaran@nasa.gov

8:1 Rectangular Exhaust, N8ZH19XTE12

<table>
<thead>
<tr>
<th>Set Point</th>
<th>NPR</th>
<th>NTR</th>
<th>M</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP03</td>
<td>1.19</td>
<td>1.0</td>
<td>0.51</td>
</tr>
<tr>
<td>SP05</td>
<td>1.42</td>
<td>1.0</td>
<td>0.72</td>
</tr>
<tr>
<td>SP07</td>
<td>1.86</td>
<td>1.0</td>
<td>0.98</td>
</tr>
</tbody>
</table>

M=0.72

Near End of Plate
Three-Stream Nozzle Experiments

Brenda Henderson, brenda.s.henderson@nasa.gov

Core Cowl Length Investigations
Tertiary Cowl Length Investigations

<table>
<thead>
<tr>
<th>$A_b/A_c$</th>
<th>$A_t/A_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>1.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Nozzle Design Space

Jet Conditions

<table>
<thead>
<tr>
<th>NPR_c</th>
<th>NPR_b</th>
<th>NTR_c</th>
<th>NPR_t</th>
<th>Jet Type</th>
<th>Condition Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>1.6</td>
<td>3.0</td>
<td>1.0</td>
<td>Two</td>
<td>10% PLR</td>
</tr>
<tr>
<td>1.6</td>
<td>1.6</td>
<td>3.0</td>
<td>1.4, 1.8, 2.1</td>
<td>Three</td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>1.8</td>
<td>3.0</td>
<td>1.0</td>
<td>Two</td>
<td>Full Throttle</td>
</tr>
<tr>
<td>1.8</td>
<td>1.8</td>
<td>3.0</td>
<td>1.4, 1.8, 2.1</td>
<td>Three</td>
<td></td>
</tr>
</tbody>
</table>
Offset Stream Results

Center Plane

Azimuthal variation in peak jet noise direction

x/D_{eqA} = 0.2

x/D_{eqA} = 0.9

x/D_{eqA} = 1.6
Noise Predictions for Offset Three-Stream Jets

Stewart Leib  Stewart.J.Leib@nasa.gov

Improved turbulence modeling for three-stream jet RANS using Explicit Algebraic Stress Model
(Nicholas Georgiadis & Dennis Yoder)

Improved predictions of azimuthal variation of sound field

- $\theta = 120^\circ$
- $\theta = 150^\circ$
JSI - Multi-Stream Nozzle

Clifford Brown, clifford.a.brown@nasa.gov

- 2 and 3 stream nozzle systems
- Vary surface length and standoff
- Acquired:
  - Far-field noise
  - Phased array noise source localizations
- Empirical modeling of JSI noise spectra

Shielded Side
Aircraft Noise Assessments

Dennis Huff, Dennis.L.Huff@nasa.gov

Lockheed Martin “1044” Aircraft

<table>
<thead>
<tr>
<th>Configuration 1044</th>
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<tbody>
<tr>
<td><strong>Weight</strong> (TOGW) 320,000 lb</td>
</tr>
<tr>
<td>(Fuel) 168,000 lb</td>
</tr>
<tr>
<td>(EW) 136,000 lb</td>
</tr>
<tr>
<td><strong>Cruise</strong> M1.7</td>
</tr>
<tr>
<td>L/D 8.7</td>
</tr>
<tr>
<td><strong>Cabin</strong> Two-class, 80 pax</td>
</tr>
<tr>
<td><strong>Range</strong> &gt;5,000 nm</td>
</tr>
<tr>
<td><strong>Boom Strength</strong> (Full carpet) &lt;85 PLdB</td>
</tr>
</tbody>
</table>

Offset Nozzle Orientations

Engine Parametric Study

Each symbol represents a different combination of engine Overall Pressure Ratio (OPR), main engine bypass and throttle ratio, and design bypass ratio of the third stream (BPRt).
Effective Perceived Noise Levels

\[ \text{NPRc} = 1.8 \]
\[ \text{NPRt} = 1.6 \]
\[ \text{Ab/Ac} = 2.5 \]

Estimated to meet jet noise requirements for new Chapter 14 noise regulations with no margin

* Not approved by the FAA
Low Noise Propulsion for Low Boom Aircraft

James Bridges james.e.bridges@nasa.gov

Design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 EPNdB less than FAR 36 Stage 4 demonstrated in ground test.

Deliverables:
1) Validate noise prediction and system modeling tools for prediction & optimization of N+2 supersonic airliner
2) Integrated aircraft solutions meeting airport noise requirements with viable range and low boom
3) Validation of acoustic performance and predicted design trades.

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-axisymmetric jet noise code created.</td>
<td>IVPv2 tests meet expectations</td>
<td>Final candidate nozzles created.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IVPv2 design confirmed with LES.</td>
<td>First empirical models for three-stream and IVP nozzle systems</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Integration of noise prediction, innovative nozzles, and system modeling to achieve aggressive goals.
Conclusions

• **Modeling and predictions**
  • Modified Explicit Algebraic Stress Model (EASM) provides improved RANS solutions and leads to improved noise predictions for offset three-stream jets compared with the Shear Stress Transport (SST) model
  • Noise radiation from jet-surface interactions is predicted with a combination of an acoustic analogy and Rapid Distortion Theory (RDT)
  • NASA’s ANOPP2, a total aircraft noise prediction capability for subsonic and supersonic aircraft, has been released
  • Empirical models for jet-surface interactions have been developed and are incorporated in ANOPP2
  • Validation of NRL’s JENRE code for subsonic jets continues and has provided promising initial results

• **N+2 Supersonic Aircraft studies**
  • Offset streams provide slight effective perceived noise level reduction over that of axisymmetric jets for flyover certification point
  • Variable cycle engines provide increased range over mixed flow turbofans but do not meet Chapter 14 noise level requirements
  • Alternative takeoff procedures such as PLR will be needed to meet noise regulations
  • Low Noise Propulsion for Low Boom Aircraft Technical Challenge concludes in September 2016