Impact of Air Injection on Jet Noise

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Fall Acoustics Technical Working Group
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Objective

Determine impact of core fluidic chevrons on noise produced by dual stream jets

- Broadband shock noise - supersonic
- Mixing noise – subsonic and supersonic
Jet Noise Sources

Shock Noise

Mixing Noise

• Mixing noise
• Mach wave radiation
  Crackle
• Shock associated noise
  Broadband
  Discrete
• STOVL noise/tones

Fine Grain Turbulence

Large Scale Turbulence (Mach Wave Emission)

Mach Waves

Courtesy of D. Papamoschou
NASA Langley (LSAWT)

Low Speed Aeroacoustics Wind Tunnel
Jet Engine Simulator (JES)
Nozzle design was the result of a partnership between NASA Langley Research Center and Goodrich Aerostructures under SAA1-561
Generation III Fluidic Chevrons

- Core fluidic chevron nozzle
- 8 injectors
  - 4 pairs independently controlled
- No common plenum
Fluidic Chevron Nozzles

BPR 5

Fan Flow

Core Flow

Injection Flow

122° Pylon Angle

Microphone

Three Air Injection Nozzles

- 6I steep injection
- 6I shallow injection
- 8I steep injection
  - azimuthal control

Gen II

Gen III

Line 1
Line 2
Line 3
Line 4

National Aeronautics and Space Administration
Enhanced mixing shortens potential core and reduces volume of acoustic sources
Characteristics of Fluidic Chevrons

X/Dc = 8

Baseline

Mach 0.28
Takeoff
θ = 90°

SPL (dB)

Fluide Chevron - Generation II
Mechanical Chevron
Baseline

National Aeronautics and Space Administration
Experiments

Single Stream Experiments

- Fan stream operated at tunnel conditions

<table>
<thead>
<tr>
<th>NPR&lt;sub&gt;c&lt;/sub&gt;</th>
<th>TTR&lt;sub&gt;c&lt;/sub&gt;</th>
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<td>2.17</td>
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<td>2.30</td>
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Dual Stream Experiments

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<th>TTR&lt;sub&gt;c&lt;/sub&gt;</th>
<th>NPR&lt;sub&gt;f&lt;/sub&gt;</th>
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Free-stream Mach number = 0.10
Single Stream Results
Baseline nozzle and injection nozzles with IPR = 1.0 have similar noise characteristics.

\[ \theta = 61^\circ \]

\[ \text{NPR}_c = 2.17 \]
Effect of Increasing $\text{NPR}_c$

Well defined shock noise peak at $\text{NPR}_c = 2.17$
Injection at Low Supersonic Speeds

- Injector noise is not suppressed
- Increases in IPR produce reductions in mixing noise near peak jet noise angle

\[ \theta = 61^\circ \]

\[ \text{SPL (dB)} \]

\[ \text{Frequency (Hz)} \]

\[ \text{IPR = 1.0} \]
\[ \text{IPR = 2.0} \]
\[ \text{IPR = 4.0} \]

\[ \text{NPR}_c = 1.93 \]

\[ \theta = 148^\circ \]

\[ \text{SPL (dB)} \]

\[ \text{Frequency (Hz)} \]

\[ \text{IPR = 1.0} \]
\[ \text{IPR = 2.0} \]
\[ \text{IPR = 4.0} \]
Injection for Well-Defined Shock Noise

Increases in IPR produce reductions in shock noise and mixing noise

\[ \theta = 61^\circ \]

\[ \theta = 148^\circ \]

\[ \text{NPR}_c = 2.17 \]
Azimuthal Control for Shock Noise

Significant shock noise reduction can be achieved with injection near pylon

\[
\frac{\dot{m}_{\text{injection}_{1,2}}}{\dot{m}_{\text{core}}} = 1.1\%
\]

\[\theta = 61^\circ\]

\[\text{NPR}_c = 2.17\]

\[\theta = 148^\circ\]
Impact of Injection on Sideline Directivity

![Graph showing the impact of injection on sideline directivity. The graph plots OASPL (dB) against angle (deg) and uses different markers for IPR values of 1.0, 2.0, and 4.0.](image)
Dual Stream Results
Injection at Subsonic Core and Fan Speeds

Mixing noise reduction can be achieved with injection near observation side of jet

\[
\frac{m_{\text{injection}}}{m_{\text{core}}} = 1.6\%
\]

NPR\(_c\) = 1.56
NPR\(_f\) = 1.75

\(\theta = 90^\circ\)

\(\theta = 148^\circ\)
Injection at Subsonic Core and Fan Speeds

Injection produces mixing noise reduction at peak jet noise angle with slight increase in high frequency noise at $\theta = 90^\circ$.

- **$NPR_c = 1.56$**
- **$NPR_f = 1.75$**

### Table

<table>
<thead>
<tr>
<th>Nozzle</th>
<th>IPR</th>
<th>EPNL (EPNdB)</th>
<th>Injection Mass (% Core)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>All = 2.3</td>
<td>90.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Air Injection</td>
<td>All = 2.3</td>
<td>89.6</td>
<td>2.9</td>
</tr>
<tr>
<td>Air Injection</td>
<td>1,2,3 = 1.4 &amp; 4 = 2.3</td>
<td>89.4</td>
<td>1.6</td>
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$\theta = 148^\circ$
Baseline Results at $NPR_f = 2.23$

Increasing $NPR_c$
- Decreases shock noise peak
- Increases mixing noise near peak jet noise angle

$\theta = 61^\circ$

$\theta = 148^\circ$
Injection at Subsonic Core Speeds

$\theta = 61^\circ$

Increasing IPR decreases shock peak

$NPR_c = 1.61$

$NPR_f = 2.23$
Azimuthal Control at Subsonic Core Speeds

No noise reduction with Gen III nozzle due to low mass flow rates or steeper injectors.

\[ \theta = 61^\circ \]

\[ \theta = 148^\circ \]

\[ \text{NPR}_c = 1.61 \]
\[ \text{NPR}_f = 2.23 \]
Injection at Supersonic Core Speeds

\[ \theta = 61^\circ \]

Increases in IPR produce reductions in noise near peak jet noise angle.

\[ \theta = 148^\circ \]

\[ NPR_c = 2.04 \]
\[ NPR_f = 2.23 \]
Injection at Subsonic Core Speeds

Increasing IPR

- Has no impact on broadband shock noise
- Slightly reduces noise at peak jet noise angle

![Graph showing SPL vs. Frequency for different IPR values at θ = 61° and θ = 148°]

\[ \text{NPR}_C = 1.82 \]
\[ \text{NPR}_f = 2.35 \]
Points of Discussion

• Injection impacts shock structure and stream disturbances through enhanced mixing
  – May impact constructive interference between acoustic sources

• High fan pressures may inhibit mixing produced by core injectors
  – Fan stream injection may be required for better noise reduction
Future Plans

• Modification of Gen II nozzles to allow for some azimuthal control
  • Will allow for higher mass flow rates
  • Will allow for shallower injection angles
• Flow field study – spring, 2008
• CFD analysis of flow
Conclusions

• Injection can reduce well-defined shock noise

• Injection reduces mixing noise near peak jet noise angle