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
  - Broadband
  - Screech

- Mixing Noise
  - Fine Grain Turbulence
  - Large Scale Turbulence (Mach Wave Emission)

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

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 Line 1
Line 2
Line 3
Line 4

Gen III

National Aeronautics and Space Administration
Chevron Mixing Enhancement

- Enhanced mixing shortens potential core and reduces volume of acoustic sources
Characteristics of Fluidic Chevrons

X/Dc = 8

Tt, K

Baseline

Mach 0.28 Takeoff
\(\theta = 90^\circ\)

SPL (dB)

Fluidic Chevron - Generation II
Mechanical Chevron
Baseline

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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>1</td>
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<tr>
<td>2.04</td>
<td>1</td>
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<tr>
<td>2.17</td>
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<td>2.30</td>
<td>2.5</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.
Effect of Increasing NPR_{c}

Well defined shock noise peak at NPR_{c} = 2.17

θ = 61°

θ = 148°
Injection at Low Supersonic Speeds

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

\[ \theta = 61^\circ \]

\[ NPR_c = 1.93 \]
Injection for Well-Defined Shock Noise

Increases in IPR produce reductions in shock noise and mixing noise.

\[ \theta = 61^\circ \]

\[ \theta = 148^\circ \]

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

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Significant shock noise reduction can be achieved with injection near pylon.

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

\(NPR_c = 2.17\)

\(\theta = 61^\circ\)

\(\theta = 148^\circ\)
Impact of Injection on Sideline Directivity

![Graph showing OASPL (dB) vs. Angle (deg) for IPR values of 1.0, 2.0, and 4.0.](image)

- **OASPL (dB)**
- **Angle (deg)**

Legend:
- **IPR = 1.0**
- **IPR = 2.0**
- **IPR = 4.0**

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

$$\frac{\dot{m}_{\text{injection}}}{\dot{m}_{\text{core}}} = 1.6\%$$

(National Aeronautics and Space Administration)
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 $\theta = 90^\circ$.

$\theta = 90^\circ$

$NPR_c = 1.56$
$NPR_f = 1.75$

<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>$1,2,3 = 1.4$ &amp; 4 = 2.3</td>
<td>89.4</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Baseline Results at $\text{NPR}_f = 2.23$

Increasing $\text{NPR}_c$

- Decreases shock noise peak
- Increases mixing noise near peak jet noise angle

$\theta = 61^\circ$

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

Increasing IPR decreases shock peak

$\theta = 61^\circ$

$\theta = 148^\circ$

$NPR_c = 1.61$

$NPR_f = 2.23$
No noise reduction with Gen III nozzle due to low mass flow rates or steeper injectors.

\[ \theta = 61^\circ \]

\[ \text{NPR}_c = 1.61 \]
\[ \text{NPR}_f = 2.23 \]

\[ \theta = 148^\circ \]
Injection at Supersonic Core Speeds

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

\[ \theta = 61^\circ \]

IPR = 1.0
IPR = 2.5
IPR = 4.0

NPR_c = 2.04
NPR_f = 2.23

\[ \theta = 148^\circ \]

IPR = 1.0
IPR = 2.5
IPR = 4.0
Injection at Subsonic Core Speeds

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

\[ \theta = 61^\circ \]

\[ \text{NPR}_c = 1.82 \]
\[ \text{NPR}_f = 2.35 \]

\[ \theta = 148^\circ \]
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