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
- Screech
- Broadband

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

6I steep injection

6I shallow injection

8I steep injection

– azimuthal control

Three Air Injection Nozzles

Gen II

Gen III

Line 1
Line 2
Line 3
Line 4
• Enhanced mixing shortens potential core and reduces volume of acoustic sources
Characteristics of Fluidic Chevrons

X/Dc = 8

Baseline

Tt, K

8l

6l

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

5 dB

SPL (dB)

10 100 1000 10000

Frequency (Hz)

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>2.04</td>
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<td>2.17</td>
<td>1</td>
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<tr>
<td>2.30</td>
<td>2.5</td>
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Dual Stream Experiments

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<tr>
<td>1.56</td>
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<td>1.61</td>
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<td>1.05</td>
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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.

NPR\(_c\) = 2.17
Effect of Increasing NPR$_c$

Well defined shock noise peak at NPR$_c$ = 2.17

$\theta = 61^\circ$

$\theta = 148^\circ$
Injection at Low Supersonic Speeds

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

$\theta = 61^\circ$

$\text{NPR}_c = 1.93$

$\theta = 148^\circ$
Injection for Well-Defined Shock Noise

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

$\theta = 61^\circ$

$NPR_c = 2.17$

$\theta = 148^\circ$
Azimuthal Control for Shock Noise

Significant shock noise reduction can be achieved with injection near pylon

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

NPR\(_c = 2.17\)

\( \theta = 61^\circ \)

\( \theta = 148^\circ \)

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Impact of Injection on Sideline Directivity

Graph showing OASPL (dB) vs Angle (deg) for different IPR values: IPR = 1.0 (diamonds), IPR = 2.0 (squares), and IPR = 4.0 (triangles).

Graph indicates a trend where higher IPR values result in lower OASPL values at the same angle.

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Dual Stream Results
Injection at Subsonic Core and Fan Speeds

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

\[
\frac{\dot{m}_{\text{injection}_2}}{\dot{m}_{\text{core}}} = 1.6\%
\]

\[\theta = 90^\circ\]

\[\theta = 148^\circ\]

NPR\textsubscript{c} = 1.56
NPR\textsubscript{f} = 1.75

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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 90°.

\[ \theta = 90^\circ \]

\[ \text{NPR}_c = 1.56 \]
\[ \text{NPR}_f = 1.75 \]

<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>All = 2.3</td>
<td>89.6</td>
<td>2.9</td>
</tr>
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<td>1,2,3 = 1.4 &amp; 4 = 2.3</td>
<td>89.4</td>
<td>1.6</td>
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\[ \text{NPR}_c = 1.56 \]
\[ \text{NPR}_f = 1.75 \]

\[ \theta = 148^\circ \]
Baseline Results at NPR$_f$ = 2.23

Increasing NPR$_c$

- Decreases shock noise peak
- Increases mixing noise near peak jet noise angle
Injection at Subsonic Core Speeds

\[
\theta = 61^\circ
\]

Increasing IPR decreases shock peak

\[
\theta = 148^\circ
\]

\[
NPR_c = 1.61
\]

\[
NPR_f = 2.23
\]
Azimuthal Control at Subsonic Core Speeds

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

$\theta = 61^\circ$

$NPR_c = 1.61$
$NPR_f = 2.23$

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

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

\[ \theta = 61^\circ \]

\[ \theta = 148^\circ \]

\[ \text{NPR}_c = 2.04 \]

\[ \text{NPR}_f = 2.23 \]
Injection at Subsonic Core Speeds

Increasing IPR

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

\( \theta = 61^\circ \)

\( \theta = 148^\circ \)

\( \text{NPR}_c = 1.82 \)

\( \text{NPR}_f = 2.35 \)

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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