Fluidic Injection for Jet Noise Reduction

Brenda Henderson
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Investigations into fluidic injection for jet noise reduction began over 50 years ago. Studies have included water and air injection for the reduction of noise in scale model jets and jet engines and water injection for the reduction of excess overpressures on the Space Shuttle at lift-off. Injection systems have included high pressure microjets as well as larger scale injectors operating at pressures that can be achieved in real jet engines. An historical perspective highlighting noise reduction potential is presented for injection concepts investigated over the last 50 years. Results from recent investigations conducted at NASA are presented for supersonic and subsonic dual-stream jets. The noise reduction benefits achieved through fluidic contouring using an azimuthally controlled nozzle will be discussed.
Fluidic Injection for Jet Noise Reduction

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Overview

• Brief history of fluidic injection
  – Water and air

• NASA’s acoustic measurements since 2002 on air injection
  – Generation I nozzles
  – Generation II nozzles
  – Generation III nozzles

• NASA’s flow-field measurements - 2009

• Concluding remarks
First Experiments – Kurbjun (1958)

- Engine produced 8000 lb thrust with afterburning
- 880 gallons of water/minute at 100 psig

Results from Kurbjun (1958)

- Low frequency reduction
- Roughly 6 dB OASPL in peak jet noise direction
- Reductions at other angles much smaller

150°, 150 feet
First Patent – Lilley (1961)

July 4, 1961

G. M. LILLEY

JET NOISE SUPPRESSION MEANS

Filed May 8, 1958

2,990,905

Reduction of jet noise through

- Enhanced mixing
- Restricted formation of large eddies

Fig. 1. Fig. 2.

Fig. 3. Fig. 6.
40 - 50 Years Later


Water
40 – 50 Years Later

Water and Air
40 - 50 Years Later

G. M. LILLEY

JET NOISE SUPPRESSION MEANS

Filed May 8, 1958

1961


Air

2006
What Have We Learned?

Air and Water

- Penetration into primary jet is a function of momentum ratio
- High pressure microjet systems are more effective at reducing noise than low pressure systems with larger injectors
  - High pressure systems – usually operate above 300 psia
  - No strict definition of ‘microjet’

Microjet System

Low Pressure, Large Injector System
What Have We Learned?

Water

• Reduces jet velocity through momentum transfer
• Reduces jet temperature through evaporation
• Modifies turbulence
• Often more effective at reducing noise in cold jet than in hot jets
• Effectively reduces overpressures in Shuttle lift-off environment – MFR can be > 100%
What Have We Learned?

**Air**
- Counter-rotating vortices are created in primary jet
  - Alters mixing characteristics of primary jet
  - Alters turbulence of primary jet

What Have We Learned?

Air

- Reductions in low frequency noise can be offset by increases in high frequency noise for dual stream jets
  - 1 EPNdB – studies limited
- Limited studies conducted for dual stream supersonic jets

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  – Supersonic jets – Generation II and III

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Motivation for NASA Experiments

- Enhanced mixing shortens potential core and reduces low frequency acoustic radiation
Mechanical Chevron Noise Reduction

OASPL

90° Observation Angle

150° Observation Angle

SPL dB

1/3 Octave Frequency Band (Hz)
Can Mixing Be Achieved Another Way?

Mechanical Chevrons

Fluidic Chevrons

Fan Flow

Injection Flow

Core Flow
Total Temperature Contours

X/Dc = 2

X/Dc = 5

X/Dc = 8

Baseline

8l

6l
Low Speed Aeroacoustics Wind Tunnel Langley
Generation I Air Injection Nozzles

- Common plenum
- Exhaust slots
- No control over flow angle
- Thick trailing edges
- Inflow and alternating nozzles
Generation I Noise Characteristics

- Low frequency reductions offset by high frequency increases on an EPNL basis

\[ \theta = 90^\circ \]

Representative takeoff conditions at \( M_{fj} = 0.28 \)
Generation II Nozzles

Gen II Nozzles

- Common plenum
- Contoured channels
- Exhaust slots near nozzle trailing edges
- Thin trailing edges between injection ports
- All 6 inflow injectors
  - Steep & shallow
  - Short & long
  - Perforated
Generation II Steep Injectors

- Increasing IPR reduces low frequency noise and increases high frequency at small observation angles

Representative takeoff conditions at $M_{fj} = 0.28$
Comparison with Generation I Nozzles

Improved Acoustic Characteristics

- Controlled injection angle
- Thin nozzle trailing edges
- Controlled injection location

\[ \theta = 90^\circ \]
Comparison with Mechanical Chevrons

Noise reduction characteristics are approaching those of the mechanical chevron after two generations of development.
Noise Reduction Characteristics

Noise Reduction Approach
- Decrease low frequency noise with increased perpendicular velocity
- Control high frequency noise with reduced perpendicular momentum
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Single Supersonic Stream - Gen II

$\theta = 61^\circ$

$NPR_c = 2.17$

Cold

Increasing IPR reduces shock noise and mixing noise

$\theta = 148^\circ$
Supersonic Fan, Transonic Core–Gen II

Increasing IPR decreases shock noise

\[ \theta = 61^\circ \]
\[ \text{NPR}_c = 1.61 \]
\[ \text{NPR}_f = 2.23 \]

Hot Core

\[ \theta = 148^\circ \]
Supersonic Fan, Transonic Core–Gen II

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

\[ \theta = 61^\circ \]
\[ \theta = 148^\circ \]

\[ NPR_c = 1.82 \]
\[ NPR_f = 2.35 \]

Hot Core
Generation III Nozzle
Azimuthally Controlled

- 8 Inflow injectors
  - 4 pairs independently controlled
- No common plenum

<table>
<thead>
<tr>
<th>Feature</th>
<th>Gen II</th>
<th>Gen III</th>
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<tbody>
<tr>
<td>Higher Mass Flow</td>
<td></td>
<td>●</td>
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<tr>
<td>Steeper Injection Angle</td>
<td>●</td>
<td></td>
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<tr>
<td>Greater # of Injectors</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Azimuthal Control</td>
<td>●</td>
<td>●</td>
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</table>
Single Supersonic Stream – Gen II & III

Similar shock noise reductions for Gen II and III

\[ \text{MFR}_{\text{inject, GenIII}} = 0.8\% \]
\[ \text{MFR}_{\text{inject, GenII}} = 1.9\% \]

\[ \theta = 148^\circ \]

\[ N\text{PR}_c = 2.18 \]

Cold

**Diagram Notes:**
- **SPL (dB)**
- **Frequency (Hz)**
- **Legend:**
  - LIPR = 1.0 (Gen III)
  - LIPR = 2.0 (Gen III)
  - LIPR = 2.0 (Gen II)
Effect of Azimuthal Control

- One injection line needed for significant shock noise reduction
- Some mixing noise reduction with four lines

$\theta = 61^\circ$

$\theta = 148^\circ$

$NPR_c = 2.18$
Effect of Azimuthal Control

Injection near pylon reduces shock noise more than injection at other azimuthal locations

$\theta = 61^\circ$

$NPR_c = 2.18$

$\theta = 148^\circ$
Equal Mass Injection

$\theta = 61^\circ$

$MFR = 0.7\%$

$NPR_c = 2.18$

$\theta = 61^\circ$

$MFR = 1.2\%$
Equal Mass Injection

\[ \theta = 148^\circ \]

\[ MFR = 0.7\% \]

\[ MFR = 1.2\% \]

\[ NPR_c = 2.18 \]
Supersonic Fan, Transonic Core–Gen II

- No shock noise reduction
- Little mixing noise reduction

\[ \theta = 61^\circ \]

\[ NPR_f = 2.36 \]
\[ NPR_c = 1.82 \]

\[ \theta = 148^\circ \]
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Aero-Acoustic Propulsion Laboratory
Glenn
Subsonic Dual Stream – Gen II

Mean Velocity

High Injection Pressure

Intermediate Injection Pressure

No Injection

Takeoff
Subsonic Dual Stream – Gen II

Turbulence

Intermediate Injection Pressure

No Injection

Takeoff
Supersonic Fan, Transonic Core–Gen II

Intermediate Injection Pressure

No Injection

\[ NPR_c = 1.61 \]
\[ NPR_f = 2.23 \]

Hot Core
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Conclusions

• Noise reduction in subsonic dual-stream jets
  – Control injection angle and location
  – Control nozzle trailing edge thickness
• Noise reduction in single stream supersonic jets
  – Broadband shock noise controlled with moderate injection pressure
  – Higher pressures are required for mixing noise reduction
• Noise reduction in dual-stream supersonic jets
  – Limited reduction possible with core injection