Screech Noise Modes in Supersonic Rectangular Twin Jets

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Motivation

• Twin-jet engines are prevalent in military aircraft
  Coupled flow fields radiate much higher noise to certain directions and much higher near-field dynamic pressure load/structural fatigue
  Understanding and control of coupling is expected to lead to significant reduction of noise levels as well as dynamic pressure loading

• Dual-use application - Future commercial aircraft
  Highly integrated propulsion and airframe with closely spaced engines
Non-Axisymmetric Twin Jets
Geometry of the Future

- Non-axisymmetric jet and twin-jet configurations are of interest for better integration of propulsion & aerodynamics among other reasons
Jet Noise Components

- Mixing Noise
  - Large scale turbulent structures
- Broadband Shock Associated Noise
- Screech
Screech

- Discrete tonal noise present in imperfectly expanded supersonic jets
- Can be detrimental to structural integrity of engine nozzle
- Upstream and sideline directivity

http://www.spl.ch/old/news/index.html
Screech Feedback Loop

- The interaction between shock waves, and large-scale turbulent structures in the shear layer form acoustic waves traveling in the upstream direction outside the jet.
- These acoustic waves interact with the receptive region of the jet-plume, located in the vicinity of the nozzle exit, reinforcing the formation of large-scale turbulent structures, creating a closed feedback loop.

Screech Modes

- Structure of screech feedback loop can vary depending on jet Mach number.
- Coupling and amplification of noise for twin jets can vary depending on each mode.

Phase of feedback loop for each jet can vary

Out-of-phase

In-phase

‘Axisymmetric’
In-phase on both axes
Project Objectives

• Ultimate Goal: Explore the flow physics of closely spaced, low aspect ratio rectangular nozzles for a range of operating regimes and to control the jets using Localized Arc Filament Plasma Actuators (LAFPAs).
  – Coupling between turbulent structures in twin jets may then be reduced, thus reducing the overall noise amplification between the jets.

• Specific Objective: Identify the screech modes for flow regimes ranging from highly overexpanded to highly underexpanded cases.
Experimental Approach:

Facility:
- $6.2 \, m \times 5.6 \, m \times 3.4 \, m$ chamber size and anechoic down to 160 Hz
- Compressed air source for continuous running of unheated jets and capable of running heated jet up to $TTR \sim 2.5$ (800 K)
- Co-flow allowing forward-flight simulation ($M \approx 0.3$)

Flow Excitation:
- 16 independently-controlled LAFPA channels powered by dedicated power supplies
- 8 plasma actuators per nozzle
Experimental Approach:

Facility: Twin Jets

- Two 0.95” × 0.47” (AR = 2), bi-conical nozzles
- Modular design
- $M_d = 1.5$
- Nozzle spacing: $s/D_e = 2.35$ ($D_e = 0.724”$
- 8 independent LAFPA actuators on each nozzle
Experimental Approach:

Diagnostics: Near-field Microphone Array

- **Setup specs:**
  - 5 microphones located at $r/D_e = 5$ and $x/D_e = 0$
  - Extremely low gain (1 mV/Pa) to prevent saturating the microphones
  - The microphones were aligned with nozzle centerlines using a laser level to improve accuracy.
  - All reflective surface were covered with thick acoustic foam.

- 100 blocks of 8192 recordings were acquired at 200 kHz for each excited case
Near-Field Coherence/Phase/Spectra: Baseline $M_j = 1.25$, Mic. 2 & 3, Vertical Plane, Out-of-Phase Coupling (Mode I)
Near-Field Coherence/Phase/Spectra: Baseline \(M_j = 1.80\), Mic. 2 & 3, Vertical Plane, In-Phase Coupling (Mode II)
Near-Field Coherence/Phase/Spectra: Baseline $M_i = 1.70$, Mic. 1 & 4, Horizontal Plane, In-Phase Coupling (Mode III)
Near-Field Coherence/Phase/Spectra: Baseline $M_i = 1.70$, Mic. 2 & 3, Vertical Plane, In-Phase Coupling (Mode III)
<table>
<thead>
<tr>
<th>Range of Mach numbers</th>
<th>Coupling Mode</th>
<th>Mode Characteristics</th>
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<td>$M_j = 1.25 - 1.55$</td>
<td>Mode I</td>
<td>Out-of-phase flapping in vertical plane</td>
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<tr>
<td>$M_j = 1.60 - 1.65$</td>
<td>Mode II</td>
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<td>$M_j = 1.70$</td>
<td>Mode III</td>
<td>In-phase coherence in vertical and horizontal planes</td>
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<tr>
<td>$M_j = 1.75 - 1.85$</td>
<td>Mode II</td>
<td>In-phase flapping in vertical plane</td>
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