Testing Installed Propulsion for Shielded Exhaust Configurations

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Challenges of installed exhaust noise

• Prediction
  – Complex geometries, tightly integrated propulsion make complex grids
  – Distributed noise sources hard to propagate
  – Multiple-stream nozzles create large parameter space

• Model-scale Experiments
  – Large planforms to fit in facilities
  – Scale factors push frequencies
  – Jet flow supply bigger than engines

Aeroacoustic Facility Capability/Limitations

- Nozzle Acoustic Test Rig (NATR) in Aero-Acoustic Propulsion Lab at NASA Glenn
- Three independent air streams for nozzle models, large far-field
- 53” (1.35m) Ø freejet flight stream
Simulating propulsion-airframe in NATR

- Aircraft positioned relative to microphones in ceiling
Simulating propulsion-airframe in NATR

- Aircraft superimposed on jet rig for outboard engine, matching nozzle size
- Note how much larger jet rig is than nacelle
Fitting planform inside freejet flight stream

• Can’t put whole plane in!
• Avoid crossing freejet shear layer.
• How much vehicle planform required?
Objective 1: How much planform required for aeroacoustic testing of installed exhaust noise?

- Trim aircraft planform to fit within freejet.
- Neglect curvatures outside of pylon contours in immediate contact with flow.
Objective 1: How much planform required for aeroacoustic testing of installed exhaust noise?

- Result: minimal aircraft planform
  - Captures reflection of jet plume noise sources.
  - Provides accurate trailing edge to interact with turbulent plume.
  - Minimizes support hardware that may cause parasitic noise, reflection.

Objective 1 of current test was to determine size requirements for flight stream tests.
Objective 2: Extending previous jet-surface interaction (JSI) database to realistic exhaust systems

- Initial JSI database created for simple, single-stream nozzle with semi-infinite flat surface without flight
- Modeling of acoustic impact due to shielding completed for initial JSI database\(^1\).
- Extend JSI database by including
  - Plug nozzles
  - Dual-stream nozzles
  - Finite span of surface
  - Pylon features
  - Flight stream

Progression of nozzle complexity

- Extending JSI from simple, single-stream jets to practical exhaust systems:

  - Simple, single-stream
  - External plug, single-stream
  - External plug, multi-stream
Flow matrices tested

- Single-stream on plugged nozzle to relate to simple, single-stream cases
  - Unheated, 0.5 < M < 1.4
  - Use both core stream or both to vary jet diameter
  - Equivalent diameters 3.7”-6.9” (93-172mm)

- Dual-stream flows on plugged nozzles (C1, C3)
  - Vary area ratio (1.0:1, 2.5:1)
  - Vary bypass ratio
  - Fixed temperature ratios
  - Equivalent diameters 5.2”-6.9” (132-172mm)

Table 1 Definitions of single-stream setpoints on the C1 nozzle. NPR<sub>b</sub> matches NPR<sub>c</sub> when outer stream is active.

<table>
<thead>
<tr>
<th>Setpoint</th>
<th>NPR&lt;sub&gt;c&lt;/sub&gt;</th>
<th>NTR&lt;sub&gt;c&lt;/sub&gt;</th>
<th>NPR&lt;sub&gt;b&lt;/sub&gt;</th>
<th>Ma</th>
<th>M</th>
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<tr>
<td>300</td>
<td>1.200</td>
<td>1</td>
<td>1</td>
<td>0.50</td>
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<tr>
<td>330</td>
<td>1.200</td>
<td>1</td>
<td>1.200</td>
<td>0.50</td>
<td>0.52</td>
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<tr>
<td>500</td>
<td>1.435</td>
<td>1</td>
<td>1</td>
<td>0.70</td>
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<tr>
<td>550</td>
<td>1.435</td>
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<td>1.435</td>
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<td>0.74</td>
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<tr>
<td>700</td>
<td>1.856</td>
<td>1</td>
<td>1</td>
<td>0.90</td>
<td>0.98</td>
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<tr>
<td>770</td>
<td>1.856</td>
<td>1</td>
<td>1.856</td>
<td>0.90</td>
<td>0.98</td>
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<td>3.183</td>
<td>1</td>
<td>1</td>
<td>1.19</td>
<td>1.40</td>
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</table>

Table 2 Matrix of setpoints for conventional dual-stream flows on nozzles C1 and C3.

<table>
<thead>
<tr>
<th>Setpoint</th>
<th>NPR&lt;sub&gt;c&lt;/sub&gt;</th>
<th>NTR&lt;sub&gt;c&lt;/sub&gt;</th>
<th>NPR&lt;sub&gt;b&lt;/sub&gt;</th>
<th>NTR&lt;sub&gt;b&lt;/sub&gt;</th>
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<td>1.5</td>
<td>3</td>
<td>1.8</td>
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<td>1813</td>
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<td>2323</td>
<td>2.3</td>
<td>3</td>
<td>2.3</td>
<td>1.25</td>
</tr>
</tbody>
</table>
Surface parametric variations tested—flat surface

- Vary standoff $h_E$ and length $x_E$ as before.
- Standoff and length measured from first nozzle lip.

$h_E = 0”$  

$h_E = 8.5”$ (215mm)

$x_E = 0”$  

$x_E = 42”$ (1067mm)
Complex planforms: Simulated LM1044 aircraft

- Planforms created for center engine and outboard engine configurations.
- Static test—no flight stream. No compromises on size.
- Scale factor ~9:1
Problem: Rig-Planform Integration

- Issue with fitting surface around rig
  - Irregular mating surface
  - Real problem with variable standoff

- With flight this creates a juncture flow problem
  - Rig bigger diameter than nacelle
  - Critical (nonrepresentative) because leaves low-velocity deficit near nozzle.

- Need to cover some region upstream of nozzle lip
  - Represent fore of aircraft planform
  - Diffraction of sound at upstream edge of surface?
Solution: Biplane

- Add surface above rig, parallel to planform
- Extends acoustic shielding forward
- Simple, no interference with rig
- Design questions:
  - How big?
  - How much overlap with main surface?
  - What jet conditions needed?
- Several biplane geometries tried
- Phased array used to find leakage

Long (1.2m) biplane surface, no overlap

Short (0.5m) biplane surface, max overlap (190mm)
Far-field acoustic microphones and phased array

- 24-microphone polar array at ~15m radius
  - 45°—160° @ 5° increments
  - ~70 jet diameter distance
  - 120Hz – 80kHz

- 48-element phased array (OptiNav)
  - Not at the same time as far-field!
  - Nearly the same plane as far-field
  - ~2m distance, 90° polar angle
  - 200Hz – 32kHz
  - Conventional and Functional beamforming algorithms
Impact of Biplane Geometry—Biplane Overlap

- Spectral directivity of far-field sound, colored by difference (in dB) in sound between long biplanes with and without overlap (overlap minus no overlap), at maximum standoff.
- Subsonic jet shows no difference with overlap.
- Supersonic (shock-containing) jet has significant differences in screech and broadband shock noise with biplane overlap.
Effect of biplane on subsonic jet noise

- Spectral directivity of far-field sound, colored by difference (in dB) in sound between **long** biplane with **max** overlap and **no biplane**
  - Difference is only significant at polar angles < 55°
- Source map at frequency of maximum difference (3.3kHz) suggests noise reflecting off surface supports to be the source of discrepancy
  - Not edge diffraction!
- Acquired JSI database with long biplane with max overlap anyway.
Database of dual-stream nozzles

• Examples of data acquired for dual-stream nozzle flows at various flows
  • Surface length $x_E/De = 2.2$, standoff $h_E = 0$.
  • Colors indicate difference in sound, with surface minus without.
  • Trailing edge dipole (low frequency, 90°) dominant at low speeds.
  • Significant shielding at high frequencies.
  • Surprising reduction in aft angle noise; change in directivity?
  • To be used in empirical modeling$^1$.

<table>
<thead>
<tr>
<th>NPRc:</th>
<th>1.3</th>
<th>1.8</th>
<th>2.1</th>
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<tbody>
<tr>
<td>NPRb:</td>
<td>1.22</td>
<td>1.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Source distributions of dual-stream vs single-stream

- Axial location of peak source strength (as measured by phased array) vs frequency.
- Axial location normalized by calculated potential core length $\beta$, equivalent jet diameter $D_e$, and shifted origin $x_0$.
- Values of $\beta$, $D_e$, $x_0$ that normalize flow\textsuperscript{1,2} do not collapse source distribution.

Source distributions in multi-stream jets

- Sound source maps produced by the phased array and overlaid on the array’s field of view for a range of frequencies.
- Typical of all multi-stream flows examined.
- Sources roughly located at end of potential core over wide range of frequencies.
- Sudden shift to nozzle at $St_{De} = 3$. 

![Source distributions](image_url)
Complex geometries, azimuthal observers

- Source distributions for center engine configuration
- 12.5kHz modelscale (~1500Hz fullscale)
- Source distribution predominantly at nozzle
- Residual sources (< 10dB of peak) aft of trailing edge (note scales)
- Exposed sources slightly higher with surface, suggests surface enhances mixing noise sources.

Bare nozzle, total field
Bare nozzle, exposed field
Installed, flyover observer
Installed, lateral observer
Discussion

• Phased array invaluable in determining if planform approximations are acoustically valid.
• PIV near surfaces will be critical in confirming that test articles are aerodynamically valid.
• Impact of surface on screeching jet very tricky, perhaps not surprising given that flow is dominated by resonance.
• Installed subsonic jets do not appear to need much upstream planform. Seems better to foreshorten surface and improve aerodynamics at nozzle. Use biplane if required.
• Finite span surfaces/ azimuthal angle variations show that line-of-sight blockage of sound source distributions explains majority of shielding observations.
Summary

- Aeroacoustic testing of installed exhaust is a new challenge.
  - Critical, given role of shielding in low-noise concept vehicles.
  - Working on what test model approximations are valid, what are incorrect.
- Biplane concept developed to extend surface upstream with minimal rig interference and flow impact. May not be critical for subsonic flows.
- Jet-Surface Interaction acoustic database extended to subsonic dual-stream nozzles with external plugs, on surfaces with finite span.
- Phased array confirmed planform coverage was adequate.
- Source distributions of dual-stream plumes different than single-stream.
- Planforms simulating conceptual aircraft were tested, will be used to confirm application of simple JSI models to realistic geometries.