Jet Surface Interaction

Scrubbing Noise from High Aspect-Ratio Rectangular Jets

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FW Projects
Motivation

Interaction of jet exhaust with nearby solid surfaces:
- Hybrid Wing Body (HWB) concepts
- High aspect ratio rectangular exhaust with extended beveled surfaces
- Over the wing engine mount
- Nearby structural components could provide noise shielding
- They could also produce new sources of sound
Geometry – Rectangular Exhaust

\[ b = 8a \]

\[ X_{TE} / a = 18 \]

\[ a = 5.35 \times 0.67 \text{ (in}^2) \]

\[ M_a = 0.90, \ h = 0, \ X_{TE} = 12'' , \ \theta = \pi/2 \]

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* J. Bridges, AIAA-2014-0876
Outline

- Governing Equations
- Propagation Green’s Fun (GF) in High-AR Rectangular Jets
- Sample GF - 8:1 Aspect Ratio Jet Exhaust
- Scrubbing Noise Spectra and Data Comparison
- Summary
NS Equations \( \rightarrow \) (Mean Flow + Linear Fluctuations)
- Locally Parallel Mean Flow
- Compressible
- Constant Static Pressure
- Ideal Gas Law

### Variable density Pridmore-Brown eq.

\[
L \pi' = \Gamma, \quad \pi' \approx \frac{p'(\bar{x},t)}{\gamma \bar{p}} \quad \text{(Goldstein 2010)}
\]

\[
L \equiv D \left( D^2 - \frac{\partial}{\partial x_j} \left( c^2 \frac{\partial}{\partial x_j} \right) \right) + 2c^2 \frac{\partial U}{\partial x_j} \frac{\partial^2}{\partial x_1 \partial x_j}, \quad D \equiv \frac{\partial}{\partial t} + U \frac{\partial}{\partial x_1}
\]
Green’s Function Method

\[ \pi'(\bar{x}, t) = \int \int G(\bar{x}, t; \bar{y}, \tau) \Gamma(\bar{y}, \tau) d\tau d\bar{y} \]

\[ LG(\bar{x}, t; \bar{y}, \tau) = \delta(\bar{x} - \bar{y}) \delta(t - \tau) \]

- Wetted side of the plate only
  (Trailing Edge Noise component discussed by Goldstein et al, 2013)

Transform:

\[ (x_1 - y_1, x_2 - y_2, t - \tau) \rightarrow (k_1, k_2, \omega) \]

\[ G(\bar{x}, t; \bar{y}, \tau) \rightarrow \hat{G}(\vec{k}_t, x_3; y_3, \omega) \quad \vec{k}_t \equiv (k_1, k_2) \]

- Far-field Spectrum

\[ \bar{p}^2(\bar{x}, \omega) = \int \int \int \int G^*(\bar{x}, \bar{y} - \bar{\xi}/2; \omega) G(\bar{x}, \bar{y} + \bar{\xi}/2; \omega) q(\bar{y}, \bar{\xi}, \tau) e^{i\omega \tau} d\tau d\bar{\xi} d\bar{y} \]
GF Method (Cont’d)

- Stationary Phase solution \((\kappa_o R \gg 1, \kappa_o = \omega / c_\infty)\)

\[
\tilde{k}_t^s = \kappa_o (\sin \phi^s \cos \theta^s, \cos \phi^s)
\]

\[
G(\bar{x}, \bar{y}; \omega) \sim -i \frac{e^{i\Theta(\tilde{k}_t^s, \bar{x}, \omega)}}{(2\pi)^3 R} \frac{\sin \theta^s \sin^2 \phi^s}{c_\infty^2 \sin \theta^s \sin \phi^s} \frac{b_2(\tilde{k}_t^s, \omega)V_1(\tilde{k}_t^s, y_3, \omega)}{W_o(\tilde{k}_t^s, \omega, \bar{Z})} \frac{(1 - M_\infty \sin \phi^s \cos \theta^s) \Im}{\left(1 - \frac{U(\bar{y}_3)}{c_\infty} \sin \phi^s \cos \theta^s\right)^2}
\]

\[
\Theta(\tilde{k}_t, \bar{x}, \omega) = k_1(x_1 - y_1) + k_2(x_2 - y_2) - \chi_\infty x_3
\]

\[
V_2(\tilde{k}_t, x_3, \omega) = b_2(\tilde{k}_t, \omega)e^{-i\chi_\infty x_3} \quad x_3 \to \infty
\]

- Two linearly independent solutions

\[
V_j(\tilde{k}_t, x_3, \omega), \quad j = 1, 2
\]

\[
V_j'' + f(\tilde{k}_t, x_3, \omega)V_j = 0
\]

\(0 \leq \theta \leq \pi, \quad 0 \leq \phi \leq \pi\)
Numerical Results

- SolidWorks RANS (k-ε Turb Model) – Commercial Code
- Mapping – Cloud Solution to Structured Grid
- Normalized GF \( G_N \equiv \pi c_\infty^3 \left( \frac{G}{G_{FS}} \right) \)
- Strouhal Frequency \( St \equiv a f / U_j \)
- Source Location \( \eta \equiv y_3 / a \)

Simulation Conditions

<table>
<thead>
<tr>
<th>Set Point</th>
<th>Standoff h (in)</th>
<th>XTE (in)</th>
<th>NPR</th>
<th>NTR</th>
<th>( M_j )</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP07 (H02XTE12)</td>
<td>0.20</td>
<td>12</td>
<td>1.86</td>
<td>1.0</td>
<td>0.98</td>
</tr>
<tr>
<td>SP07 (H19XTE12)</td>
<td>1.90</td>
<td>12</td>
<td>1.86</td>
<td>1.0</td>
<td>0.98</td>
</tr>
<tr>
<td>SP07 (Isolated)</td>
<td>NA</td>
<td>NA</td>
<td>1.86</td>
<td>1.0</td>
<td>0.98</td>
</tr>
<tr>
<td>SP05 (H19XTE12)</td>
<td>1.90</td>
<td>12</td>
<td>1.42</td>
<td>1.0</td>
<td>0.72</td>
</tr>
<tr>
<td>SP03 (H19XTE12)</td>
<td>1.90</td>
<td>12</td>
<td>1.19</td>
<td>1.0</td>
<td>0.51</td>
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</tbody>
</table>
SolidWorks Mesh* – N8Z

Jet Major Axis

Jet Minor Axis

* Rick Bozak, 2013
RANS Solution (Mapped to Rectangular Grid)

Block 1: 70 171 109 \((x_1, x_2, x_3)\)

Block 2: 81 171 169

SP07-H02-XTE12, \(X_1 X_3\) Plane
Mean Axial Velocity (SP07-H02-XTE12)

ON PLATE

OFF PLATE
$G_N$ – Above Surface

N8Z – SP07-H02-XTE12

$(\theta = \pi / 4, St = 0.25)$

Section Profile $(x = 0.52FT)$

$(G_N –$ Analytical Profile $)$

Greene function $G$, vs source location $(D = \pi \cdot r / D)$

$B_1$: Rectangular Jet, $H_0 = 36''$, $H_1 = 12''$, $(D = 0.6666\, \text{ft}, S = 0.25)$

$F_1$: Rectangular Jet, $H_0 = 36''$, $H_1 = 12''$, $(D = 0.6666\, \text{ft}, S = 0.25)$

NASA (solid works), Interpolation Grids of 119, Profile used at (Block1, J=33, K= Plane Of Symmetry)

Jan. 2015
GN—Downstream the Plate \( (\theta = \pm \pi / 4, St = 0.25) \)

\[ \theta = +45^\circ \]

\[ \theta = -45^\circ \]
Sample Results
(1/3 Octave Lossless Spectra, Arc = 100D_{eq})

N8Z – SP07-H02-XTE12

* Measured Spectra, C. Brown & J. Bridges, GRC
Sample Results (Cont’d)

N8Z – SP07-H02-XTE12

1/3 Octave SPL (dB)

120°

140°

Freq (Hz)
Sample Results (Cont’d)
N8Z – SP07-H02-XTE12

Trailing Edge Noise
Sample Results (Cont’d)

N8Z – SP07-Isolated

% TKE^{0.5}/U_j

\[ \begin{array}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|} \hline
x (FT) & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 \\
\hline
Y & 0.2 & 0.1 & 0 & -0.1 & -0.2 & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\hline
\end{array} \]

90°

1/3 Octave SPL (dB)

Freq (Hz)

Data
Prediction
Sample Results (Cont’d)
N8Z – SP05-H19-XTE12

% TKE$^{0.5}/U_j$

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Summary

- The GF was evaluated using RANS input (SolidWorks)
- The mean flow was considered as locally parallel in two directions (HAR rectangular jets)
- Source calibration parameters (length- and time-scales) follow the usual method (TKE and $\varepsilon$) in a RANS-based Acoustic Analogy.
- Spectral component associated with scrubbing noise dominated at HF
- Jet plume downstream of the TE contributed to low- to mid-frequency
- Trailing Edge Noise (TEN) should be superimposed on present predictions.

Next Step

- Consistency across operating conditions requires mean flow and turbulence validation (data and/or alternative RANS solvers)
- Heated jets (enthalpy-related source).
QUESTIONS ?