Jet Surface Interaction

Scrubbing Noise from High Aspect-Ratio Rectangular Jets

Abbas Khavaran
Richard Bozak
NASA Glenn Research Center

Acoustics Technical Working Group Meeting
April 21–22, 2015
NASA Langley, Hampton, VA

NASA Fundamental Aeronautics Program
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

- $b = 8a$
- $a = 5.35 \times 0.67 \text{ (in}^2\text{)}$
- $X_{\text{TE}} / a = 18$

$M_a = 0.90, h = 0, X_{\text{TE}} = 12", \theta = \pi/2$

1/3 Octave SPL (dB)

- Trailing edge noise
- Reflected/scrubbing noise

*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
Scrubbing Noise

- NS Equations \(\rightarrow\) (Mean Flow + Linear Fluctuations)
- Locally Parallel Mean Flow
- Compressible
- Constant Static Pressure
- Ideal Gas Law

Variable density Pridmore-Brown eq.

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

\[
L \equiv D \left( D^2 - \frac{\partial}{\partial x_j} \left( c^2 \frac{\partial}{\partial x_j} \right) \right) + 2c^2 \frac{\partial U}{\partial x_j} \frac{\partial^2}{\partial x_1 \partial x_j}, \quad D \equiv \frac{\partial}{\partial t} + U \frac{\partial}{\partial x_1}
\]

(Goldstein 2010)
Green’s Function Method

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

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

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

**Transform:**

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

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

- **Far-field Spectrum**

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

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

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

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

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

- Two linearly independent solutions

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

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

\(0 \leq \theta \leq \pi, \quad 0 \leq \phi \leq \pi\)
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>8:1 Aspect Ratio Rectangular Exhaust (N8Z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set Point</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>SP07 (H02XTE12)</td>
</tr>
<tr>
<td>SP07 (H19XTE12)</td>
</tr>
<tr>
<td>SP07 (Isolated)</td>
</tr>
<tr>
<td>SP05 (H19XTE12)</td>
</tr>
<tr>
<td>SP03 (H19XTE12)</td>
</tr>
</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, \(X_1X_3\) Plane
Mean Flow (SP07-H02-XTE12)

U (fps)

T(static) / T∞
Turbulence (SP07-H02-XTE12)

% $TKE^{0.5}/U_j$

LengthScale$/a$

FreqScale$^*(a/U_j)$
$G_N$ – Above Surface

N8Z – SP07-H02-XTE12

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

Section Profile ($x = 0.52$ FT)

$G_N$ – Analytical Profile

Greens function $G$, vs source location ($D = a$, $x = r / D$)
8:1 Rectangular Jel, Heo=20", Xle = 12", $\theta = 0.06061^\circ$, $b = 8$, $ST = 1 D / U_j$)
N 和 (Grid Works), Interpolation Grid20110, Profile used at (Block#1,J=33, K= PlaneOfSymmetry)
Jan. 2015
$G_N$—Downstream the Plate  ($\theta = \pm \pi / 4, St = 0.25$)

Section Profile ($x = 2.39$ FT)

$\theta = +45^\circ$

$\theta = -45^\circ$
Sample Results

(1/3 Octave Lossless Spectra, Arc = 100D_{eq})

N8Z – SP07-H02-XTE12

60° Inlet Angle

90°

N8Z-SP07-H02X12; Inlet Angle = 90 deg
(CL, CT) = (0.74, 0.93); (Am, Sm)=(4.727, 4.379), JSIT VER-5T
Arc = 17.76FT, LOSSLESS

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

N8Z – SP07-H02-XTE12

120°

140°
Sample Results (Cont’d)

N8Z – SP07-H02-XTE12

Trailing Edge Noise

% TKE$^{0.5}/U_j$

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

Y

x (FT)

B1

B2

1/3 Octave SPL (dB)

Freq (Hz)

Data

B1 (Surface)

B2

B1 + B2

90°
Sample Results (Cont’d)

N8Z – SP07-H19-XTE12

1/3 Octave SPL (dB)

Freq (Hz)

Data
B1 (Surface)
B2
B1 + B2

TEN

90°
Sample Results (Cont’d)

N8Z – SP07-Isolated

% TKE^{0.5}/U_j

Y

X (FT)

1/3 Octave SPL (dB)

Freq (Hz)
Sample Results (Cont’d)

N8Z – SP03-H19-XTE12

% TKE^{0.5}/Uj

1  2  3  4  5  6  7  8  9  10 11 12 13 14 15 16 17

B1     B2

Y

-0.2 0.1

-0.2 -0.1 0 0.1 0.2

x (FT)

B1

TEN

1/3 Octave SPL (dB)

Data

B1 (Surface)

B2

B1 + B2

Freq (Hz)

10^2 10^3 10^4 10^5
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 ?