Measurement, Prediction, and Reduction of High Frequency Aerodynamic Noise Generated and Radiated from Surfaces of Various Textures and Impedance

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Problem: Excess High Frequency Noise

Closed Test Section with Hard Walls

Closed Test Section with Soft Walls

freq/U (kph)

Ls (dBA) - 50Log(U(kph))
Problem: Excess High Frequency Noise

![Graph showing sound level vs. frequency for different tunnels and velocities.]

- Tunnel A 80 kph
- Tunnel A 100 kph
- Tunnel A 140 kph
- Tunnel A 180 kph
- Tunnel C 80 kph
- Tunnel C 100 kph
- Tunnel C 140 kph
- Tunnel C 180 kph

Closed Test Section with Soft Walls

¾ Open Jet Anechoic Test Section
Measurements – Surface Pressures

- 1” Microphones
- 4 locations in line
Measurements – In-Flow

• Sound Pressure
• Sound Intensity
  ➢ 2 closely spaced ¼” microphones
  ➢ Vector component
  ➢ Rejects flow induced noise
  ➢ Rejects off-axis background Noise
  ➢ Data quality indicators
Cases

- Full coarse sand paper
- $\frac{1}{2}$ sand paper/$\frac{1}{2}$ smooth
- Foam
  - Existing
  - Treated
- Full smooth surface
- Wall vs. floor
Turbulent Boundary Layer Pressure Fluctuations

Rough Wall

- Convected low wavenumber TBL pressure fluctuations
- Non-convected low wavenumber TBL pressure fluctuations
- Tunnel acoustic background noise (center of test section)
- Local Acoustic wall pressure fluctuations
- Radiated acoustic pressure fluctuations

Pressure Level vs. Frequency plot.
Normalized Sound Pressure Level
12", 6", & 3" from Wall Foam & Bare Floor – 80 km/h
Sound Pressure & Intensity
12” from Wall Foam & Bare Floor

1/3 Octave Band Sound Pressure/Sound Intensity Level, dB

Frequency, Hz

- SPL (wall)
- IL (wall)
- SPL (floor)
- IL (floor)
Sound Intensity at 80 km/h
Wood, Foam, Full & ½ Coarse Sand Paper

- Smooth Wood
- Current Foam
- Coarse Sand Paper
- 1/2 Coarse Sand Paper

Sound Intensity Level, dB vs Frequency, Hz
Rough vs. Smooth Wall

Pressure Level vs. Frequency for Rough Wall and Smooth Wall.
Surface Pressure

Wood, Foam, & Full Sand Paper

[Graph showing sound pressure level for Wood, Foam, and Sand Paper at 80 kph across different frequencies]
Intensity Probe Phase Shift
Above Wood, Foam, & Sand Paper

Cross Spectrum Phase, degrees

Frequency, Hz
Surface Pressure – Microphone 1
Wood, Full & ½ Sand Paper

[Sound Pressure Level vs. Frequency Graph]

- Wood at 80 kph
- Sand Paper at 80 kph
- 1/2 Sand Paper at 80 kph

Microphone 1
Flow
Surface Pressure – Microphone 3
Wood, Full & ½ Sand Paper

- Wood at 80 kph
- Sand Paper at 80 kph
- 1/2 Sand Paper at 80 kph

Sound Pressure Level, dB vs. Frequency, Hz

Microphone 3
Surface Pressure – Microphone 4

Wood, Full & ½ Sand Paper

Sound Pressure Level, dB vs. Frequency, Hz

- Wood at 80 kph
- Sand Paper at 80 kph
- 1/2 Sand Paper at 80 kph

Microphone 4
Surface Pressure at 80 km/h

Uncoated/Coated Foam

![Graph showing sound pressure level against frequency for smooth wood, existing foam, and treated foam.](image-url)
Sound Intensity at 80 km/h

Uncoated/Coated Foam

- Smooth Wood
- Coated Foam
- Uncoated Foam
- Coarse Sand Paper
Notes on Simulations

• Simulations examine separate effects of roughness size and wall impedance
• Fix patch size and the spacing of roughness elements relative to roughness size
• Assume the roughness elements are dynamically and geometrically similar; examine relative levels.
• Vary wind speed, roughness size, and impedance of the wall (rigid and foam)
• Vary height of measurement above roughness patch.
• Simulate the general geometry of the test patch in the wind tunnel floor
Measured and Simulated Sound from Patch of Roughness

Measured and simulated sound levels from a finite size patch provide levels in the same frequency band and the same relative dependence on size, as measured.
Impedance and Reflection Coefficient, Absorbing Walls

Sound-absorbing wall has reduced reflection coefficient and therefore reduced specular interference of lift dipoles with their
Far Field Sound from Patch on Rigid Surface, 2m Elevation

Sound in the geometric far field from a rough patch on a rigid wall shows classical directivity of roughness shear stress dipoles with intensity upstream and down stream.

Sound pressure level is normalized on height from the wall; i.e. 
\[ 10\log \left( \frac{p^2z^2}{P_{ref}^2} \right) \]
Near Field Sound from Patch on Rigid Surface, Rigid Surface, 6in Elevation

Sound in the geometric near field from a rough patch on a rigid wall shows a maximum in the patch center.

Sound pressure level is normalized on height from the wall; i.e. 
$10\log\left[p^2 z^2 / P_{ref}^2 \right]$. 

[Graph showing sound level along a fly-over plane, 6 in Elevation 140 km/h]
Far Field Sound from Patch of Foam Surface, 2m Elevation

Sound in the geometric far field from a rough patch on a sound absorbing wall shows directivity of roughness “lift” stress and shear stress dipoles with intensity upstream, downstream, and normal to the surface.

Sound pressure level is normalized on height from the wall; i.e.

\[ 10 \log \left( \frac{p^{2}z^{2}}{P_{\text{ref}}^{2}} \right) \]
Near Field Sound from Patch of Foam Surface, 6in Elevation

Sound in the geometric near field from a rough patch on a sound absorbing wall shows directivity of roughness shear stress dipoles with maximum intensity at the patch center. Levels are reduced by roughly 5dB relative to a hard surface.

Sound pressure level is normalized on height from the wall; i.e. $10\log \left[ \frac{p^2 z^2}{P_{ref}^2} \right]$. 

![Sound Level Along Fly-Over Plane, 6 in Elevation 140 km/h](image)

[13] The Sound Level Along Fly-Over Plane, 6 in Elevation 140 km/h
Conclusions

• Liner roughness and waviness caused excess noise; the coating remedied this.

• The foam liner also altered the acoustic propagation characteristics of the roughness dipoles
  - More omnidirectional than rigid surface
  - Still had absorptive behavior

• Low frequency excess noise is determined by global waviness and roughness condition of the liner; high frequencies locally by the roughness elements, themselves.