Comparison of Spatial Correlation Parameters between Full and Model Scale Launch Vehicles

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Introduction and Background

- Launch vehicle liftoff acoustic environment defined by multiple sound sources and vehicle/launch pad geometry
- Characterize the acoustic field generated by the propulsion system
  - Ratio of diffuse to propagating field
  - Decay coefficient
  - Angle of incidence
- Critical input to the vibro-acoustic modeling software to determine structural/component response to the acoustic loading prescribed by the liftoff acoustic environments
- State of the art application and a first in the field of heavy-lift launch vehicles
Introduction and Background

- Spatial definition of fluctuating pressure environments are needed to better determine hardware responses to a given acoustic spectra
- Use acoustic pressure measurement pairs to characterize cross-spectral relationships between individual locations within the acoustic field
Objective and Approach

- Compare spatial correlation parameters ($R$, $\beta$, $\varphi$) between two scale model tests (ASMAT, SMAT) and one full-scale vehicle flight (Delta IV Heavy)
  - Only time a full scale vehicle was instrumented with sensors capable of measuring this
  - Unique opportunity!

- Calculate auto- and cross-spectral densities during time window of largest pressure readings
  - Spatial correlation parameters can be calculated from these

- Convert spatial correlation parameters to 1/3 octave band
  - Scale model test results were converted to “full-scale” frequency
Measurement Location

- Model (SMAT): 260’
- Model (ASMAT): 252’
- Full Scale (EFT-1): ~180-190’

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Tower Side v. Open Side

Tower side

Open side

Tower side

Open side

Tower side

Open side

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Spatial Plates

SMAT Plate

ASMAT Plate

Delta IV “Plate”

Model Scale dimensions are 5% size of full scale dimensions. Roughly same spacing
Decay Coefficient, $\beta$

- Describes how sound field decays as it propagates along vehicle

$$\beta = \left(\frac{r_1}{r_2}\right)^n e^{-\alpha d \cos \phi}$$

- $r_1, r_2$: 
- $n$: geometric decay coefficient
- $\alpha$: atmospheric decay coefficient
- $d$: spacing between sensors
- $\phi$: angle of incidence

- Frequency dependent
Ratio of Diffuse to Propagating Wave, $R$

- Defines the relative relationship between the two primary field types, diffuse and propagating

\[
R = \frac{\rho_{\text{diffuse}}(r,t)}{\rho_{\text{propagating}}(r,t)} \quad \therefore \quad R = \frac{R_{dd}(\tau)}{R_{pp}(\tau)} = \frac{G_{dd}(f)}{G_{pp}(f)}
\]

- Frequency dependent
Angle of Incidence

- Defines directionality of field
  - Measured relative to the vertical axis of vehicle

- \[ \cos \phi = \frac{\theta \cdot c}{2\pi f \cdot d} \]
  - \( \theta \): relative phase
  - \( c \): speed of sound
  - \( 2\pi f \): angular frequency
  - \( d \): spacing between sensors

- Frequency independent
Linear Coherence, OS

![Linear Coherence Graph](image)

- **EFT-1**
- **ASMAT**
- **SMAT**
Linear Coherence, TS

- **EFT-1**
- **ASMAT**
- **SMAT**

Frequency [Hz]
Decay Coefficient, $\beta$, OS

![Graph showing the decay coefficient, $\beta$, for different bands. The graph plots decay coefficient against 1/3 octave band center frequency in Hertz. The bands are EFT-1, ASMAT, and SMAT.](image-url)
Decay Coefficient, $\beta$, TS

![Graph showing decay coefficient over 1/3 octave band center frequency (Hz)]
Ratio of Diffuse to Propagating Field, $R$, OS

![Graph showing the ratio of diffuse to propagating field, $R$, as a function of 1/3 Octave Band Center Frequency [Hz]. The graph includes three curves representing EFT-1, ASMAT, and SMAT.]
Ratio of Diffuse to Propagating Field, $R$, $TS$

![Graph showing the ratio of diffuse to propagating field with frequency on the x-axis and ratio on the y-axis, with curves for EFT-1, ASMAT, and SMAT labeled.]
### Angle of Incidence, $\varphi$

<table>
<thead>
<tr>
<th></th>
<th>Open Side</th>
<th>Tower Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFT-1</td>
<td>13.4</td>
<td>0</td>
</tr>
<tr>
<td>SMAT</td>
<td>11.3</td>
<td>10.3</td>
</tr>
<tr>
<td>ASMAT</td>
<td>12</td>
<td>6.4</td>
</tr>
</tbody>
</table>

### Graph

- **Open Side**
- **Tower Side**

**Azimuthal Location**

EFT-1: 13.4°

SMAT: 11.3°

ASMAT: 12°
Conclusions

- Sound field is propagating at stations high up on vehicle
  - True for both open side and tower side
- Beta near 1 at all frequencies
  - Indicates a small amount of decay for the distances investigated
  - True for both open side and tower side
- Angle of incidence
  - Good agreement for open side
  - Tower side may have been too diffuse for our method to capture angle of incidence accurately

- Agreement between model scale and full scale results suggest that using model scale spatial correlation parameters to predict full scale sound field is reasonable.
THANK YOU

QUESTIONS?
BACKUP
Measurement Location

Model (SMAT)  Model (ASMAT)  Full Scale (EFT-1)

200' C6  200' Z7  ~180-190'

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Linear Coherence, OS

![Linear Coherence Graph](image)

- EFT-1
- ASMAT
- SMAT

Frequency [Hz]

Linear Coherence

Frequency [Hz]

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000
Linear Coherence, TS

![Graph showing linear coherence vs frequency for EFT-1, ASMAT, and SMAT.](image-url)
Decay Coefficient, $\beta$, OS

![Graph showing decay coefficient vs. 1/3 Octave Band Center Frequency (Hz)]

- Red line: EFT-1
- Green line: ASMAT
- Blue line: SMAT

1/3 Octave Band Center Frequency [Hz]

Decay Coefficient, $\beta$
Decay Coefficient, $\beta$, TS

![Graph showing decay coefficient $\beta$ over 1/3 octave band center frequency in Hz for EFT-1, ASMAT, and SMAT.]
Ratio of Diffuse to Propagating Field, $R$, OS

![Graph showing the ratio of diffuse to propagating field for different frequency bands.](Image)

The graph illustrates the ratio of diffuse to propagating field ($R$) across various 1/3 Octave Band Center Frequencies (Hz). The frequencies range from 10 Hz to 1000 Hz, with the ratio $R$ spanning from 0 to approximately 4.5.

- The red line represents the EFT-1 data.
- The green line represents the ASMAT data.
- The blue line represents the SMAT data.

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Ratio of Diffuse to Propagating Field, $R$, $TS$

![Graph of Ratio of Diffuse to Propagating Field, $R$, $TS$]

- **EFT-1**
- **ASMAT**
- **SMAT**

1/3 Octave Band Center Frequency [Hz]

Ratio of Diffuse to Propagating Field, $R$