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 \( (R, \beta, \phi) \) 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’
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

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

- $r_1, r_2$: 
- $n$: 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

- $R = \frac{p_{\text{diffuse}}(r,t)}{p_{\text{propagating}}(r,t)} \therefore R = \frac{R_{dd}(\tau)}{R_{pp}(\tau)} = \frac{G_{dd}(f)}{G_{pp}(f)}$

- 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]

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

- EFT-1
- ASMAT
- SMAT
Decay Coefficient, $\beta$, OS

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

![Graph showing the ratio of diffuse to propagating field, $R$, across different $1/3$ octave band center frequencies. The graph includes curves labeled EFT-1, ASMAT, and SMAT.]
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>

Azimuthal Location

- Open Side
- Tower Side

EFT-1
ASMAT
SMAT
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) 200' C6

Model (ASMAT) 200' Z7

Full Scale (EFT-1) ~180-190'

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Linear Coherence, OS

![Graph showing linear coherence over frequency]

- EFT-1
- ASMAT
- SMAT

Frequency [Hz]

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Linear Coherence, TS

Frequency [Hz]

0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000

EFT-1  ASMAT  SMAT
Decay Coefficient, $\beta$, OS

![Graph showing the decay coefficient, $\beta$, for three different categories: EFT-1, ASMAT, and SMAT. The graph plots $\beta$ against the 1/3 Octave Band Center Frequency in Hz. The x-axis ranges from 10 to 1000 Hz, and the y-axis from 0 to 1.]
Decay Coefficient, $\beta$, TS

![Graph showing decay coefficient $\beta$ versus 1/3 Octave Band Center Frequency [Hz] for EFT-1, ASMAT, and SMAT.](image)
Ratio of Diffuse to Propagating Field, R, TS

![Graph showing the ratio of diffuse to propagating field (R) across different 1/3 octave band center frequencies (Hz) for EFT-1, ASMAT, and SMAT.](image)

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