Low and High Frequency Models of Response Statistics of a Cylindrical Orthogrid Vehicle Panel to Acoustic Excitation

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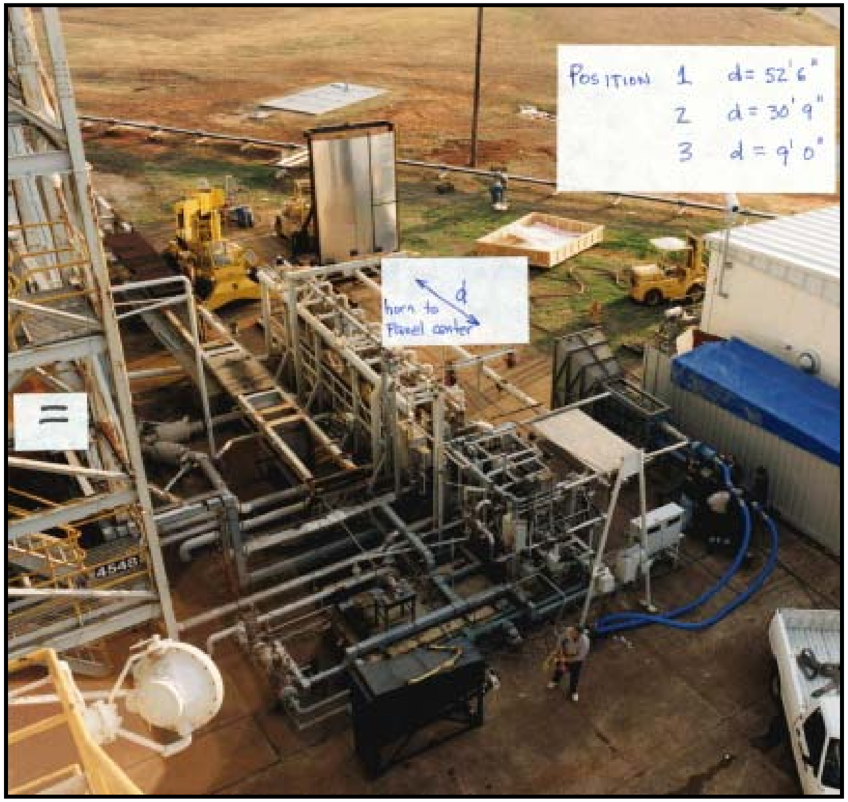
Outline

- **Background**
- Model for Low/Mid Frequency (Finite Element)
- Model for High Frequency (SEA)
- Conclusions

Reference: "Orthogrid Acoustic Test Report," 809-2087, Lockheed Martin Contract NAS8-36200, April 1997.

Acoustic noise generating equipment from building 4619 was moved to the Hot Gas Facility and setup such that the panel could be located at varying distances from the noise source.

More Information In Backup Slides.



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Background: Analysis Trials Compared to Ground Test Data

- This presentation further develops the orthogrid vehicle panel work of Reference 1. Employed Hybrid Module capabilities to assess both low/mid frequency and high frequency models in the VA One simulation environment. The response estimates from three modeling approaches are compared to ground test measurements.
  - Detailed **Finite Element Model** of the Test Article - Expect to capture both the global panel modes and the local pocket mode response, but at a considerable analysis expense (time & resources).
  - A **Composite Layered Construction** equivalent global stiffness approximation using SEA - Expect to capture response of the global panel modes only.
  - An SEA approximation using the **Periodic Subsystem Formulation.** A finite element model of a single periodic cell is used to derive the vibroacoustic properties of the entire periodic structure (modal density, radiation efficiency, etc… Expect to capture response at various locations on the panel (on the skin and on the ribs) with less analysis expense.

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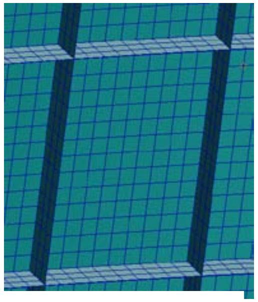
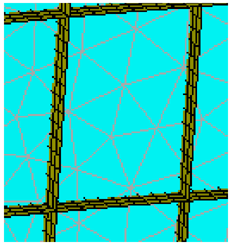
Model for Low/Mid Frequency

Response for a detailed Finite Element model to both Diffuse Acoustic Field (DAF) and Propagating Wave Field (PWF) was calculated in VA One

- Create FEM with enough fidelity for frequency range of interest:
  - Element Edge Length “Rule of Thumb”: minimum of 6 elements per flexural (bending) wavelength to accurately represent higher order mode shapes [18]
  - Element Edge Length Actual ~0.54” adequate for bending wavelength of ~3.24.”
  - FEM Subsystem **“Face Re-meshing”** for application of DAF and PWF type pressure loading can improve computational efficiency. (“Face” also provides interface with Fluid subsystems in the Hybrid Simulation Space.)
- Calculated 2800 modes below 2000 Hz. Explored the results for frequency bands below 1000 Hz.
- Using the face re-mesh speeds up the solution. Results were computed by selecting 500 modes to support each band in ~14 h (64bit, 2.13 GHz, 24 GB RAM up to 8 parallel Processors) Expensive Calculation.
  - Solutions were possible on a machine with less resources by focusing on just a few frequency bands at a time (6) and using ~100 modes per band.
  - (32bit, 2.39 GHz, 3.43 GB RAM machine was possible ~1.5h)



“Face Re-meshing”



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Model for Low/Mid Frequency

Finite Element Model- Cylindrical Orthogrid Panel (~ 10ft x 15 ft)

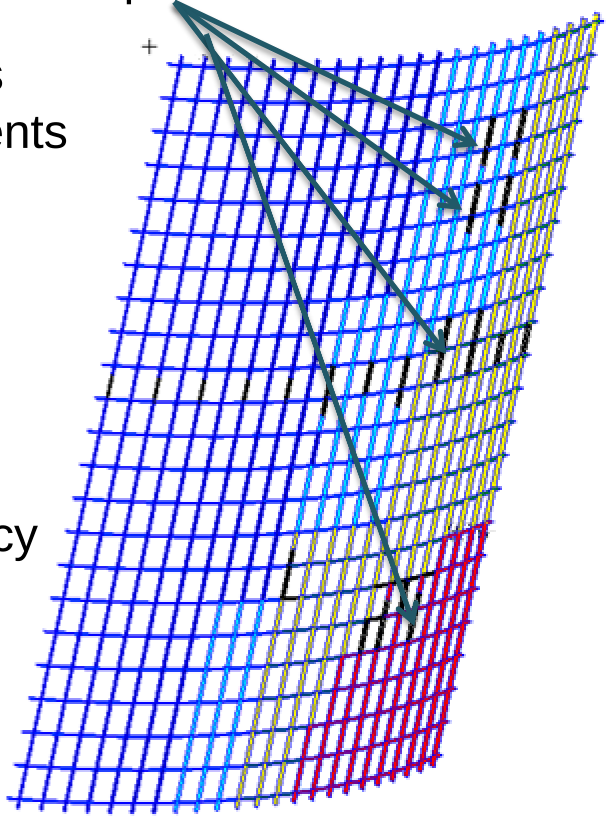
Results were computed in 1/36th octave bands to maximize response magnitude

115032 nodes
115927 elements

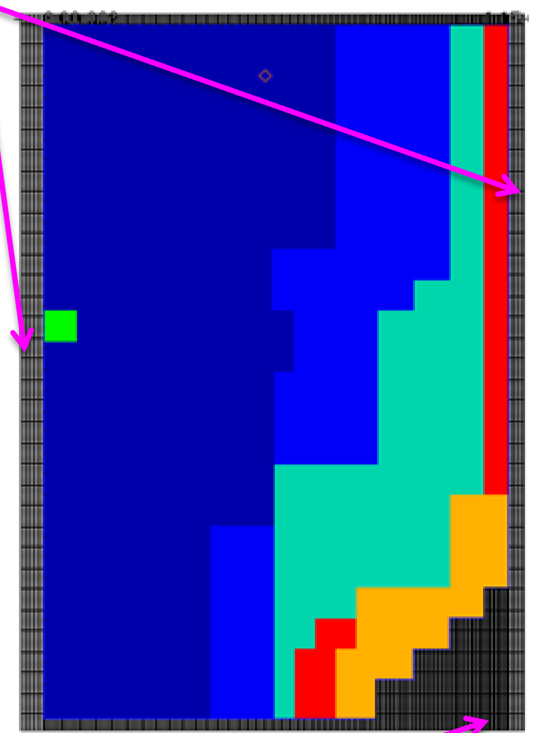
1/36th octave band Solution

500 modes bracketing the center frequency of each band

Rib Build-ups



Weld-Land Thickness around Perimeter

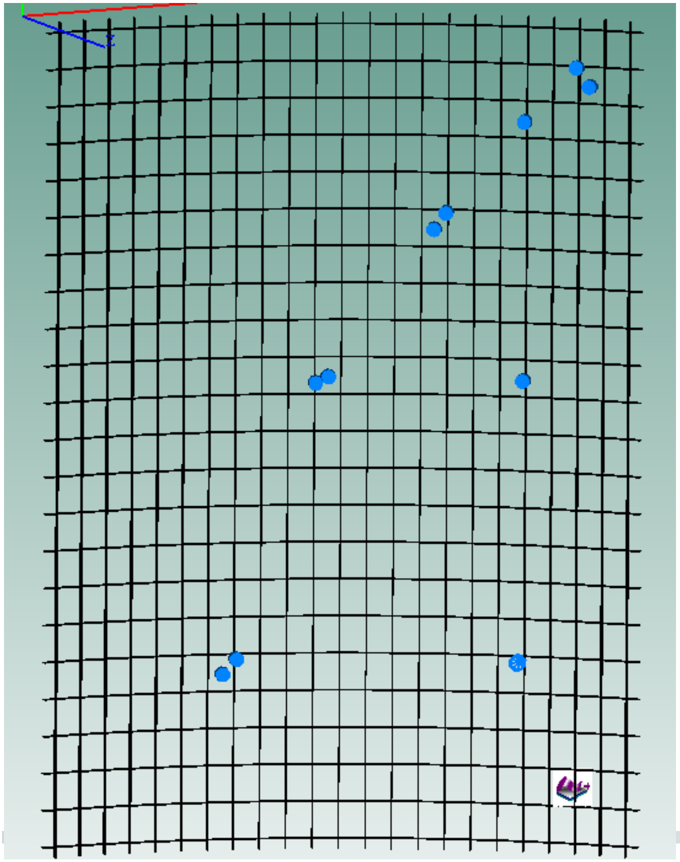


Thickest Skin at Bottom Corner

Model for Low/Mid Frequency

A random distribution of Sensors at Pocket Skin locations supplements those Sensors representing measurement locations from the ground test

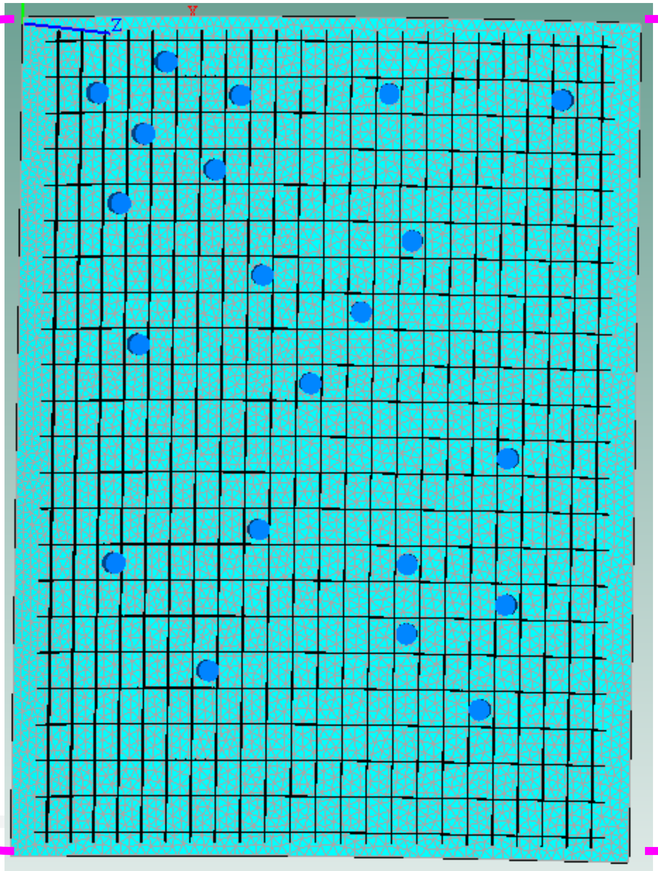
Sensors at Measurement Locations



Fixed Boundary Condition applied to two long edges of panel.

Radiation to SIF not included

Random Distribution of Sensors



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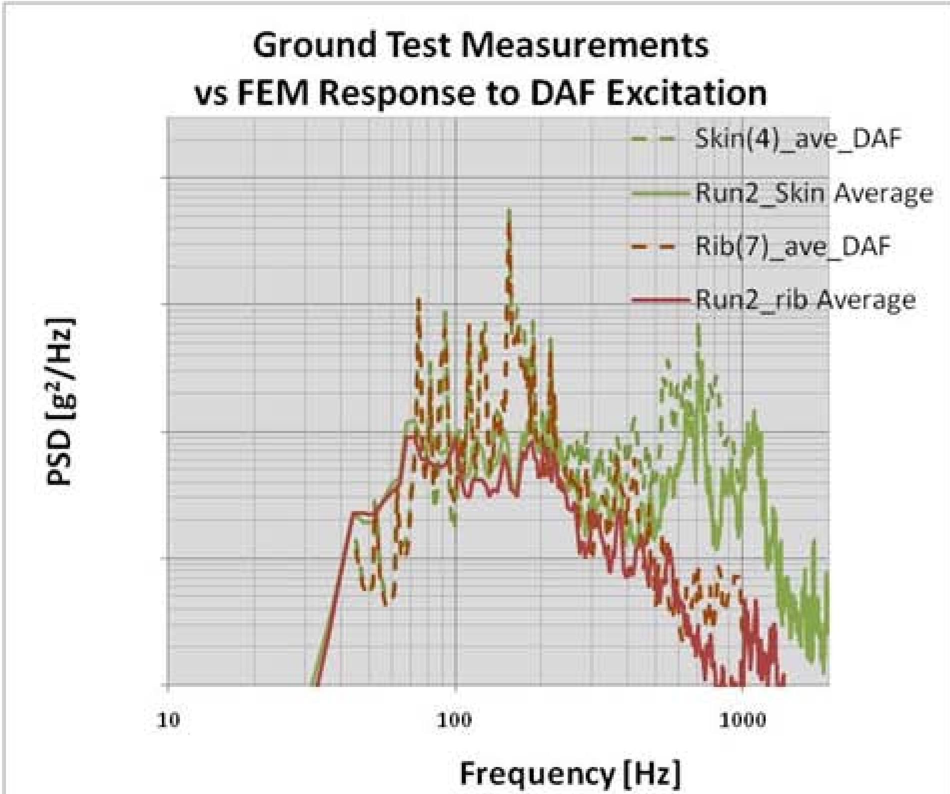
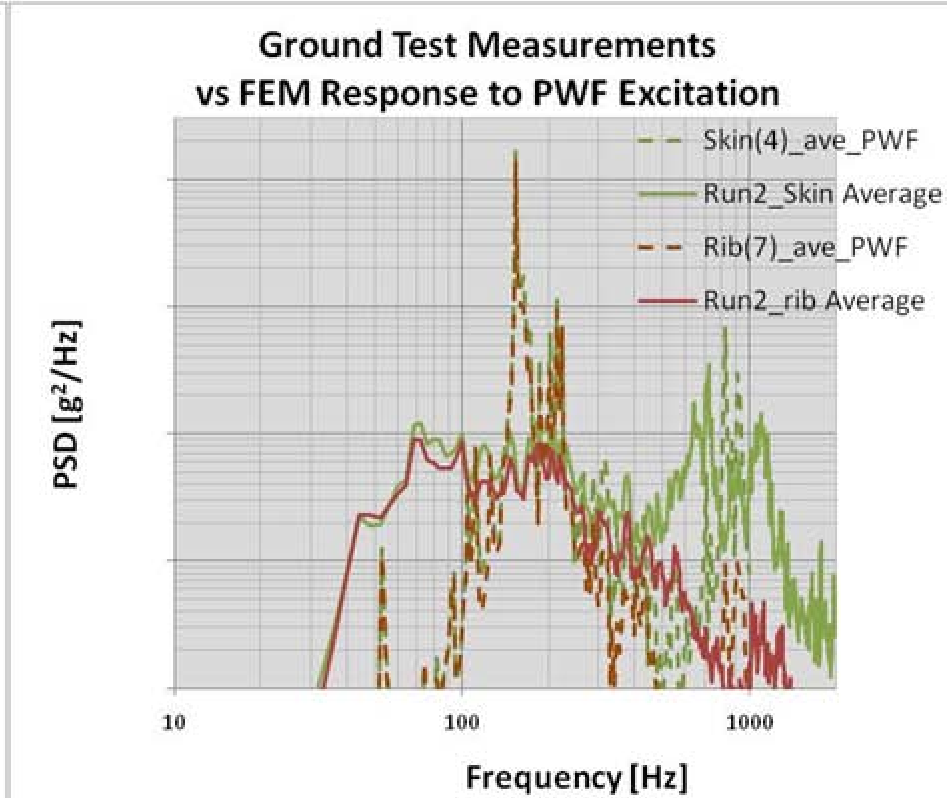
Model for Low/Mid Frequency

Response Results were Computed for Test Case Run-2. DAF is a better match in the frequency domain -Many modes are excited, but an adjustment to Damping is needed.

Average from DAF Analysis 1% DLF with Average from Measurements



Average from PWF Analysis 1% DLF with Average from Measurements



Dashed Curves Represent Analysis Results

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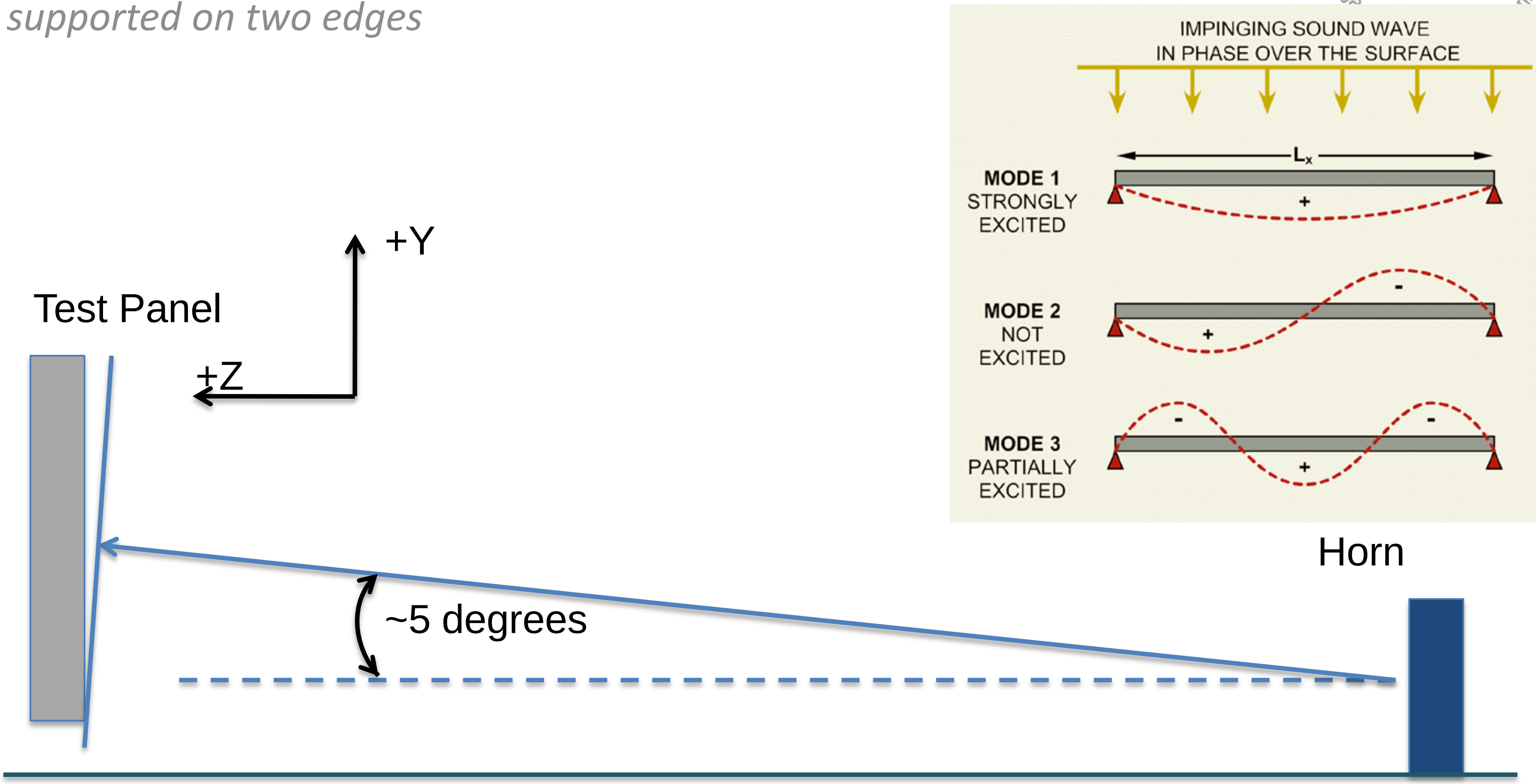
Model for Low/Mid Frequency

PWF with nearly normal incidence does not excite all the modes for panel supported on two edges



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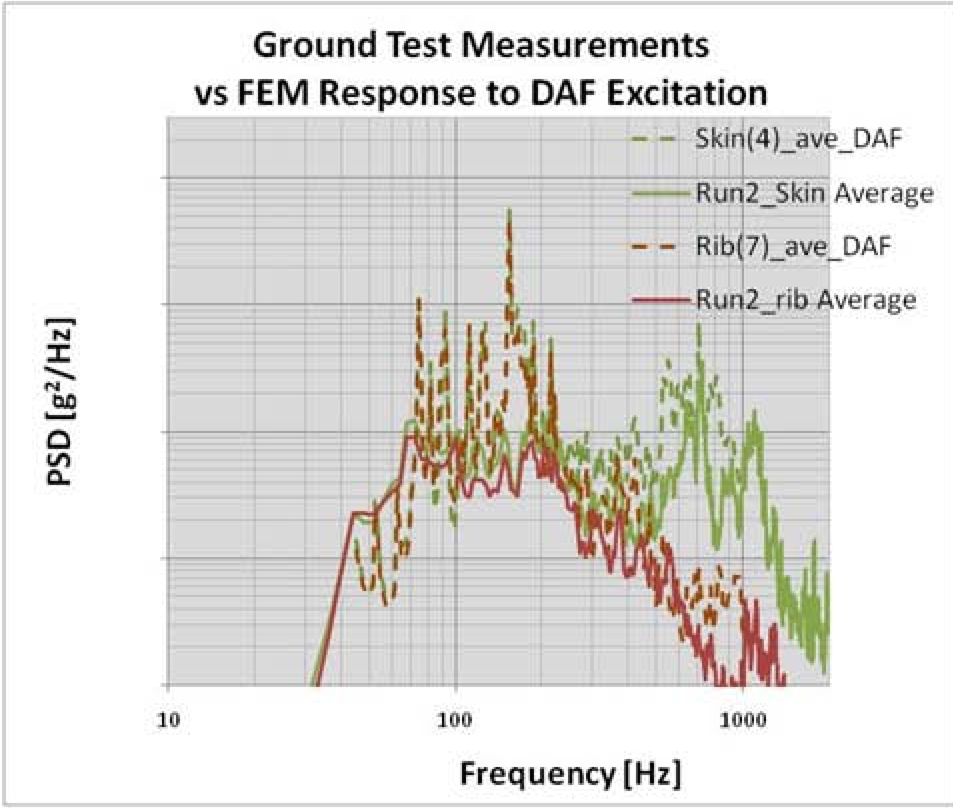
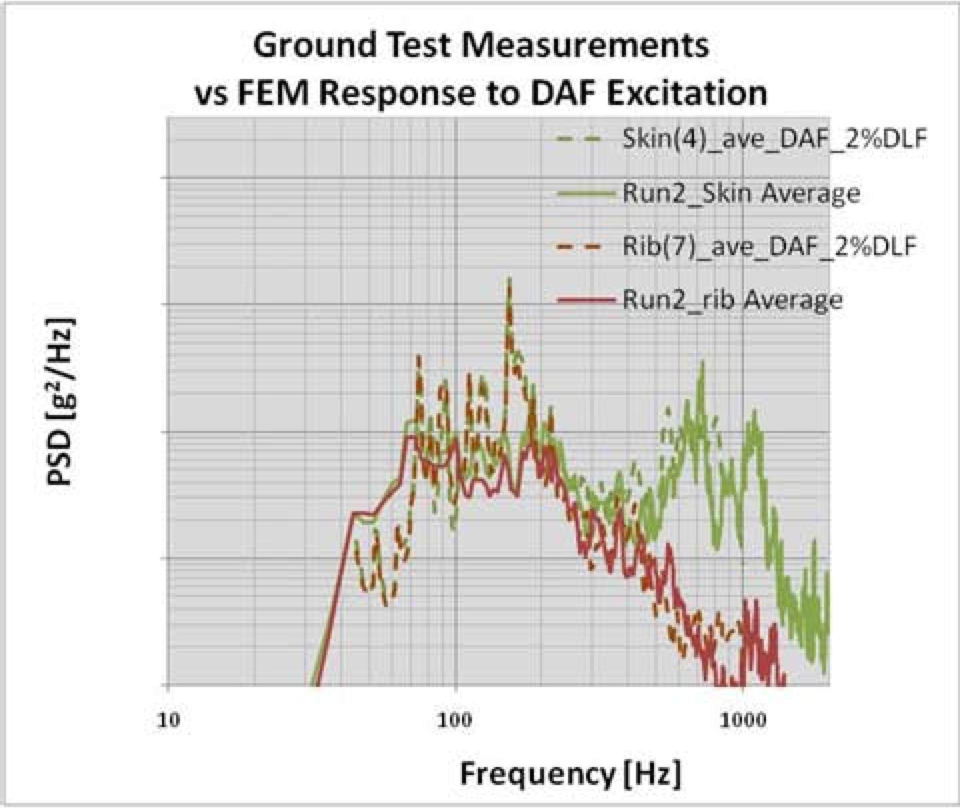
Model for Low/Mid Frequency

Adjustment to Damping helps the DAF solution line-up better with the measured results. Test article is bolted to the Test Fixture → More damping in bands below 200 Hz?

Average from DAF Analysis with 1% DLF



Average from DAF Analysis with 2% DLF



Dashed Curves Represent Analysis Results

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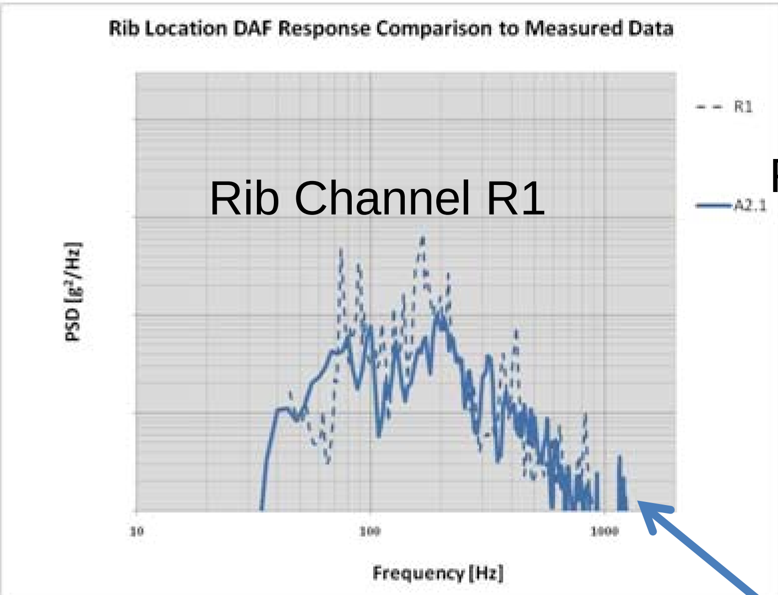
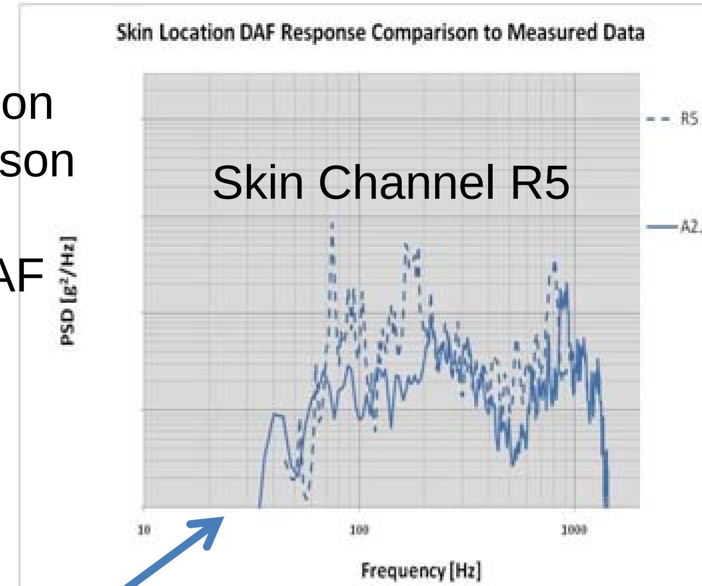
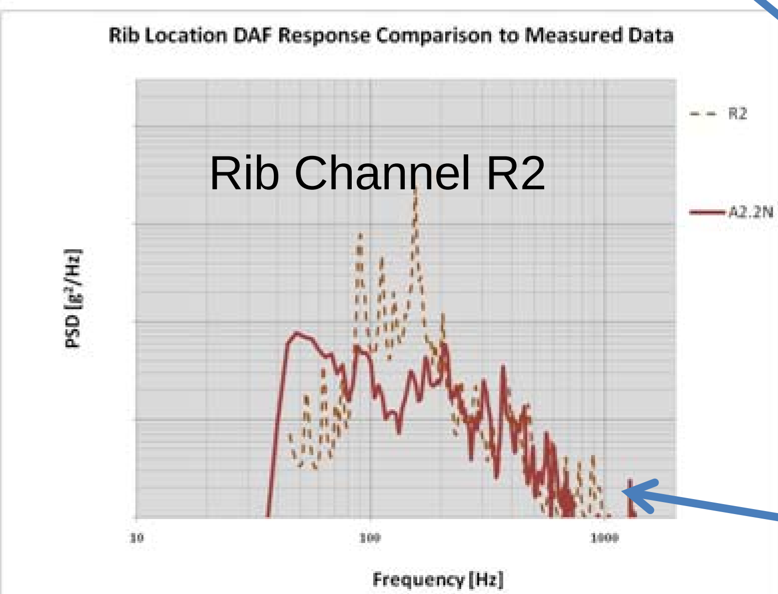
Model for Low/Mid Frequency

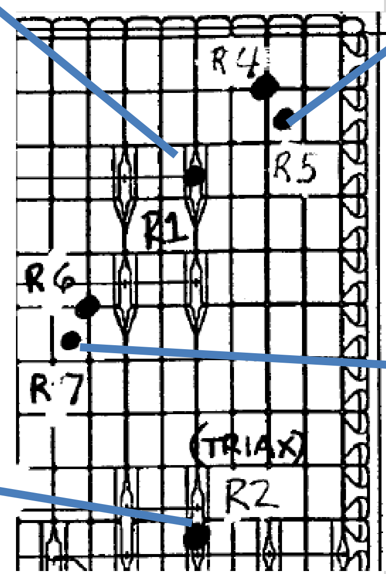


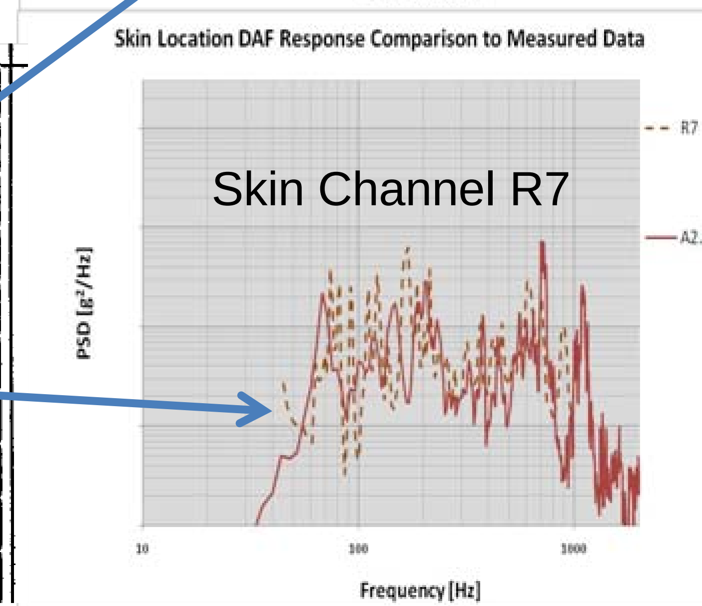
Typical
Location-by-Location
Response Comparison
From
Run 2 Average DAF
at 2% DLF



Trends







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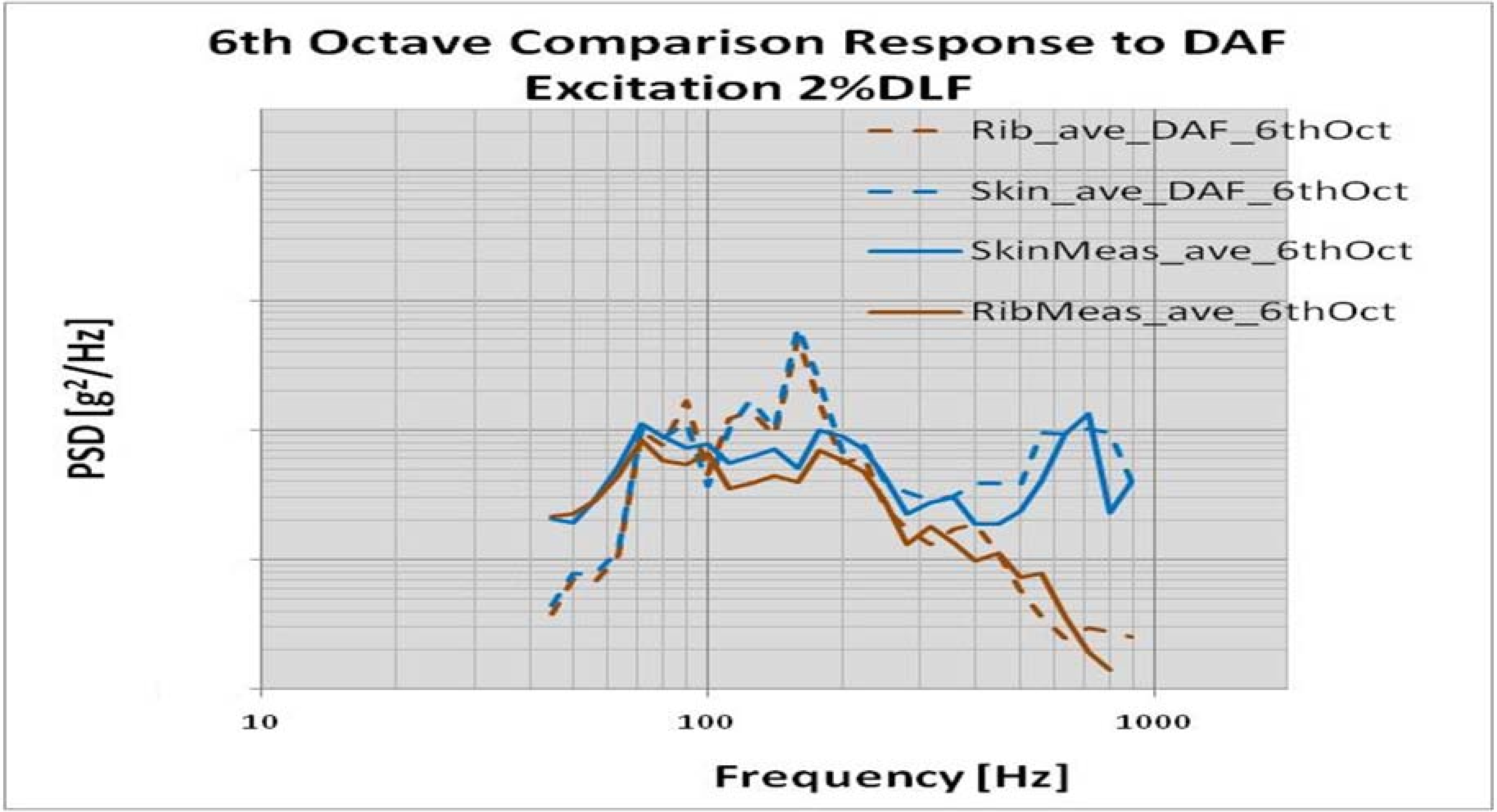
Dashed Curves Represent Analysis Results

Model for Low/Mid Frequency

Comparison of Average DAF solution with Average Ground Test results in 1/6th octave bands shows nice correlation except in band between 100-200 Hz where it is conservative.



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Model for High Frequency

Modeling Strategy

- Large number of modes above 500 Hz $\Rightarrow$ SEA.
- When bending wavelength > rib spacing $\Rightarrow$ a single SEA subsystem is adequate.
- User wants the details of spatial distribution of the response.
- When structure is periodic $\Rightarrow$ periodic subsystem formulation is appropriate.

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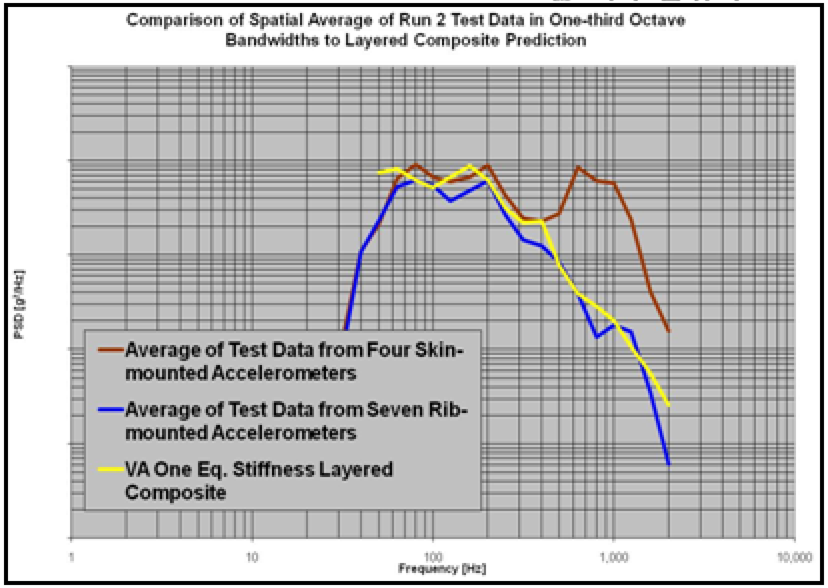
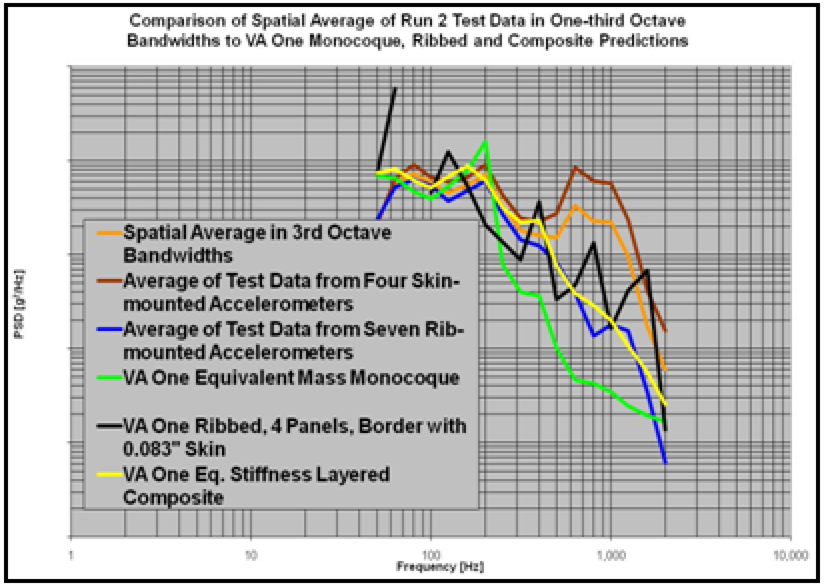
Panel Modeled as an SEA composite

- Used exactly the same model as in [1] except that an equivalent stiffness, two-layer composite formulation was used instead of the SEA ribbed approach.
- Prediction from the layered composite model shows good correlation with the average of test data from the seven rib-mounted accelerometers. (However no correlation with high frequency response measured from skin transducers.)
- Poor ring frequency estimate:
  - SEA composite model
  - SEA ribbed model
- Good ring frequency estimate:
  - SEA monocoque model





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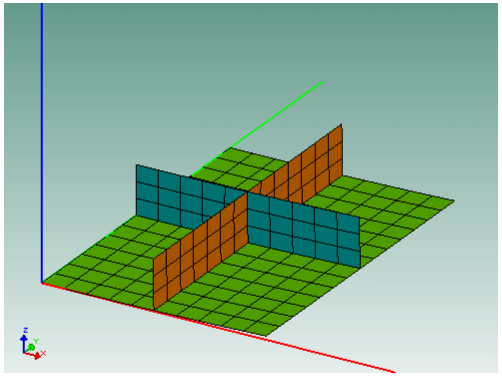
Model for High Frequency

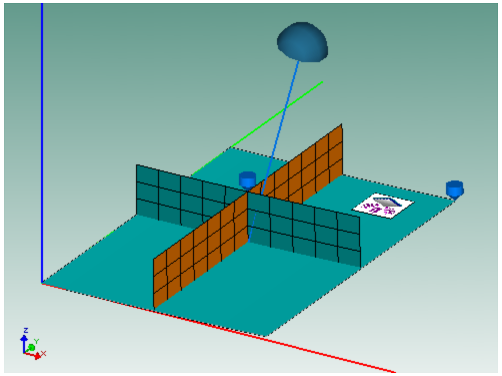
Periodic Subsystem Model

- FE model of a single periodic cell
  - 240 nodes for analysis up to 4000 Hz
  - Nodes on opposite edges must be at same location
  - Includes curvature
  - FE face defines the area that is coupled with fluid



- Sensors to request local response

- Specify number of periodic cells in each direction: 22×23 (computational gain is ~ 506)



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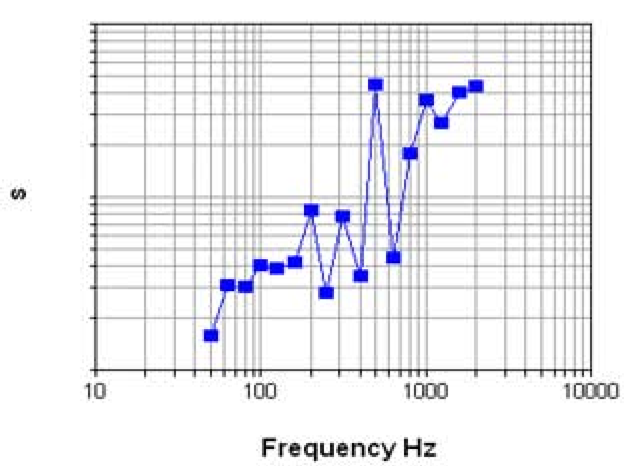
Model for High Frequency

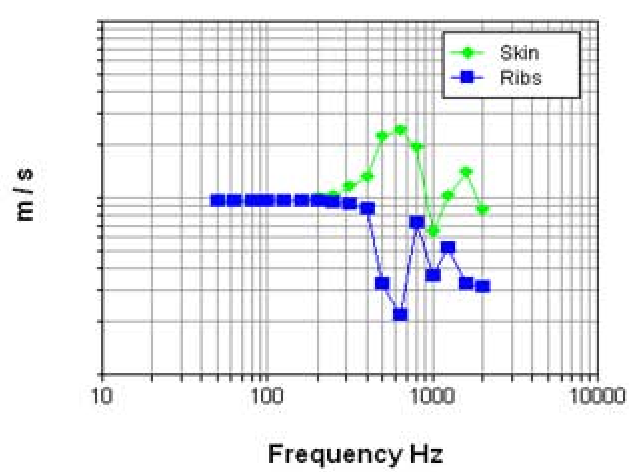
Solution of Periodic Subsystem Model

- In the background:
  - Use of periodic structure theory to find the wave propagation properties in each frequency band.
  - Apply “SEA Wave Approach” to derive the parameters of interest.
- Results computed in ~2 minutes (32bit, 3 GHz, 2 GB RAM)

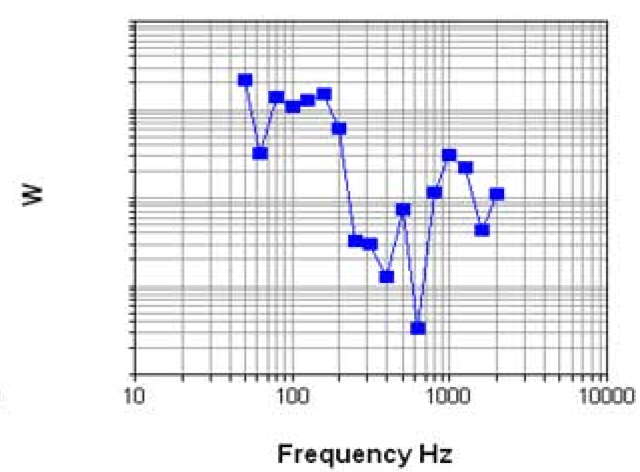
Modal Density



Sensor Response per Unit Energy



Power Input from Diffuse Acoustic Fields



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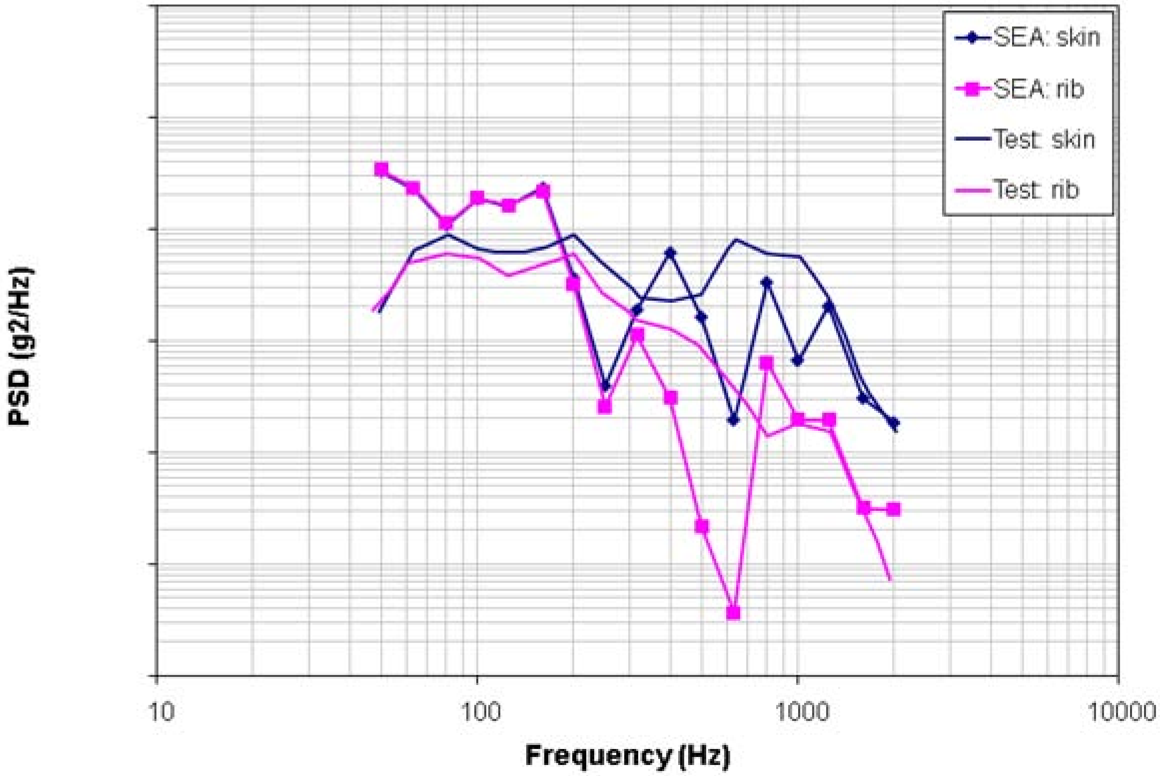
Model for High Frequency

Prediction of SEA Model

- Mean PSD of acceleration at the center to the skin pocket and at the rib crossing.



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Model for High Frequency

Comments on SEA Variance Prediction

- SEA primary output is the averaged energy response:
  - Energy of a subsystem = the **space** average of the squared velocity
  - Averaged over the **frequency** band
  - Averaged over an **ensemble** of similar systems

- Variance formulation gives the ensemble variance of the frequency-band averaged and space averaged response. Depends on:
  - Modal overlap: Variance decreases with increasing damping, modal density.
  - Bandwidth of frequency band: Variance decreases with increasing averaging bandwidth.

  - To capture variance of narrowband data, use small frequency bands.
  - **To capture variance of point response, need an additional spatial variance term (Reference 14-JSV 2005).**

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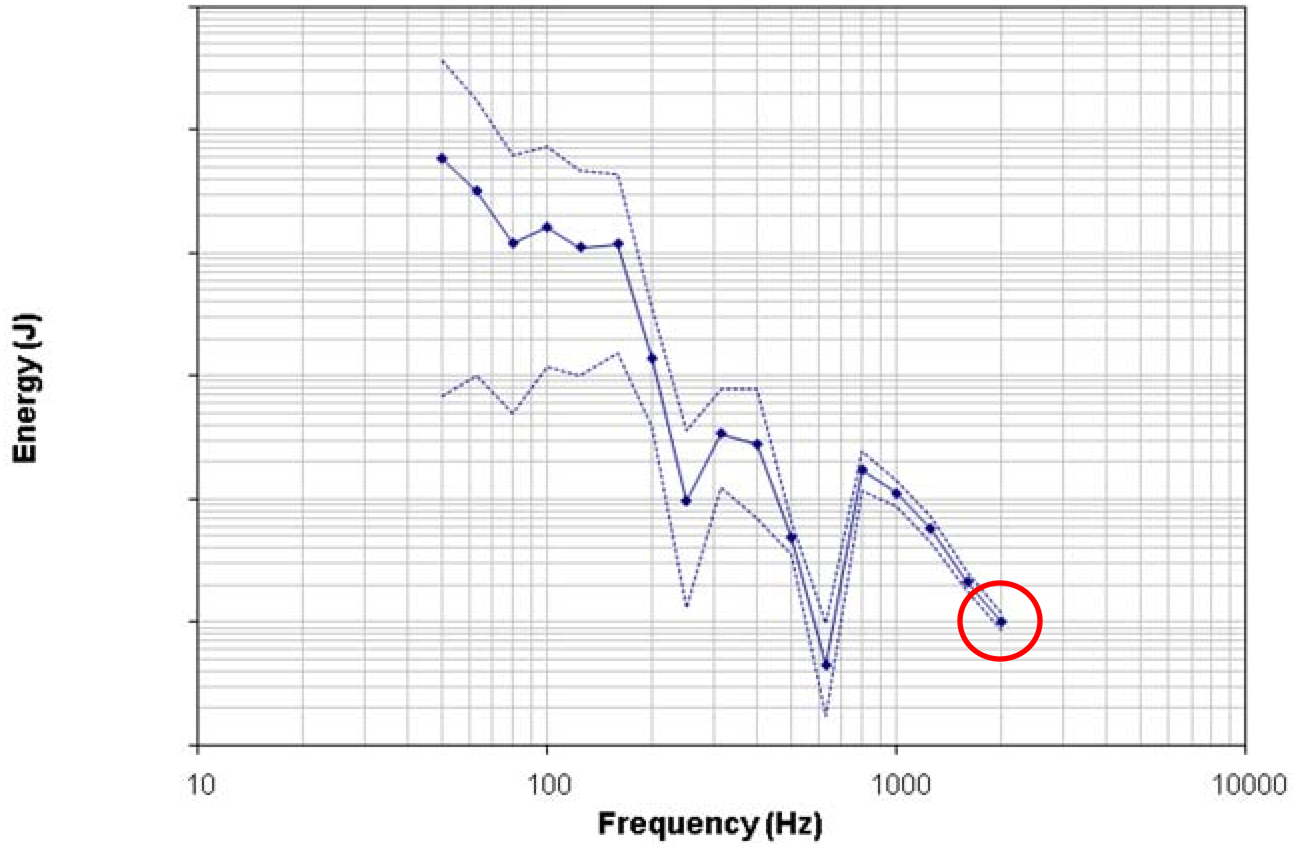
Model for High Frequency

SEA Variance Prediction

- Mean ± 95% confidence interval of the **narrowband energy** response.



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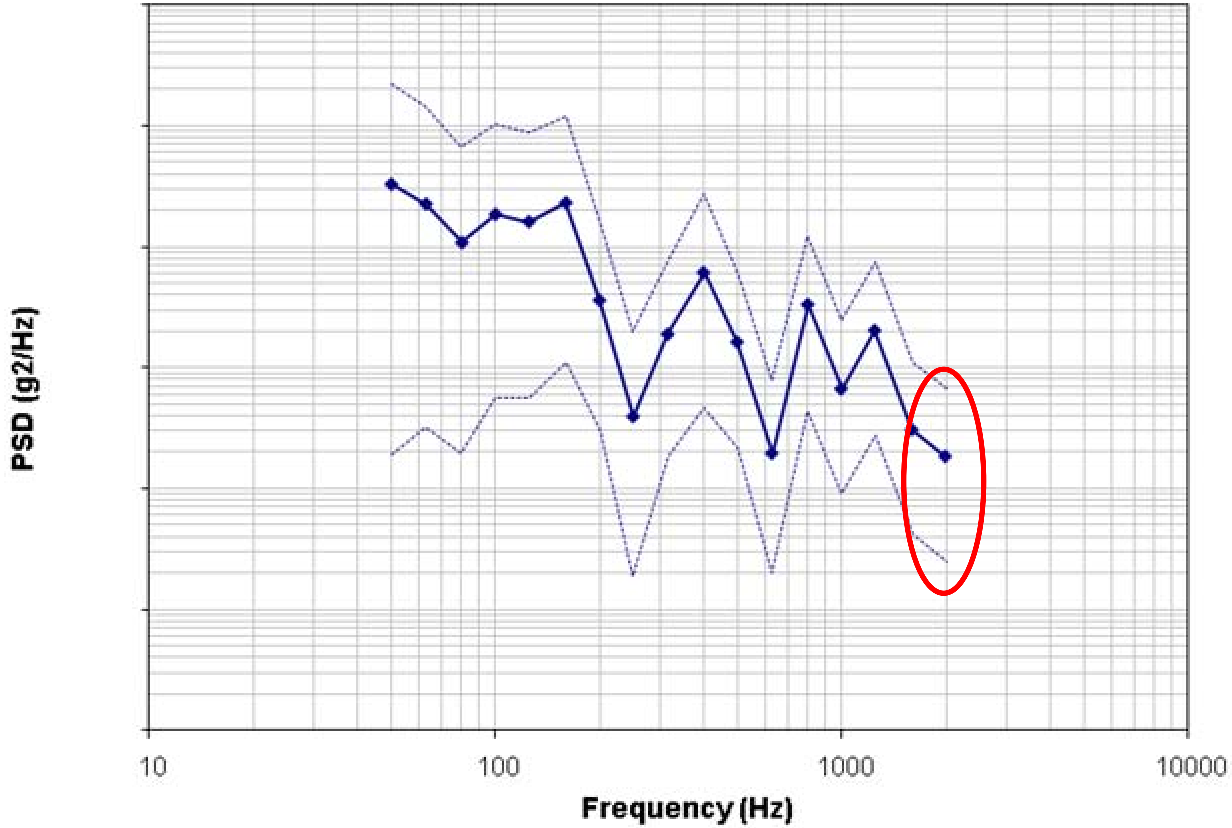
Model for High Frequency

SEA Variance Prediction - Including point-to-point variation term (variation about space average)

- Mean ± 95% confidence interval of the PSD of **narrowband acceleration response at a point** on the skin.



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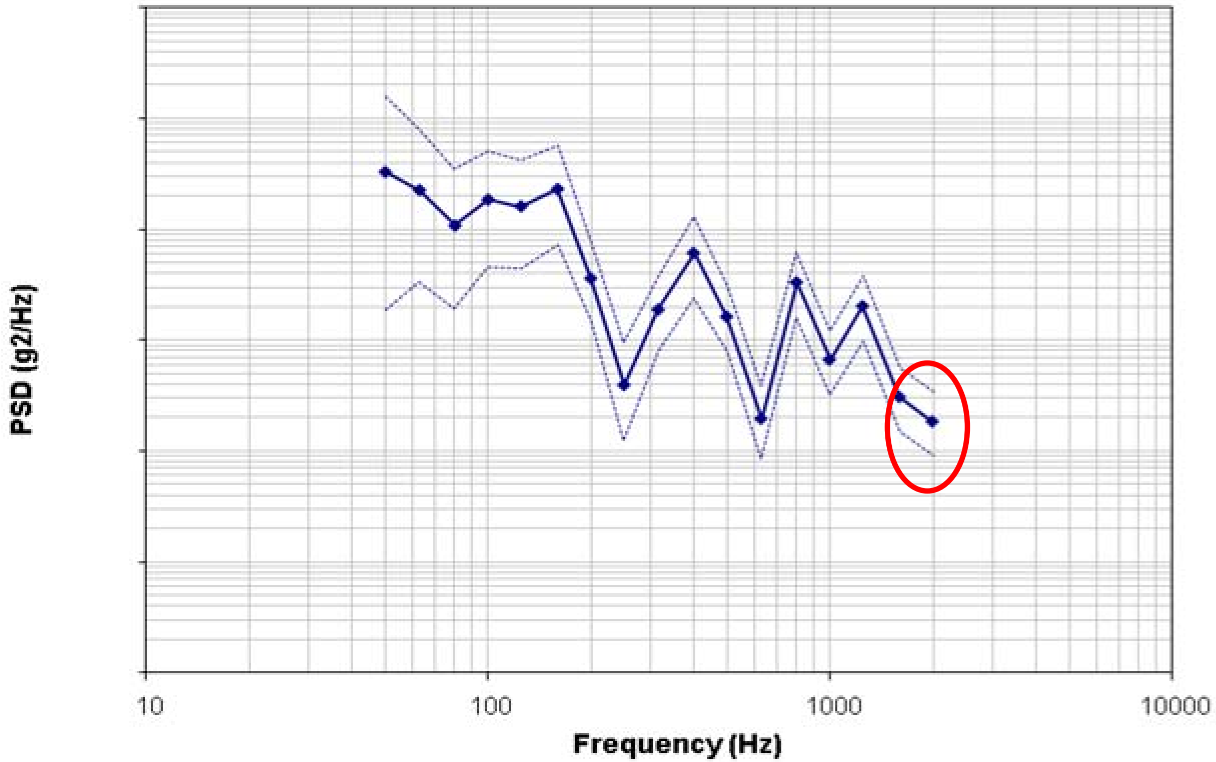
Model for High Frequency

SEA Variance Prediction

- Mean $\pm$ 95% confidence interval of the PSD of **band-averaged (1/3rd oct.) acceleration response at a point** on the skin.



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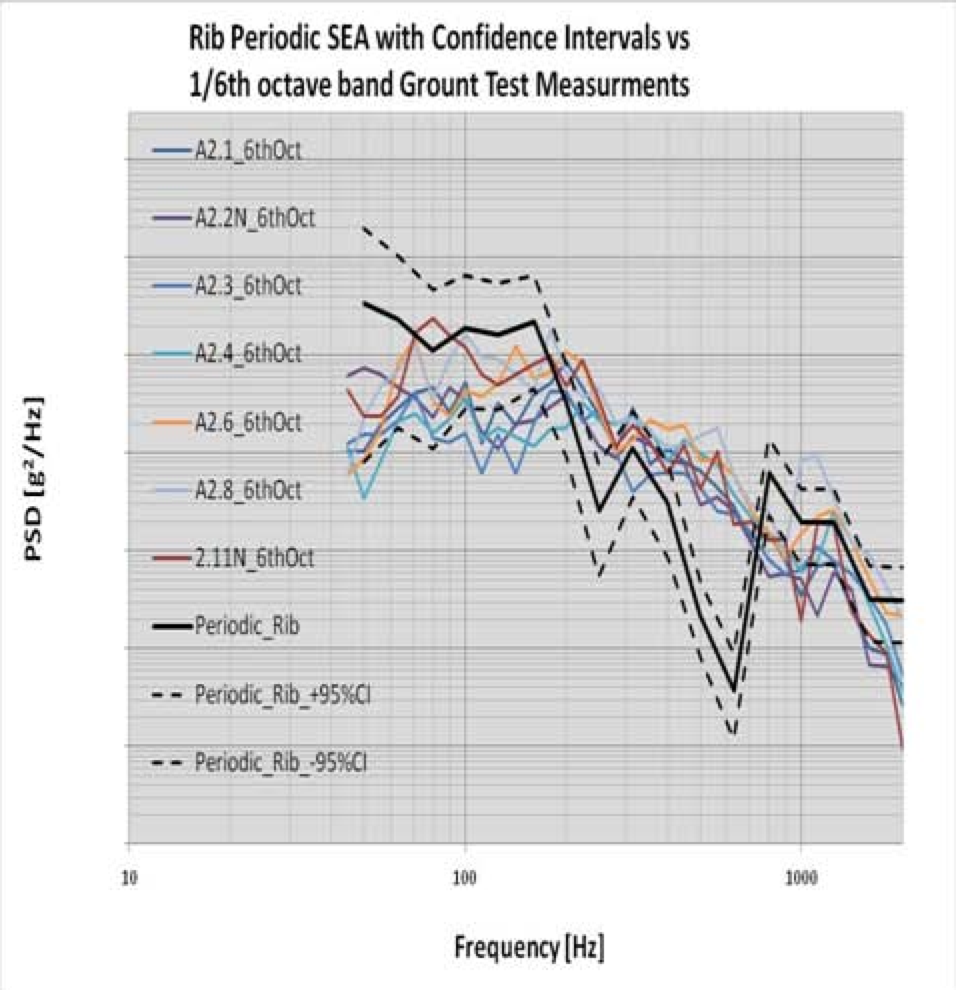
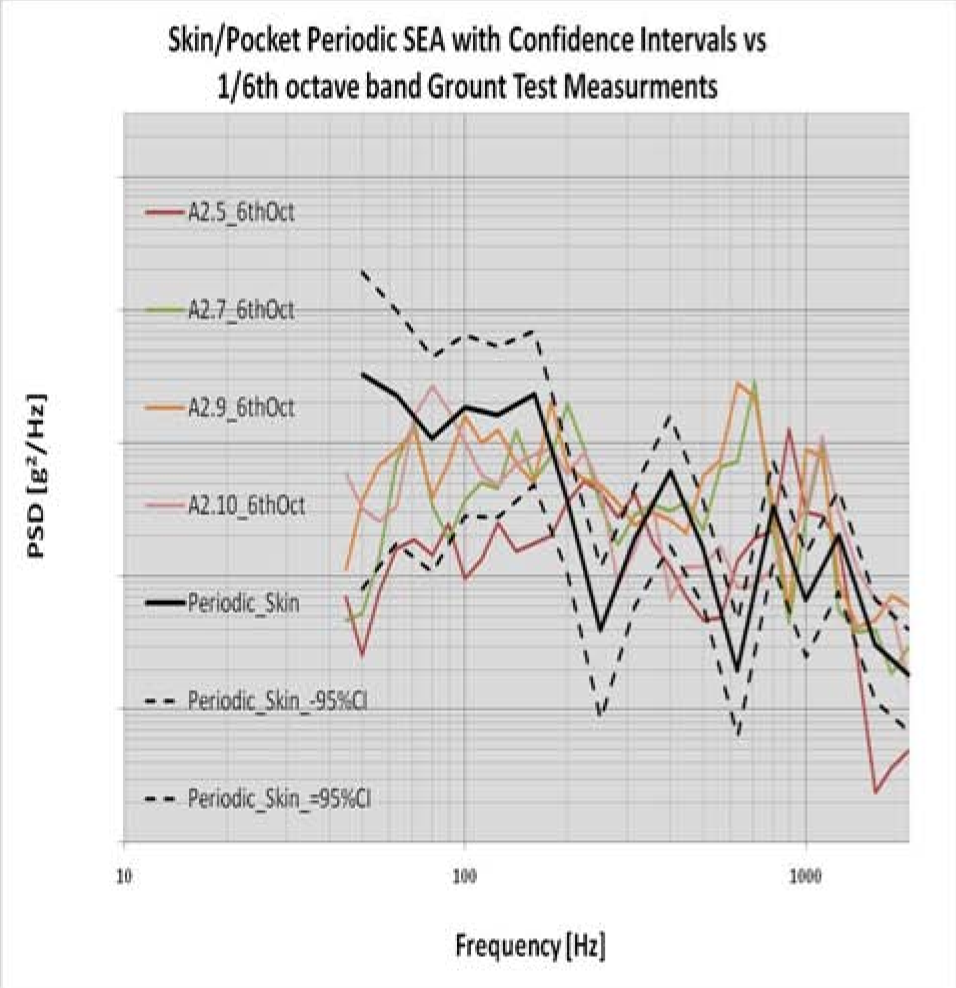
Model for High Frequency

Does the 1/3rd octave Periodic SEA Result with narrowband confidence intervals envelope the 1/6th octave overlay of Ground Test Measurement Channels?





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Conclusions

Finite Element Model:

- DAF approximation of the loading proved to a better match for the test observations than PWF. Perhaps a fair amount of reflection from the concrete pad in front of the test article contributed to the randomness of the incident acoustic field.
- The detailed **Finite Element Model** provided admirable location specific results.
- Spatial variation produced in the FEM based analysis was fairly constant across the frequency range of interest. Using Mean ±4.5 dB on the 1/6th octave processed results tended to nearly envelope the analytical results.

SEA Model:

- The **composite layered construction** with equivalent global did well when compared to the average measured channels on the rib. Not able to represent the skin/pocket behavior in mid/high frequency.
- The **Periodic Subsystem** was able to capture both rib and skin/pocket response.
- Point response SEA variance is consistent with test observation and FE prediction.

Finite Element & SEA Models:

- The damping assumption is critical to preventing over or under prediction.
- The spatial correlation of the excitation field is also important.

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References

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Backup Slides

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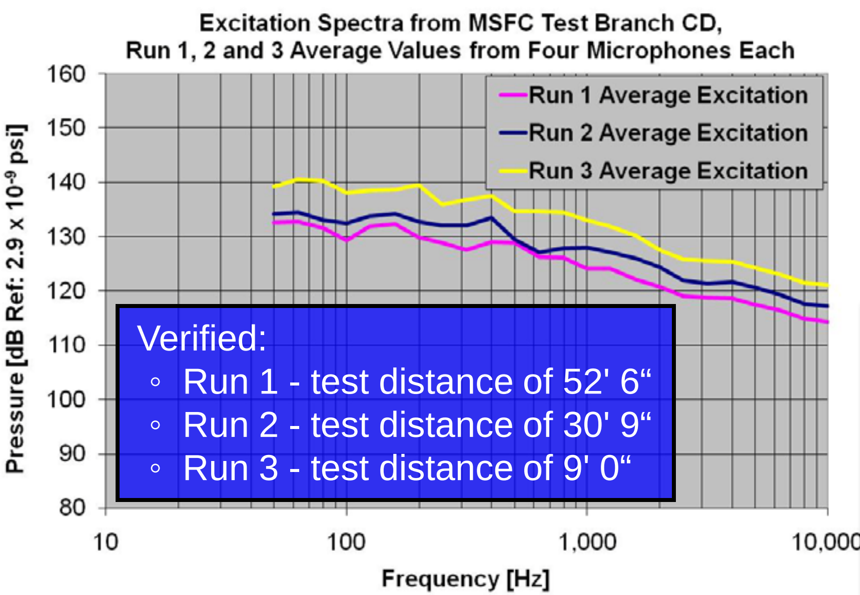
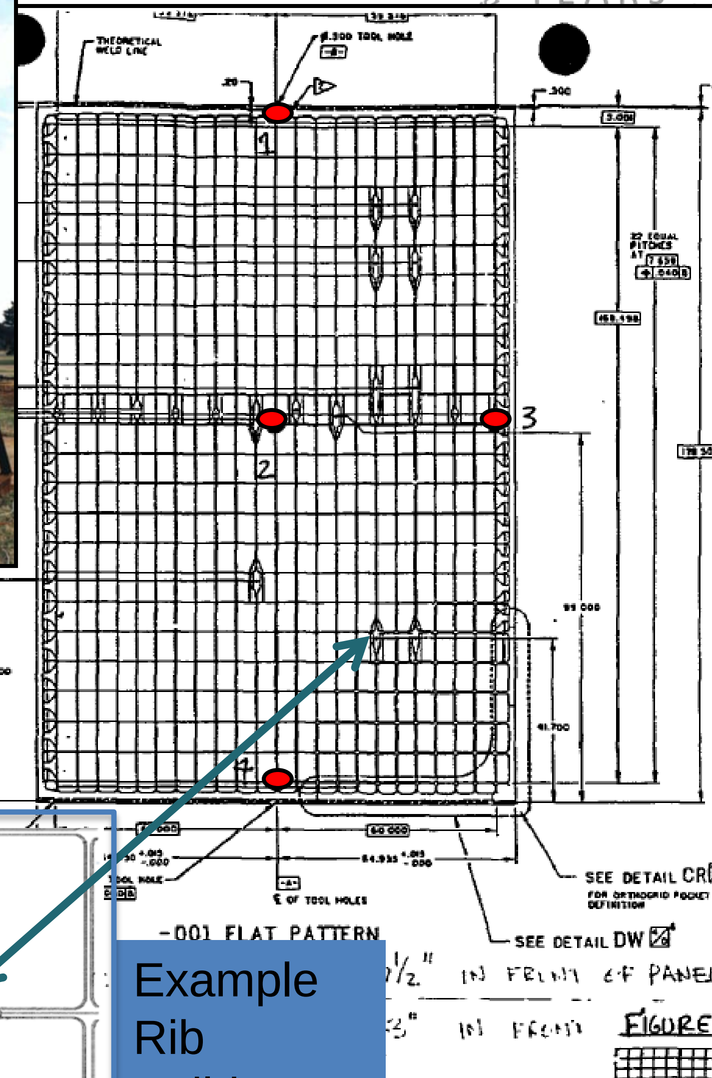
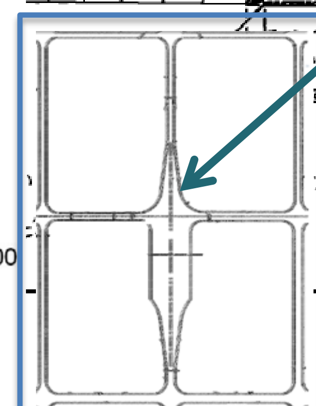
Background: Measured Excitation – Pressure Spectra

- **Location of microphones used during tests are shown at right.**
- **Microphones mounted on light support structure. Minimum distance in front of panel is approximately 37 inches.**



Verified:
- Run 1 - test distance of 52' 6"
- Run 2 - test distance of 30' 9"
- Run 3 - test distance of 9' 0"





Example Rib Buildup

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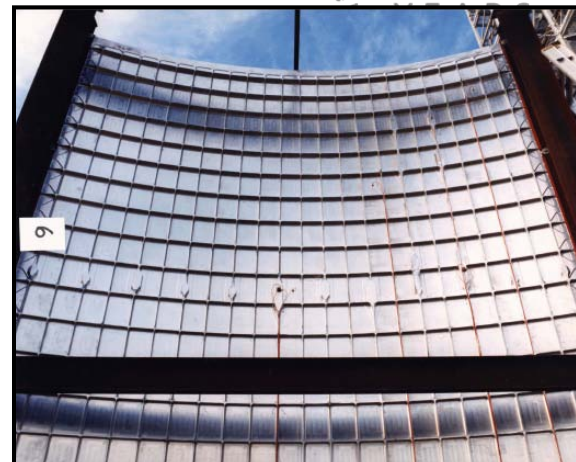
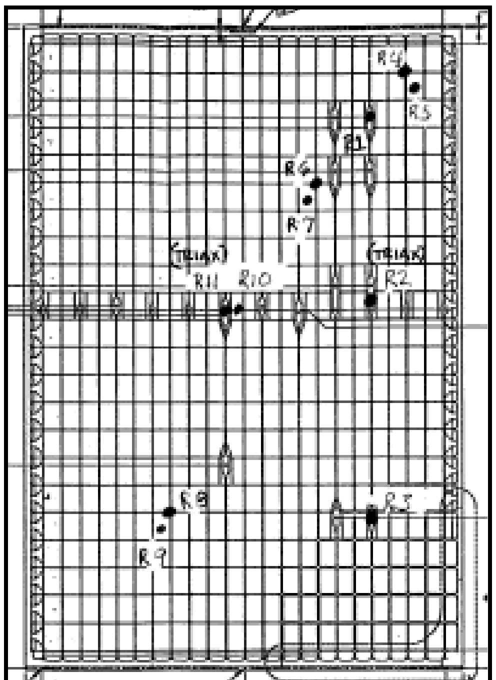
Background: Measurement Locations and Design Details of Flight-Like Test Article



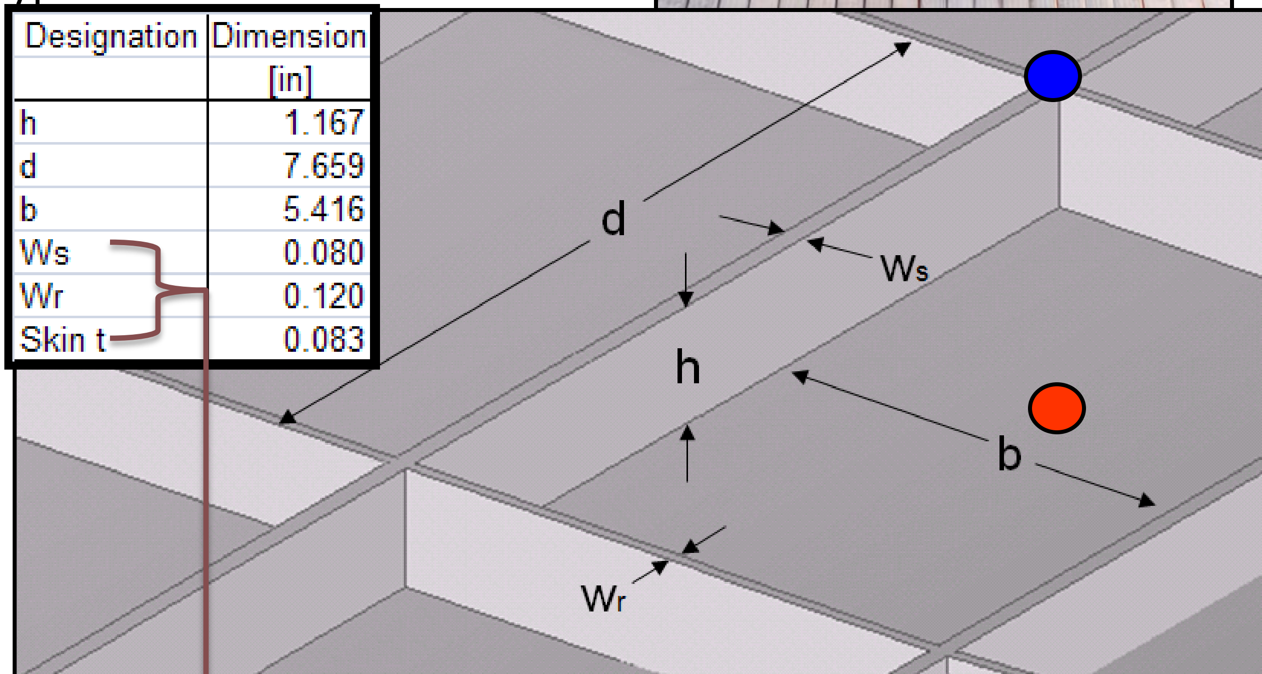
The upper half of a 10 by 15 ft Orthogrid panel is depicted at right. 11 vibration response measurements [4 skin-mounted and 7 rib-mounted transducer locations].

An Example of the orthogrid properties used to define subsystem is provided below.

Each rectangular pocket measured 7.659” by 5.416”, Centerline [CL] to CL. Typical dimensions follow:



Designation	Dimension [in]
h	1.167
d	7.659
b	5.416
Ws	0.080
Wr	0.120
Skin t	0.083



Three dimensions varied by zone

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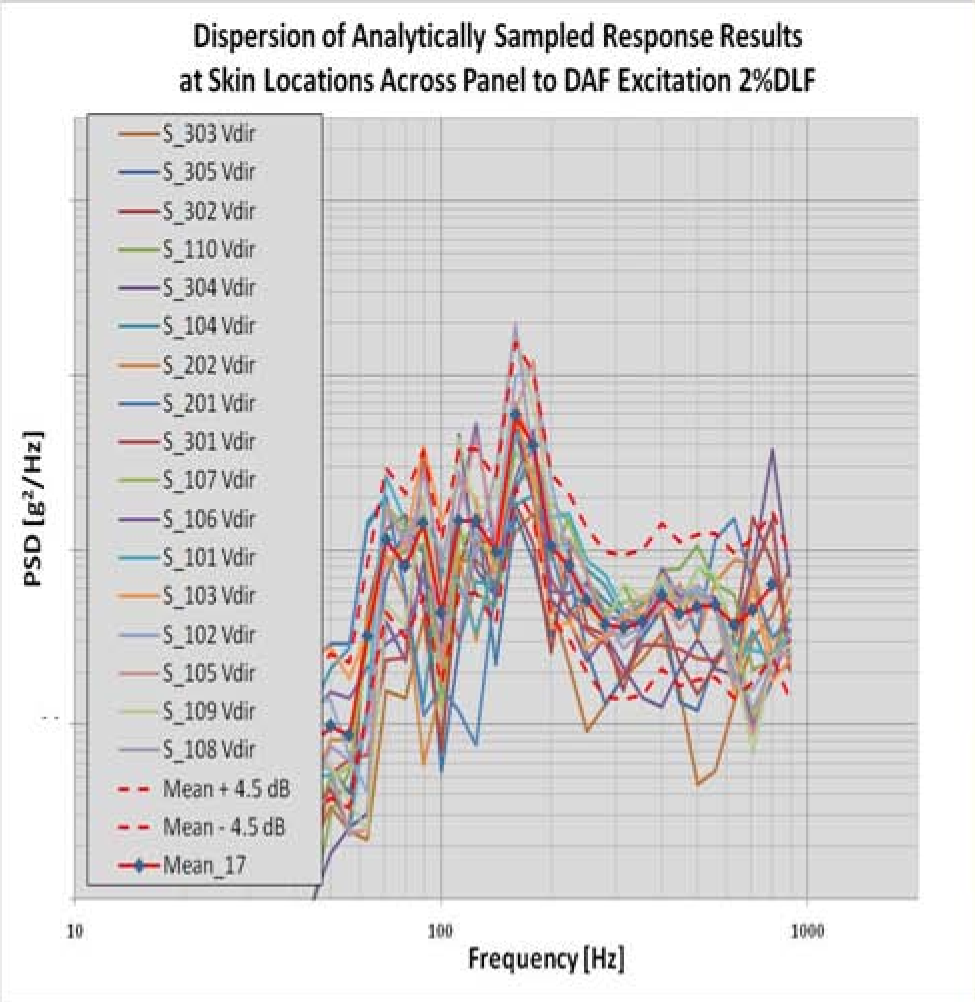
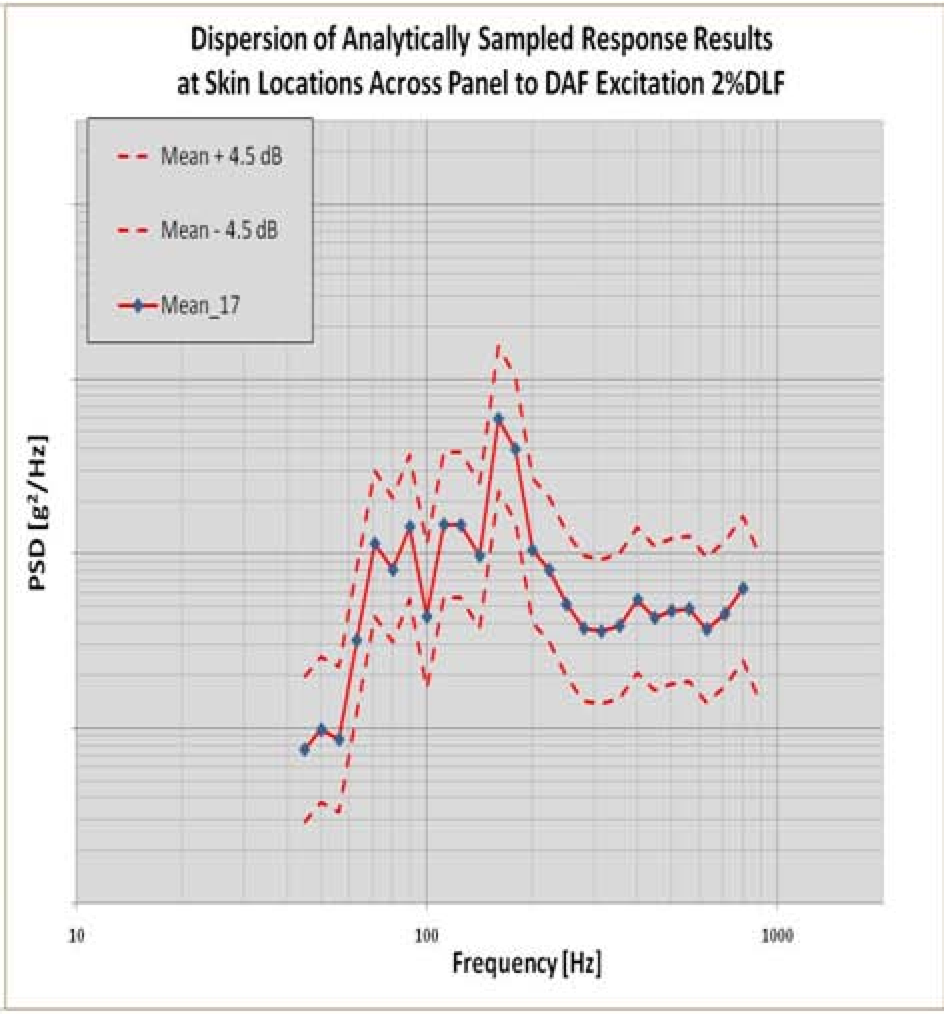
Model for Low/Mid Frequency

Mean +4.5 dB may serve as an estimate of variation about the mean of the analysis results. Nearly envelopes the response curves when examined as 1/6th Octave Band Averages.





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Thank you