Correlating Attenuation of Vibroacoustic Response to a System Damping Schedule using Ground Test Measurements, the Finite Element Method and the DampID Optimization Tool

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Spacecraft and Launch Vehicle Dynamic Environments Workshop
19–21 June 2012

Validation of Measured Damping Trends

Agenda

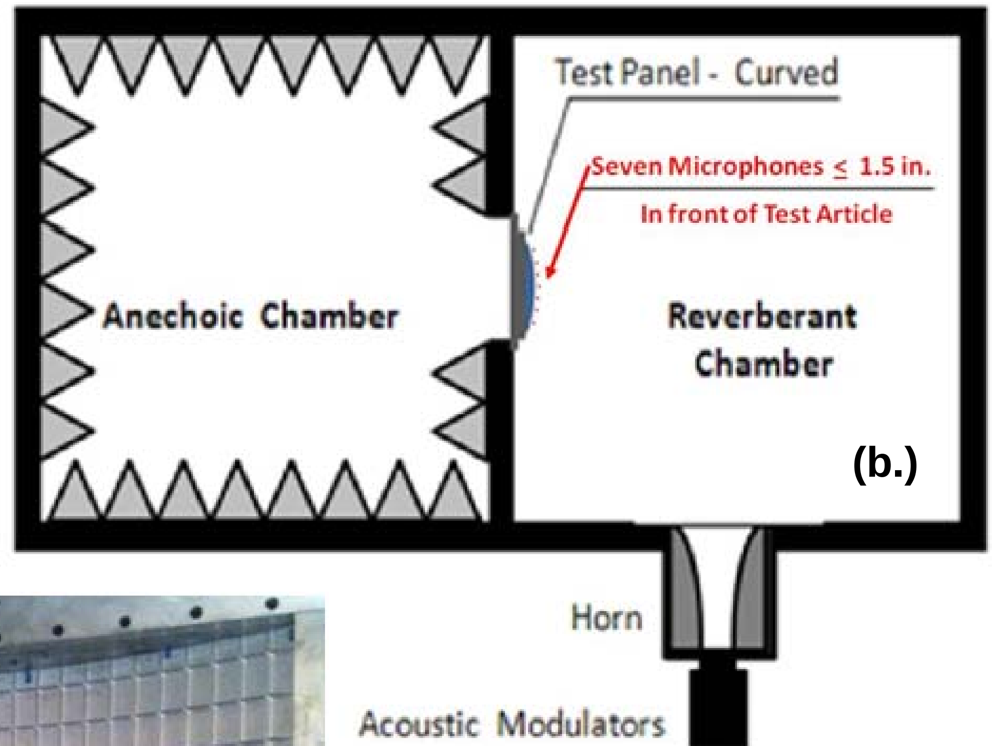
- Addressing the need:
  - *Validate/Refine the approach used to estimate the vibration environments associated with* ***Equipment-Mass-Loaded-Exterior-Panels*** *of launch vehicles. This is of major importance to New Vehicle Programs.*
  - *This Validation has been identified by the NASA Engineering and Safety Center (NESC) as an area of uncertainty that is worthy of on-going study.*
  - ***System damping can increase with greater levels of integration****.*
  - *Important to test* ***validate damping under flight like conditions****.*
- Test Program & Preliminary Observations
- Use of Finite Elements with Modal Updating for Damping
- Updating for Damping with use of DampID Optimizer Tool:
  1. *Software tool that can help identify the damping associated with the cables without explicitly modeling the complex energy loss mechanisms they introduce to the system*
  2. *Results represent a best fit solution over multiple response channels. These should be used with Engineering Judgment to Guide Analyst to construct Reasonable System Damping Schedule.*
  3. *Can reveal areas of the analysis that require further study.*
- Conclusions (Assessment of test results is a work in Progress)

Test Program & Preliminary Observations

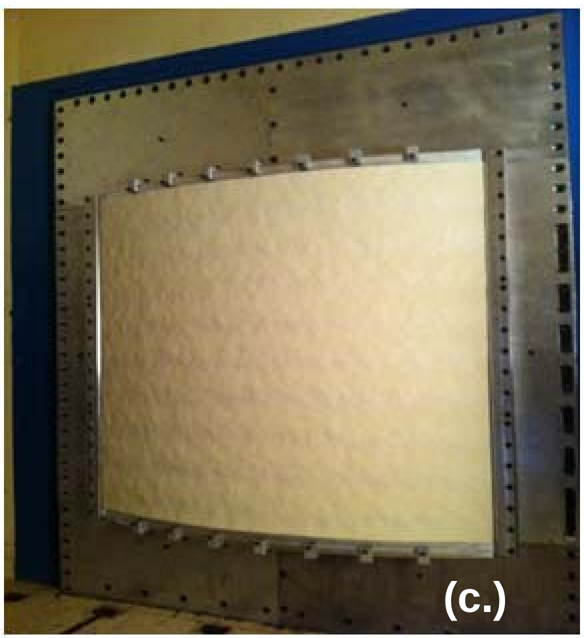
Test setup

a. Acoustic or Fluctuating Pressures affect the exterior surface of Vehicle panels.
b. Ground test setup.
c. Flight like excitation of exterior surface in Baffled panel test setup. (Reverberant)
d. View of Flight like test article from Anechoic receiver room.

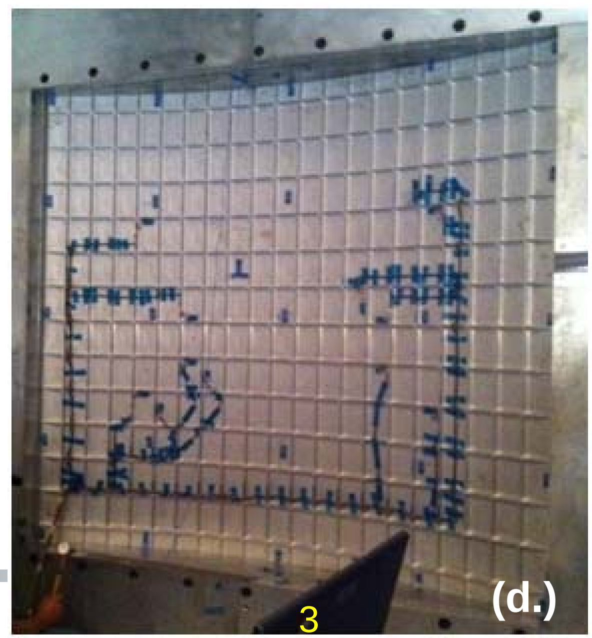
(a.)



(b.)



(c.)



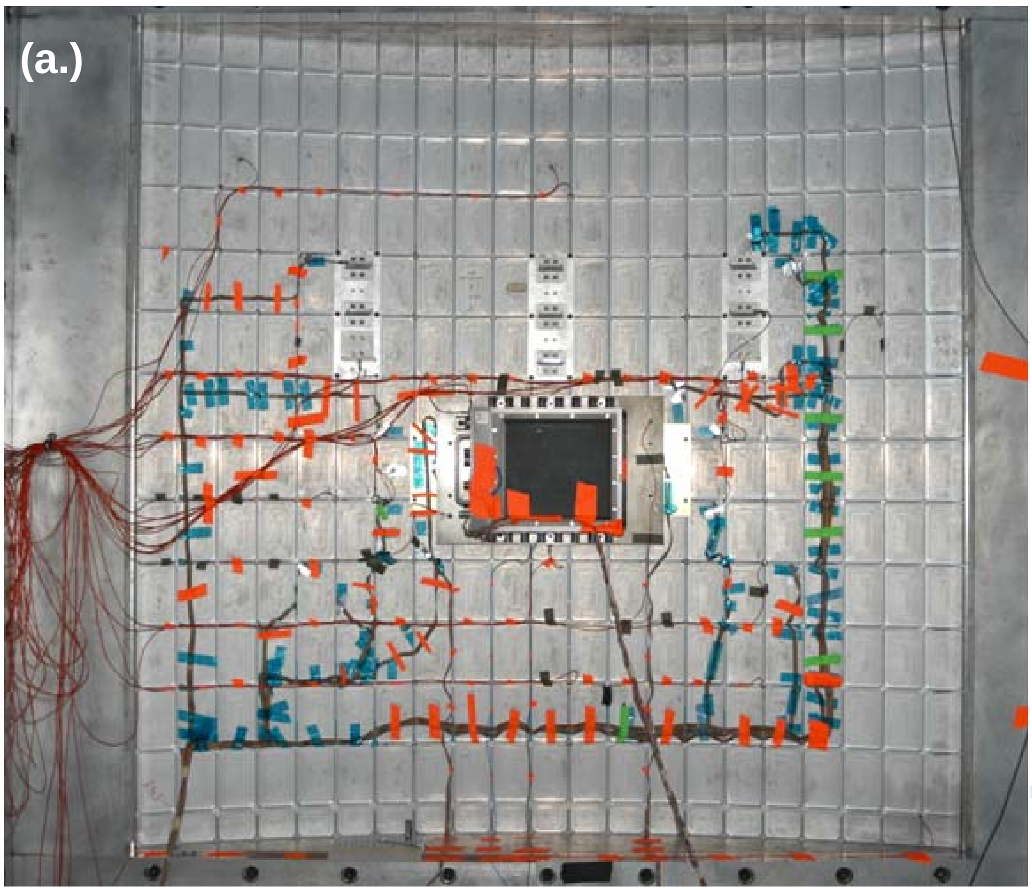
(d.)

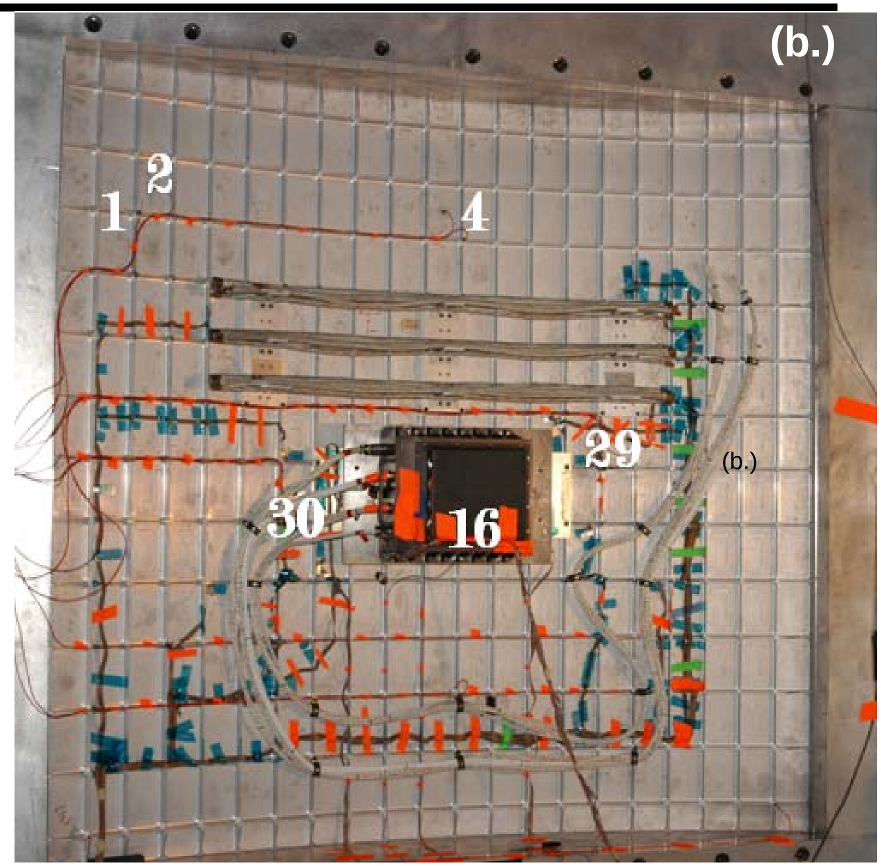
- Note that the Vehicle Panel Test Article can be configured as a bare panel as in (d.) or further integrated with equipment/cables.

Test Program & Preliminary Observations

Test setup

- In figure (a.) at the left bottom the test article is configured with Equipment only
- Very incidental wires are present for measurement transducers
- 56 test cases covering 14 configurations and 4 different excitation levels were addressed in the test series.





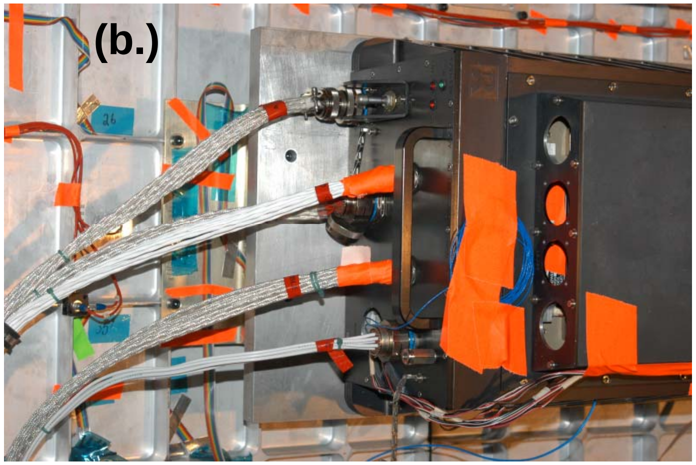
- In figure (b.) at the right top the test article is configured with both Equipment and a significant set of Flight like cables.
- The results from these two configurations are presented on subsequent slides in this paper.

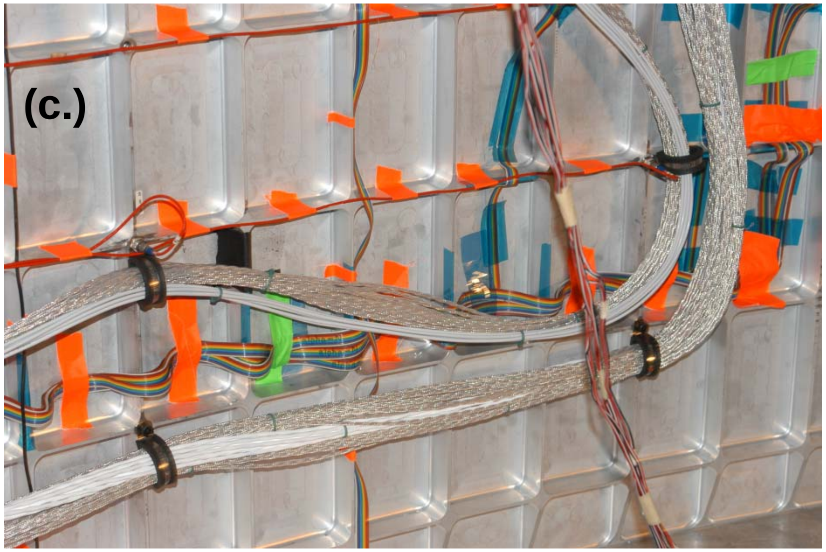
Test Program & Preliminary Observations

Cable Installation

Potential damping sources:

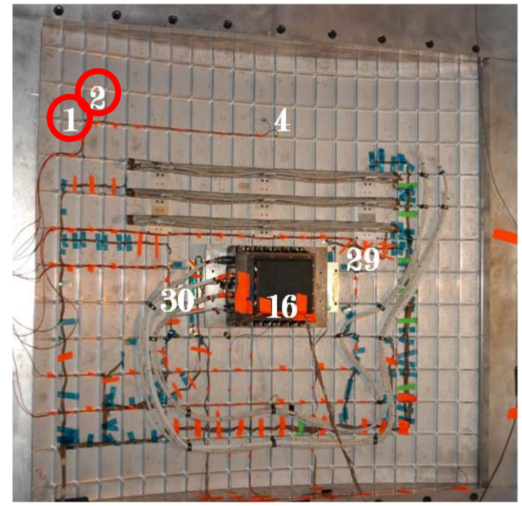
a. Cables routed over brackets and secured with plastic tie wraps.
b. Cables attached to flight-like equipment box with pin connectors.
c. Cables routed and secured using p-clamps.
d. Close-up views of a bracket (left) and p-clamps (right).

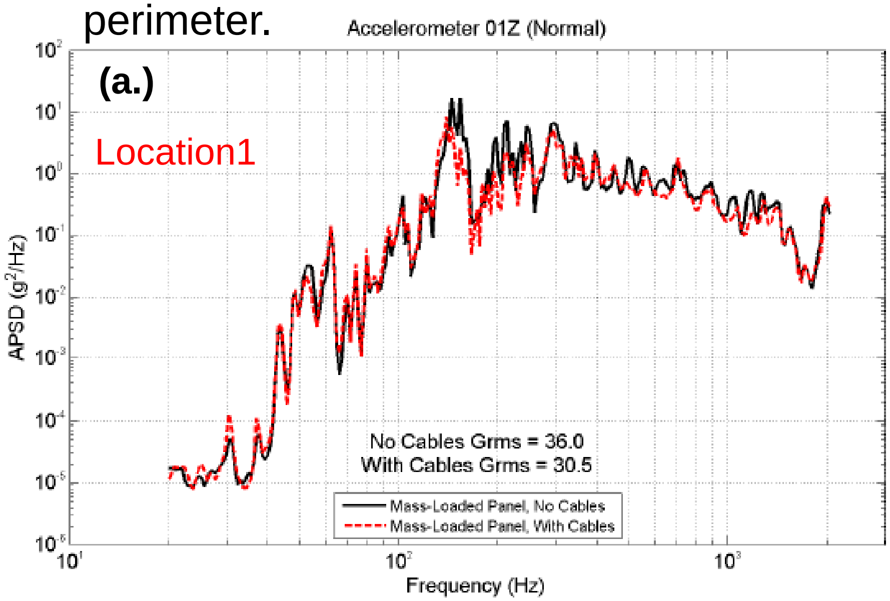


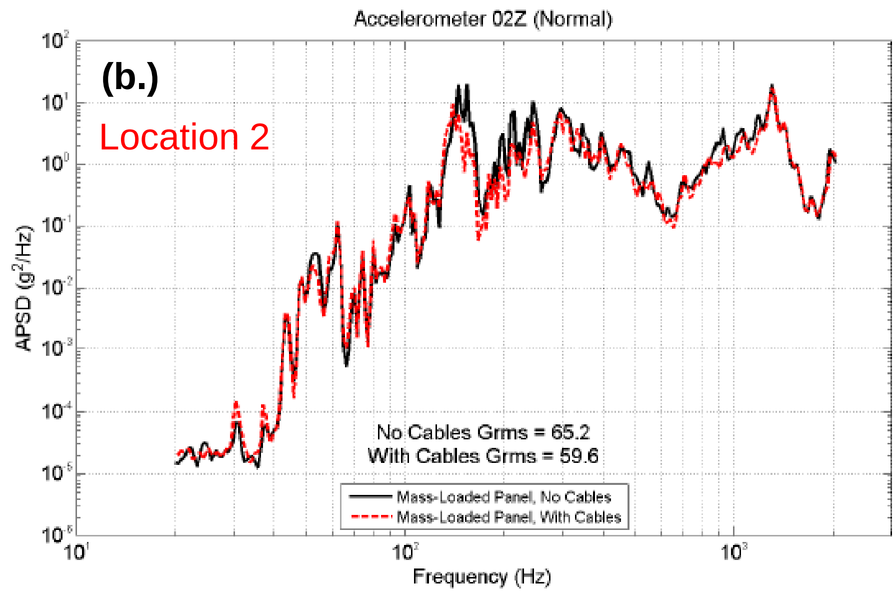


Preliminary Observations From Test

- The plots labeled a and b below present response at locations 1 and 2 for **configurations with and without cables**.
- Both provide evidence of attenuation in the range from 100 to 400 Hz. Note these two responses have nearly identical spectral shapes below 600 Hz. In this frequency range the structural bending wavelengths remain large relative to the orthogrid cell size. Global panel behavior is exhibited.
- Above 600 Hz, the responses shown diverge from each other:
  - the bending wavelengths are small enough for the response at the center of an orthogrid cell to be different from the response on the perimeter.

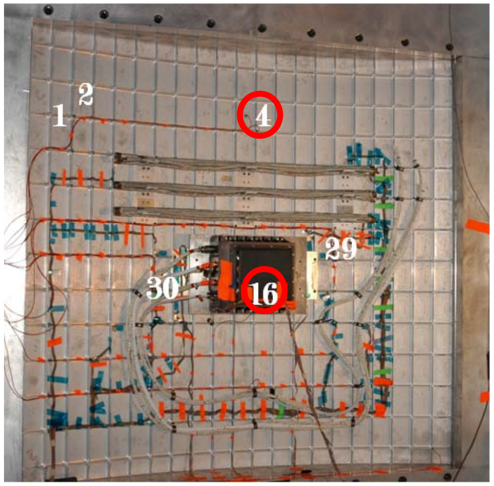


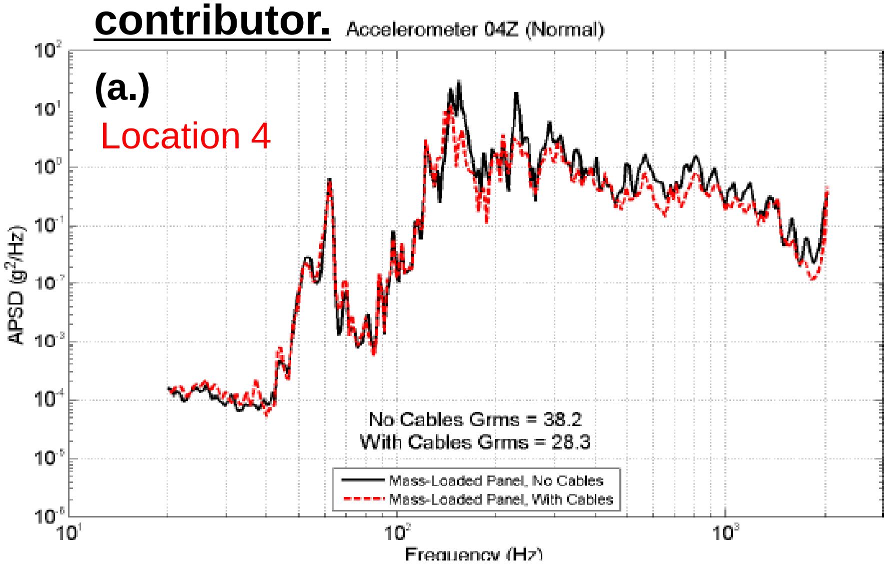


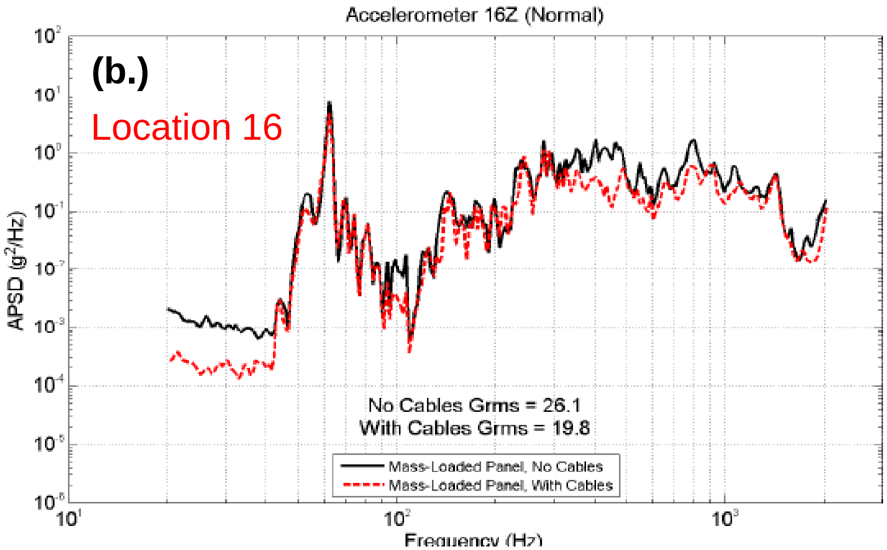


Preliminary Observations From Test

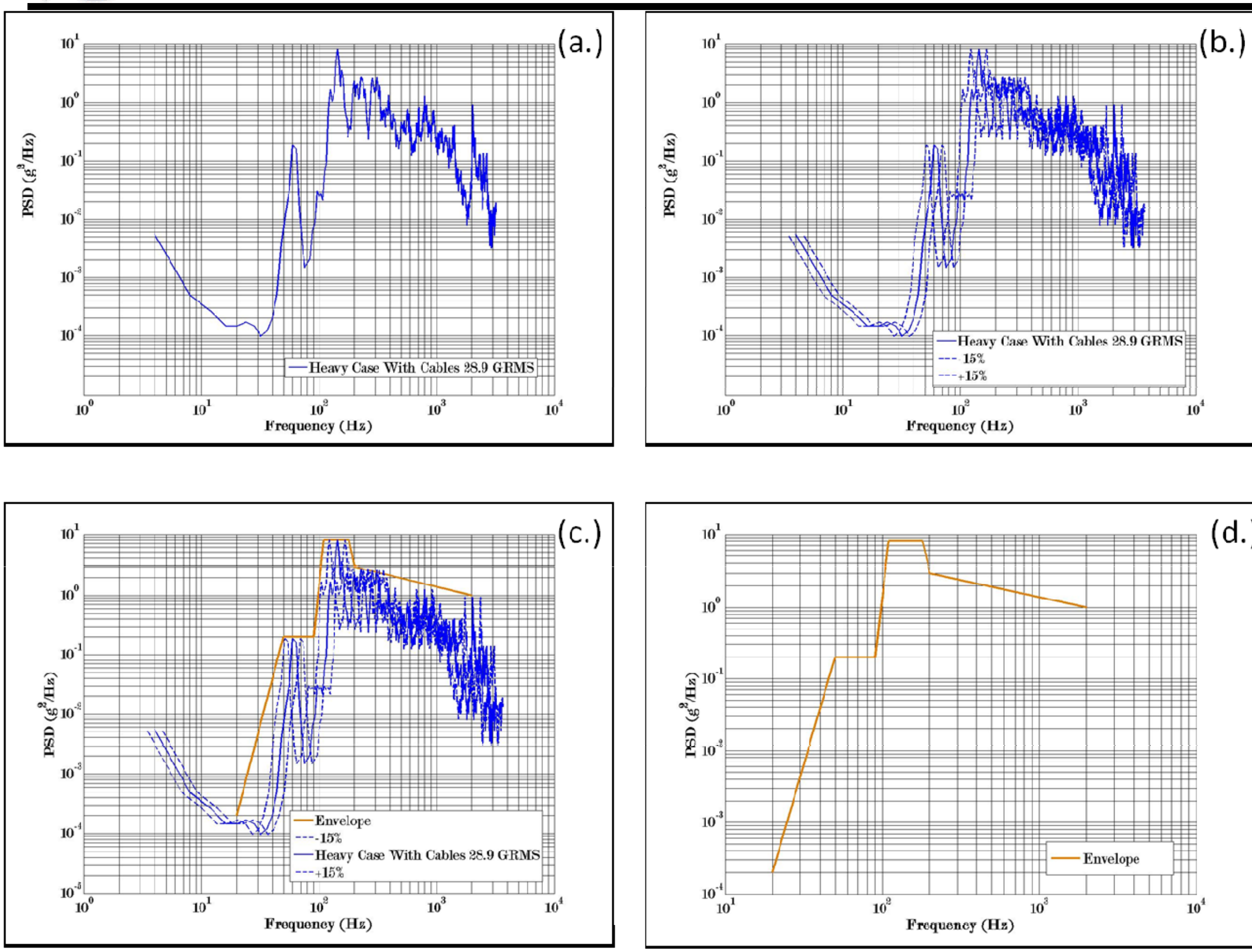
- The plots labeled a and b below present response at locations 4 and 16 for **configurations with and without cables**.
- Attenuation effects are perhaps best observed in figure (a.) below, which seems to have been sensitive to the presence of the cables over a wide frequency range.
- The observed attenuation is not necessarily purely the result of additional damping introduced by the cable harnesses :
  - Attenuation of response, **accompanied by shifts in the frequency** of certain response peaks indicates that inertial mass effects of the added cables are a likely contributor to the response reduction.
  - Without an appreciable shift, **damping is thought to be chief contributor.**



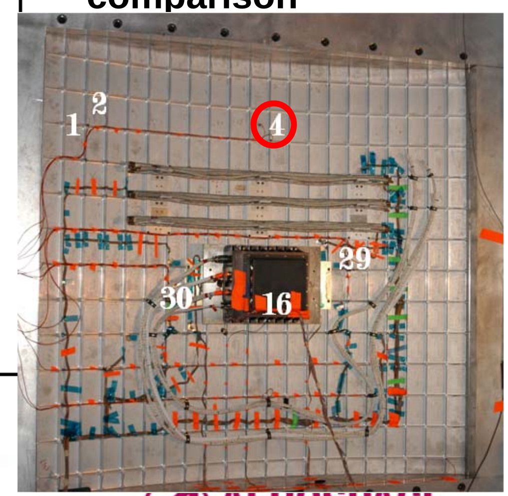




Preliminary Observations From Test

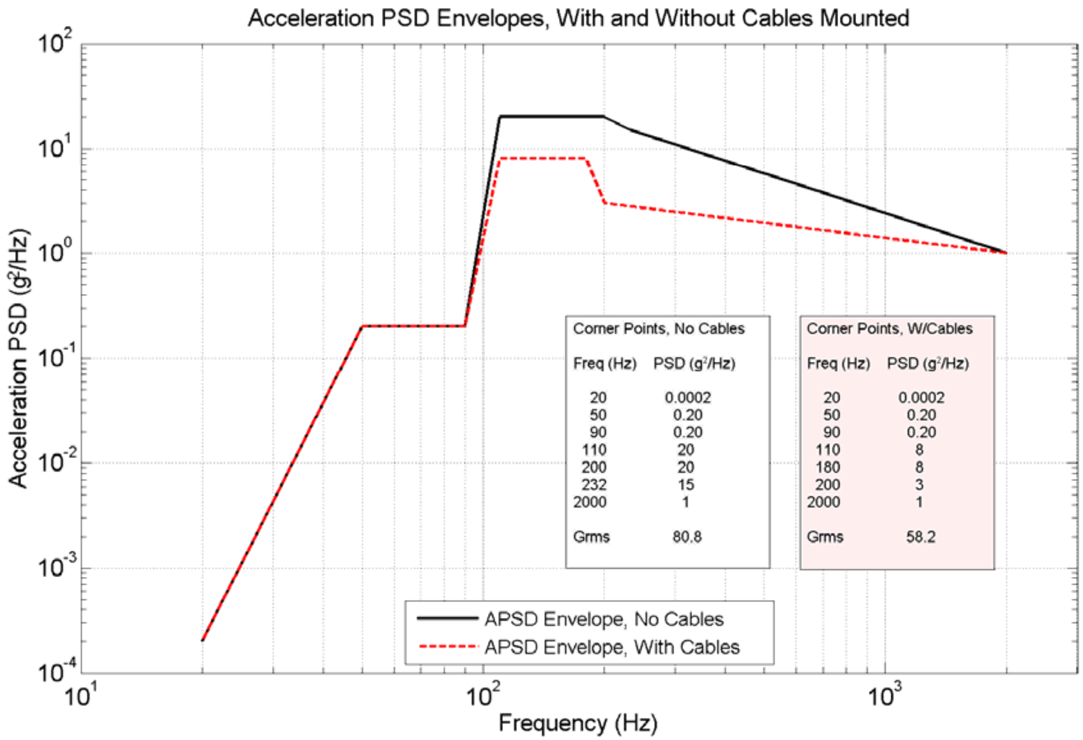


(a.) 4z Acceleration Response Spectral Density (5 Hz frequency resolution),
(b.) Frequency uncertainty considered - measured spectrum shifted by 15% in either direction.
(c.) Smooth envelope over frequency dispersed measurement,
(d.) Envelope retained for comparison



Preliminary Observations From Test

- The measurement from the case with no cables was processed by repeating the same steps. The figure below provides a comparison of the smoothed envelope for this pair of measurements.
- Not all measurement locations will be as sensitive to proximity to cable harnesses, but this reduction may be appropriate for light weight equipment that may stretch across panels that are not heavily mass attenuated.
- The damping attenuation provided by cable harnesses may prove to be most effective in the zones which are large responders.



Use of Finite Elements with Modal Updating for Damping

- Analysts seek agreement between analysis and test to:
  - Validate models
  - Improve predictive capability in untested configurations
  - Validate new analysis methods or tools

- Typically, agreement is sought through model updating

- Without knowledge of test damping, damping becomes a “knob” in the model updating process

- When updating, analysts typically:

1. Assume flat damping across spectrum
   - *Easiest, but can yield poor agreement*
2. Estimate modal damping using half power points
   - *Better agreement, but can be time consuming and tedious*
   - *Intractable for systems with high modal density*
   - *Do not always have quantitative measures of agreement*
3. *The Subjective Eyeball Method*

Updating for Damping with use Of DampID Optimizer Tool

- New MATLAB-based software tool developed at MSFC
  - *Employs MATLAB optimization toolbox*

- Systematically arrives at a damping schedule such that the difference between FEM response and test data is minimized

- Required user inputs:
  - *Frequency response data at each test channel*
  - *FEM nodes that correspond to each test channel*
  - *FEM natural frequencies and modes*
  - *Excitation Definition*
    - *Drive point and forcing function for Base Shake*
    - *Spatially Correlated Pressure PSD for Panels excited by Fluctuating Pressure such as Acoustic Field*

DAMP ID eliminates need to assume flat damping or create complex damping schedules via trial and error

DAMP ID Features

- **Key Capabilities**

- Identifies damping based on multiple channels of response data simultaneously

- Allows multiple channels of input spectra
  - *Either correlated or uncorrelated*

- Accepts forcing input in form of:
  - *Force spectral density*
  - *Acceleration spectral density (via large mass method)*
  - ***Acoustic pressure spectral density***

User Defined Options

- Frequency range of interest
- Number of “bins” in frequency range
- Lower and upper bounds on damping fraction
- Weight agreement at peaks more heavily
- Apply penalty to non-conservative solutions
- Filter out contributions from other bins
- Apply linear or log scaling
- Save plots at each iteration for purposes of making movies

Statistics in Objective Function

1. Bin Peak
2. Bin Average
3. Bin Standard Deviation
4. Bin Variance
5. Bin RSS
6. Bin Correlation Coefficient
7. Bin Minimum

Methodology

- DAMP ID uses MATLAB Optimization Toolkit function **FMINCON**
  - Based on conjugate gradient-based nonlinear constrained optimization technology*

- Seeks a local minimum of a user-defined objective function

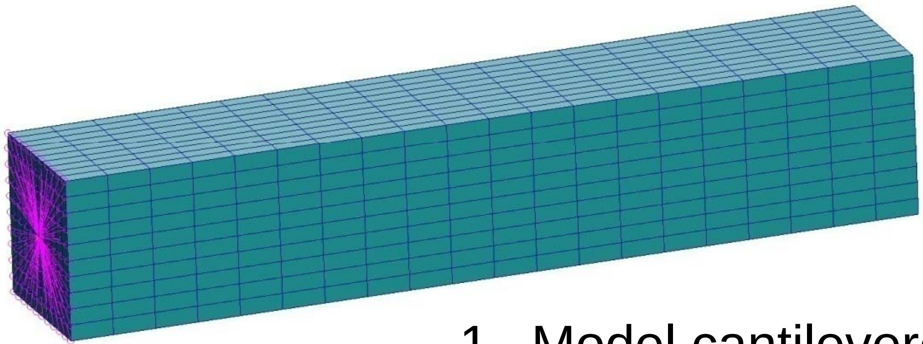
- At each iteration:
  1. Trial damping schedule used to find frequency response via MATLAB functions developed at MSFC
  2. Objective function and its gradients calculated
  3. Calculates new trial damping schedule

- Identification process ends when objective function converges within prescribed tolerance

* Good reference: Matlab Optimization Toolkit User Manual, Chapter 6, "Constrained Nonlinear Optimization Algorithms," Mathworks, 2011

Case 1

Simple Structure with Known Damping



Solution Steps

1. Model cantilevered beam with square cross-section

2. Develop arbitrary, but known, damping schedule and generate response to flat acceleration input spectrum (SOL 111)
   - *Consider this the "test" response*

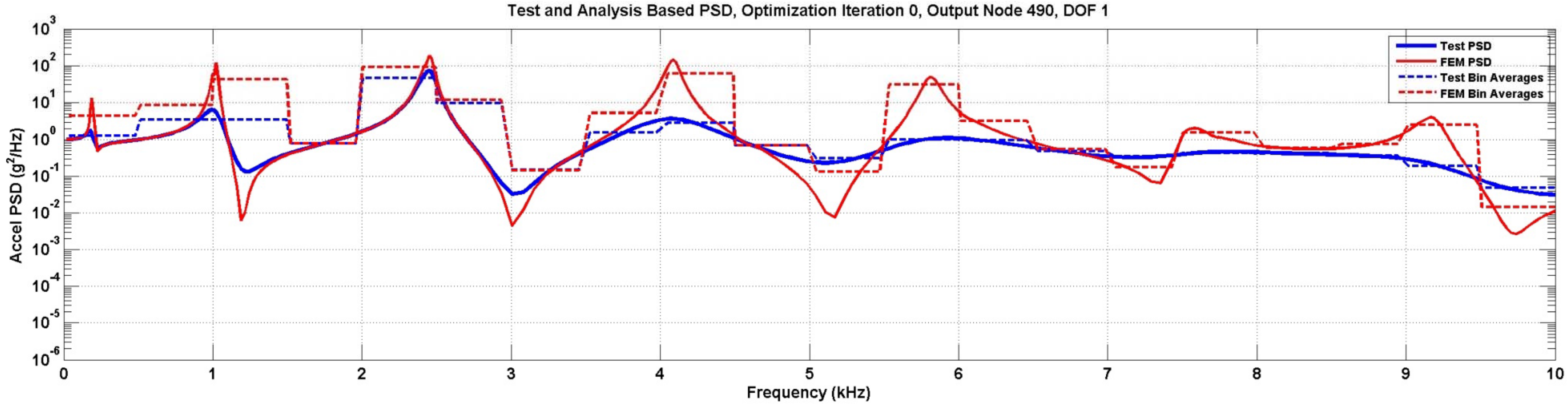
3. Initialize analytical response with a flat 0.01 damping

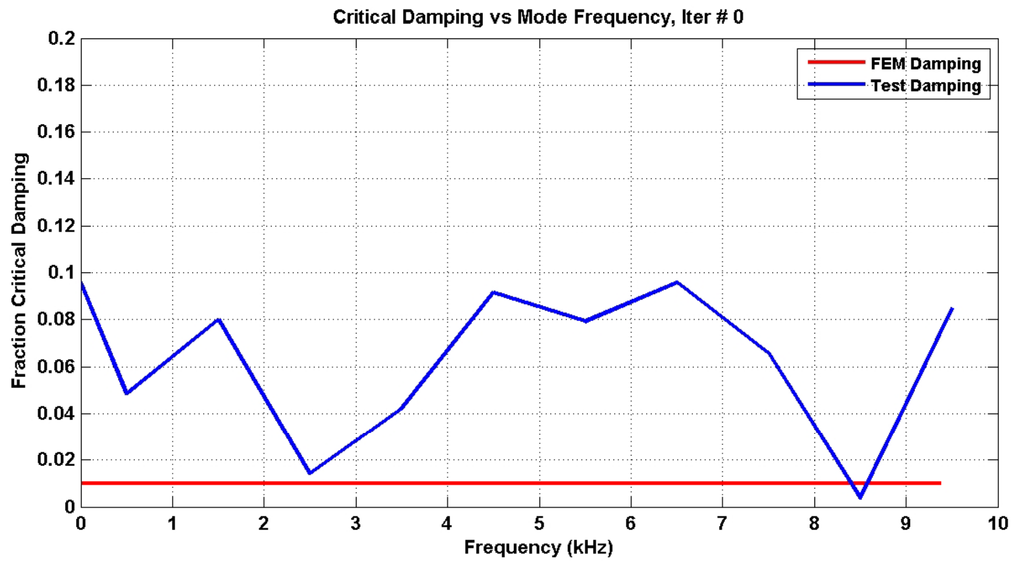
4. Observe Damp ID attempt to match analytical and "test" response by adjusting damping schedule

Case 1 (cont'd)

Simple Structure with Known Damping

Iteration 0

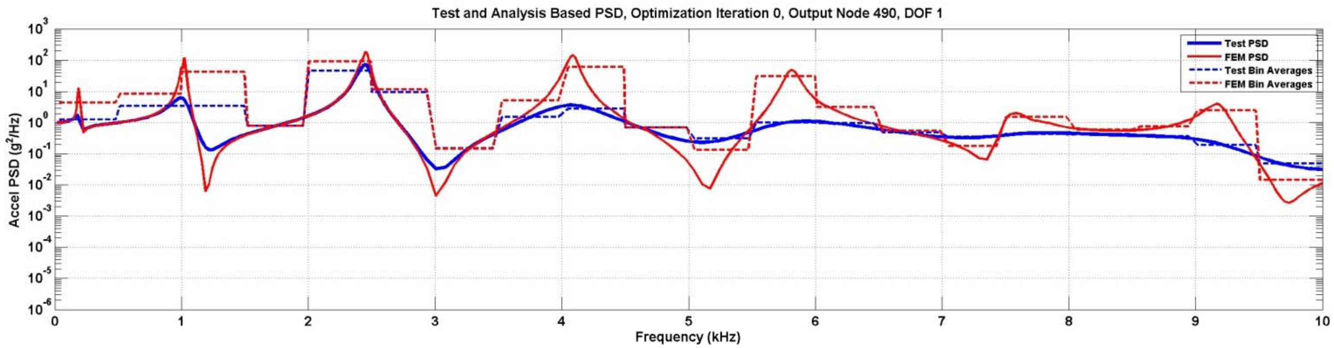


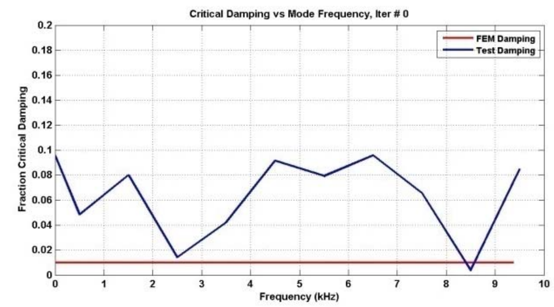


Case 1 (cont'd)

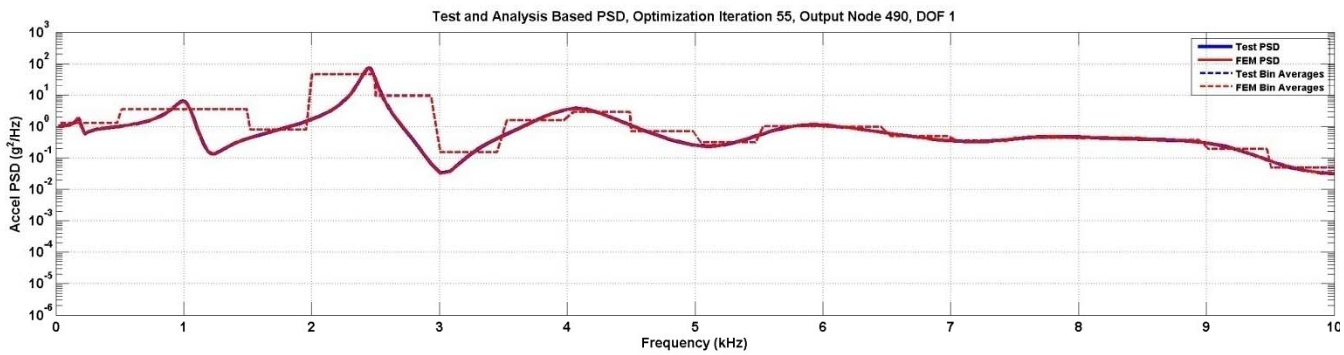
Simple Structure with Known Damping

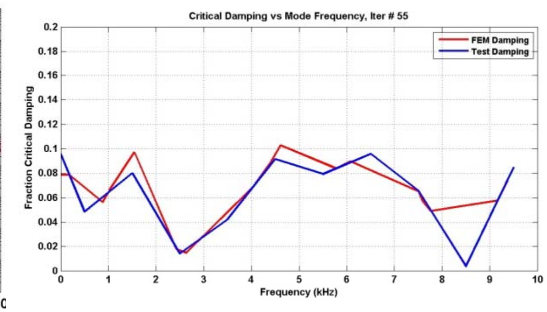
Iteration 0





Iteration 55

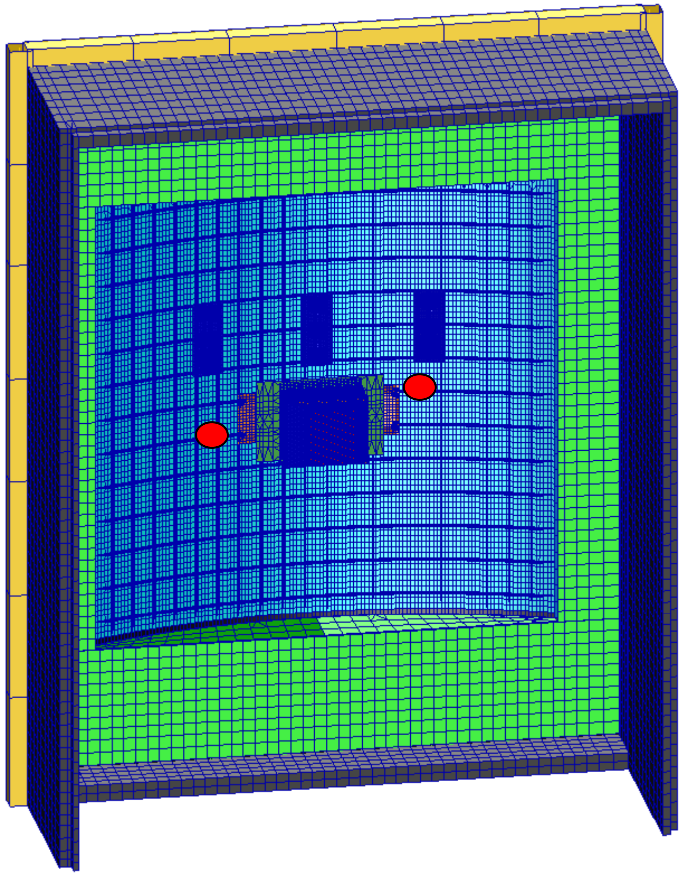




- Excellent agreement between "test" and analysis responses
- Damp ID finds known damping schedule quite well
- Areas of damping discrepancy indicate response is insensitive to damping at those frequencies

Case 2

Vehicle Panel Responding to Fluctuating Acoustic Pressure Excitation



Solution Steps

Use model matching 3 different Test configurations:

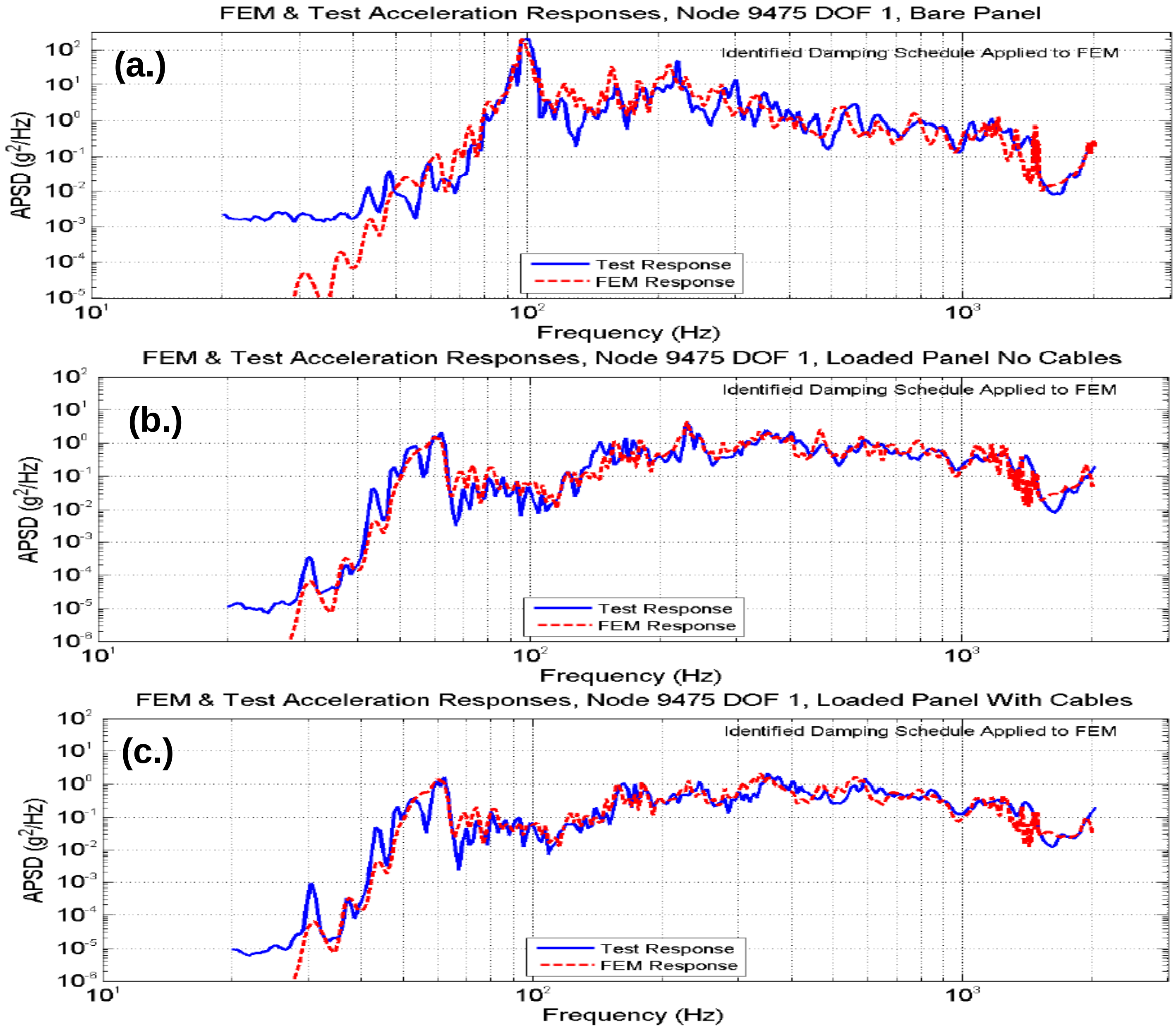
- Bare Panel
- Loaded without cables
- Loaded with cables

Use “test” measured response and optimize for 6 channels of response at 2 locations

Observe Damp ID attempt to match analytical and “test” response by adjusting damping schedule.

Case 2a, 2b,& 2c (cont'd)

Vehicle Panel Responding to Fluctuating Acoustic Pressure Excitation



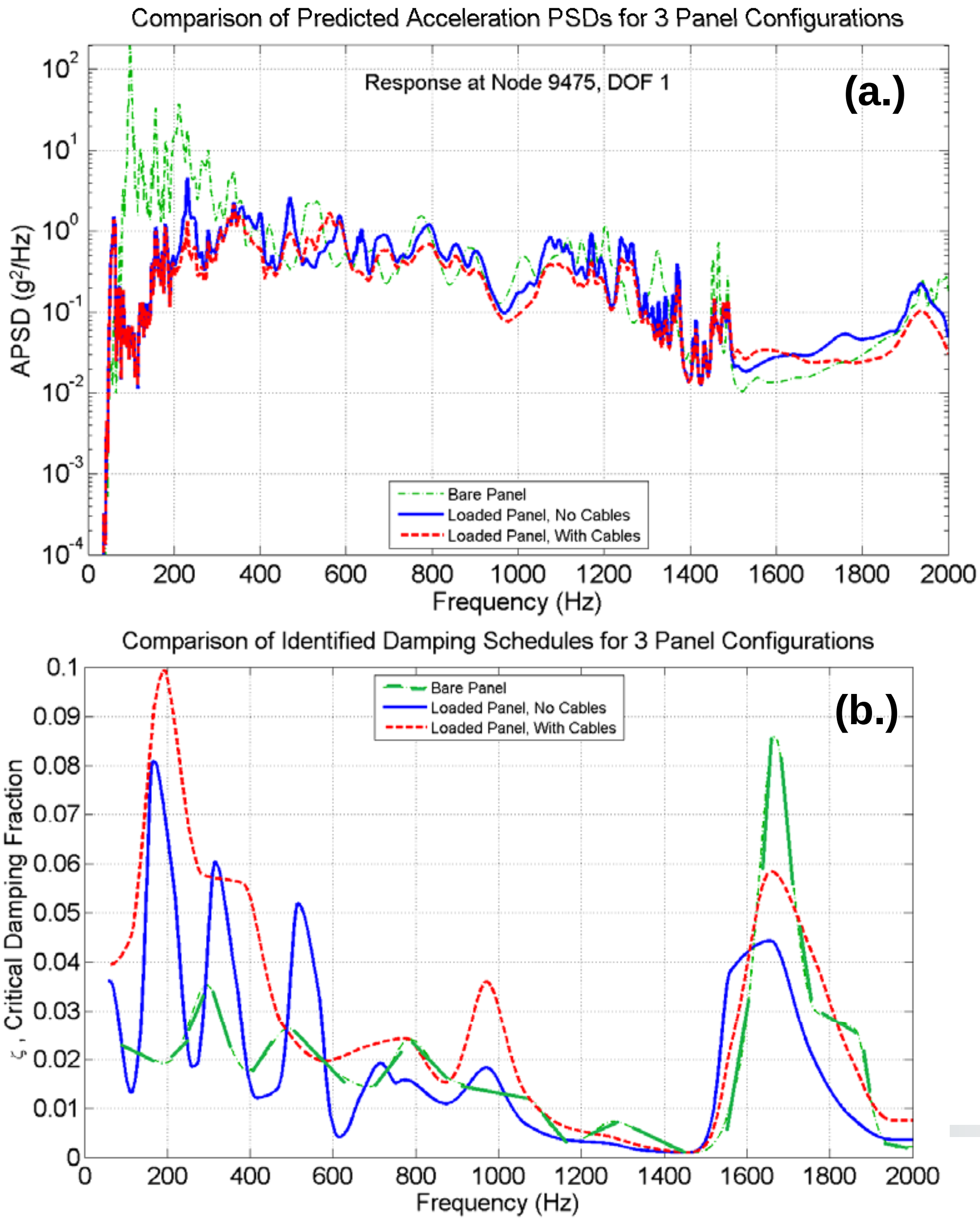
(a.) Bare Panel Configuration -FEM Result with optimized damping compared to test measured response

(b.) Equipment Loaded **(No Cables)** Configuration -FEM Result with optimized damping compared to test measured response

(c.) Equipment Loaded **(With Cables)** Configuration -FEM Result with optimized damping compared to test measured response

Case 2a, 2b,& 2c (cont'd)

Vehicle Panel Responding to Fluctuating Acoustic Pressure Excitation



(a.) The FEM Predicted response for three configurations are compared. Bare Panel, Equipment Loaded **(No Cables),** Equipment Loaded **(With Cables)** Configurations - Using System Damping Schedules from Optimizer

(b.) Comparison of the System Damping Schedules from Optimizer for the same three configurations.

Note that system Damping increases with increasing levels of integration:

- Loaded Panel greater than Bare Panel (correlates with presence of more bolted joints and friction mechanisms).
- Loaded Panel **(With Cables)** greater than Loaded Panel **(No Cables)** (correlates with presence of energy sinks and friction mechanisms).

Optimized damping from 1500-1800 Hz is Curious and warrants further study.

Conclusions and Future Work

- Three example configurations were assessed and compared.
- Assessment of Cable Harness test results is a work in Progress.
- Attenuation due to damping was significant at certain measurement locations.
- DAMP ID Optimization routine was demonstrated addressing a long-standing need to systematically update FEM Response assessments by adjusting damping.
- Computationally efficient and flexible with applications to both acoustic and base drive excitation.

Cautions:

- Damping schedules are not unique.
- Damping schedules may not be consistent across all spatial locations and/or forcing functions. Nonlinear with excitations amplitude.
- Care should be taken when assigning physical significance to damping schedules.

Future work:

- Use Damp ID to assist in completing the assessment of Cable Harness test cases in recent acoustic panel testing conducted at MSFC
- Present results in NASA report and or Technical paper.
  - *Report sensitivity to amount of cable harnesses*
  - *Report Linearity/Nonlinearity of observations for different levels of excitation.*
- Investigate curious results from 1500-1800 Hz.

Reference:

[1]Smith, A., Davis, R.B., LaVerde, R., Fulcher, C., Jones, D., Waldon, J., Craigmyle, B., "Validation of Measured Damping Trends for Flight-Like Vehicle Panel/Equipment Including a Range of Cable Harness Assemblies", AIAA SDM April 2012.

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Thank you