

Vibro-acoustic Predictions of the MSL Cruise Stage and Correlation with Acoustic Measurements

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Introduction

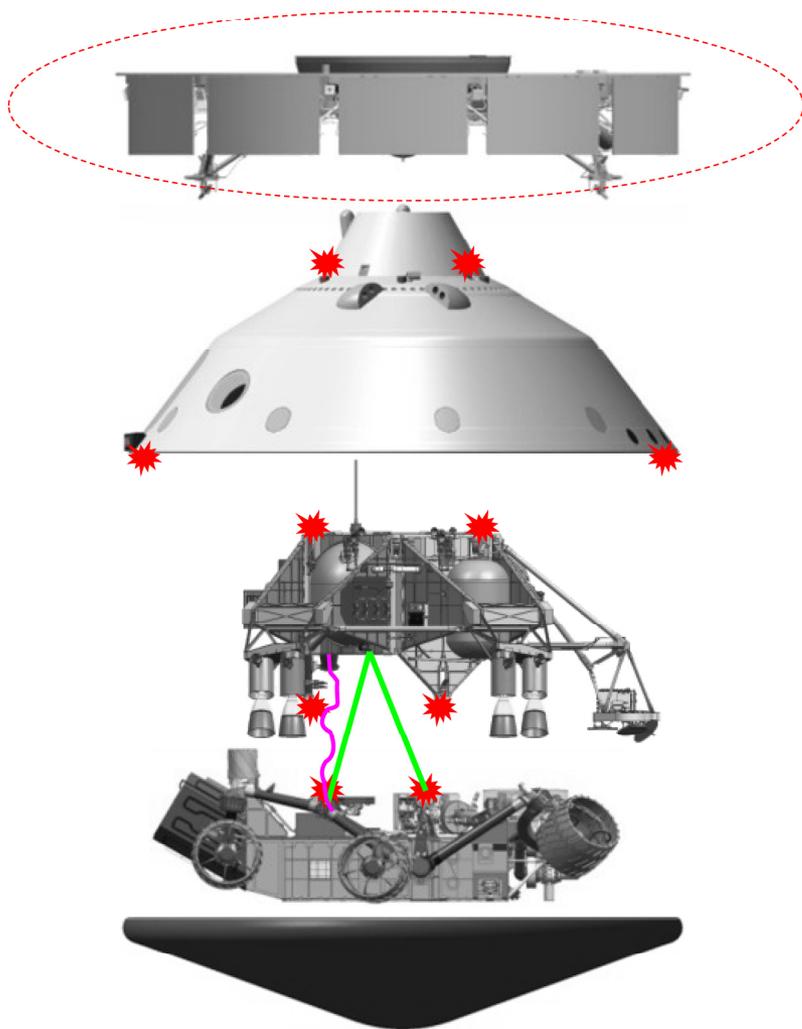
➤ Objectives:

- Compute acoustically-induced stress and acceleration responses of the Mars Science Lab (MSL) Cruise Stage (CS) by utilizing a combined Boundary Element Method (BEM) and Statistical Energy Analysis (SEA)
 - Correlate the prediction results with acoustic test performed on the MSL spacecraft.
- Hybrid BEM/SEA analysis in VA ONE software was performed.
- BEM is a deterministic approach in which the structural modes are coupled with the acoustic modes. It is computationally expensive and appropriate for low frequencies (in this case up to 400 Hz).
- SEA is a low-fidelity statistical approach and computationally much less expensive. The SEA in general works reasonable at higher frequencies, where adequate structural modes in a frequency band exist, and consequently statistical averaging is meaningful (in this case > 300 Hz).

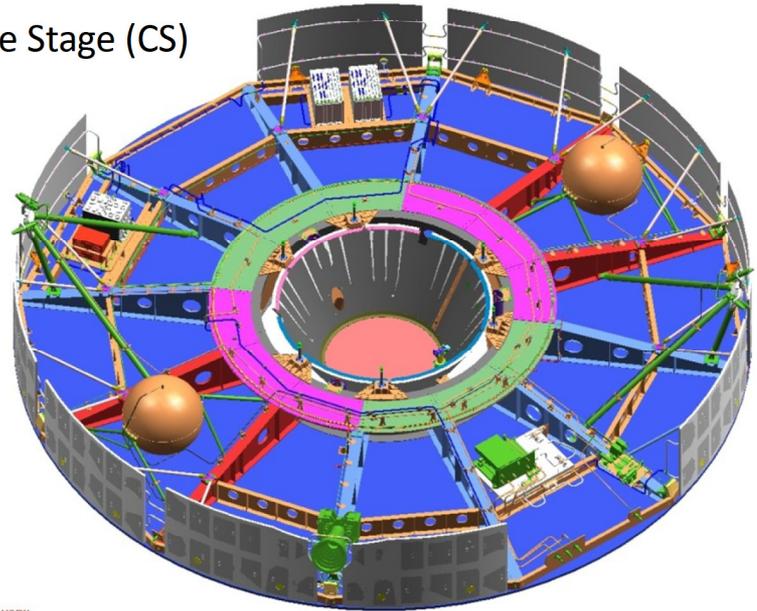




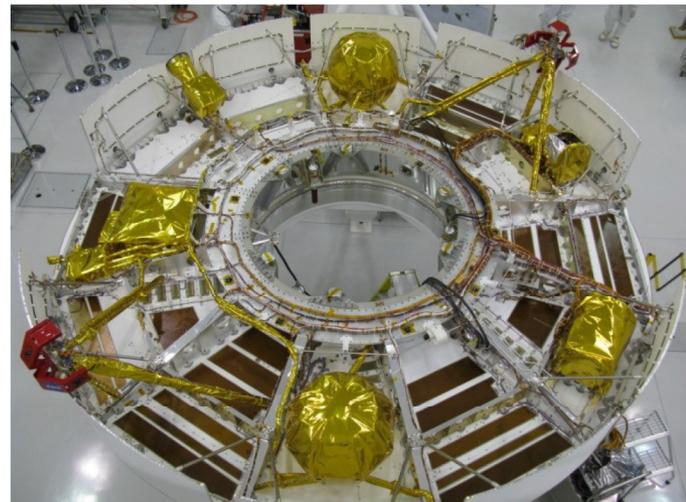
MSL Spacecraft Overview



MSL Cruise Stage (CS)



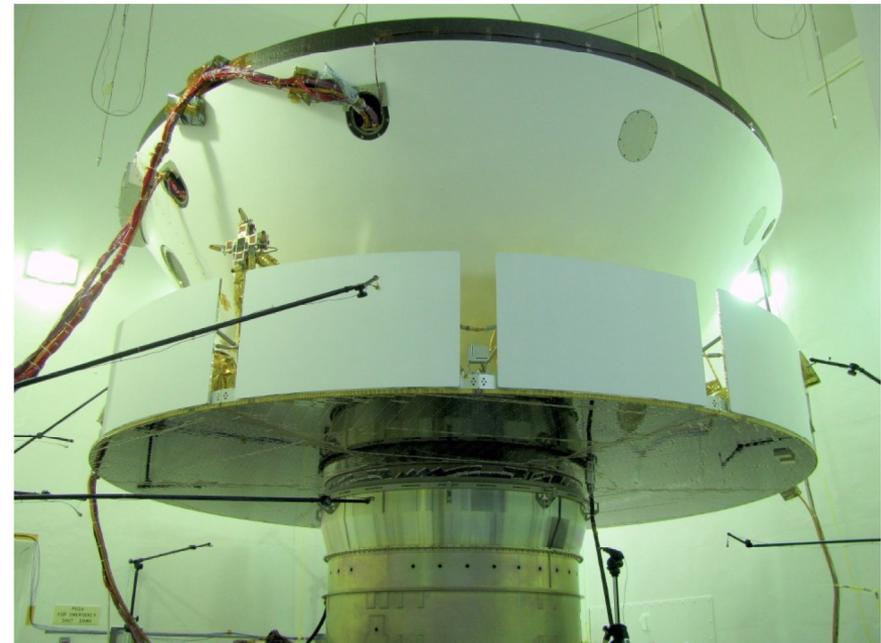
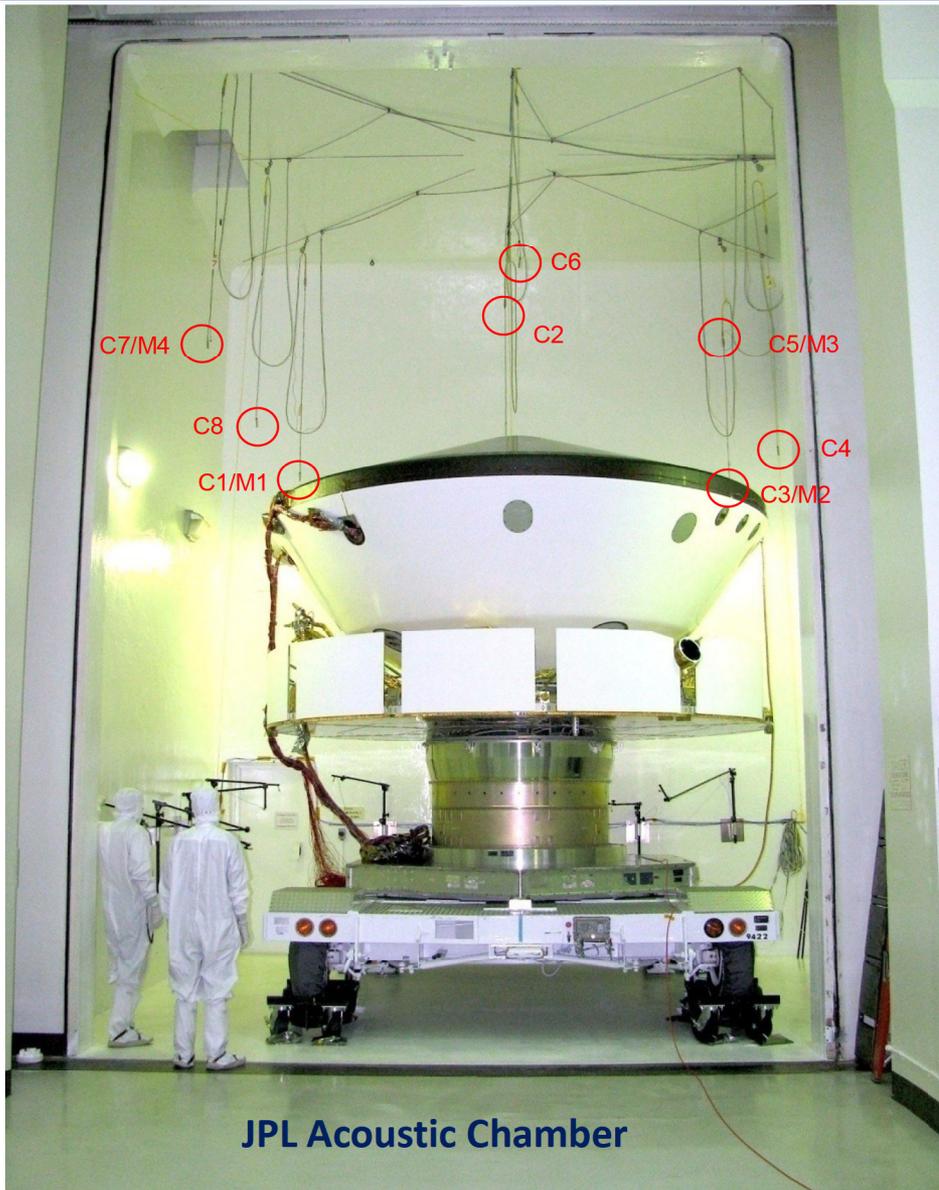
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MSL Spacecraft Protoflight Acoustic Test

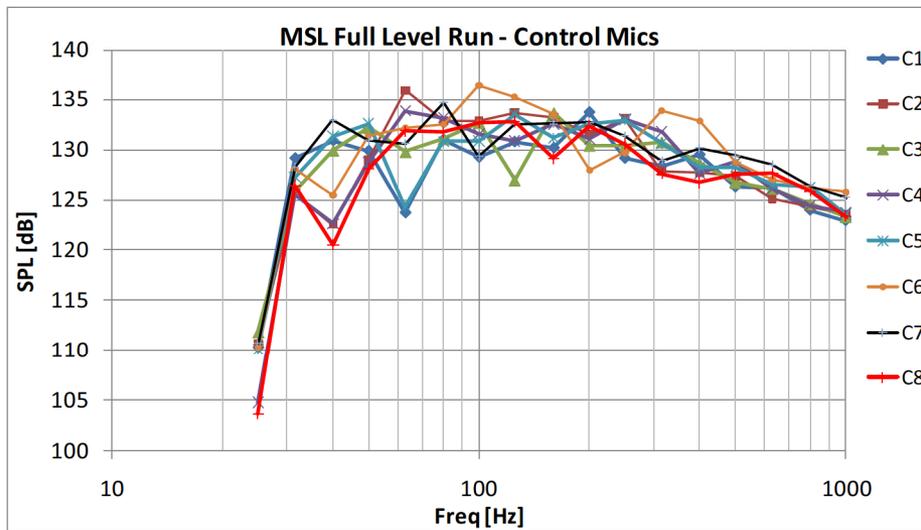
C1 thru C8 - Control Microphones
M1 thru M16 - Monitor/Response Microphones



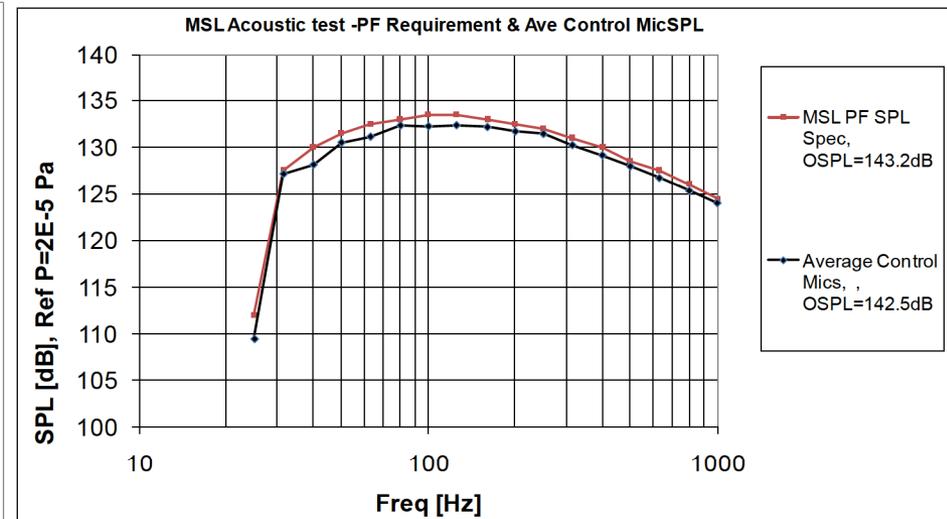


Acoustic Test SPL

Sound Pressure Level (SPL) obtained from the Individual Control Mics



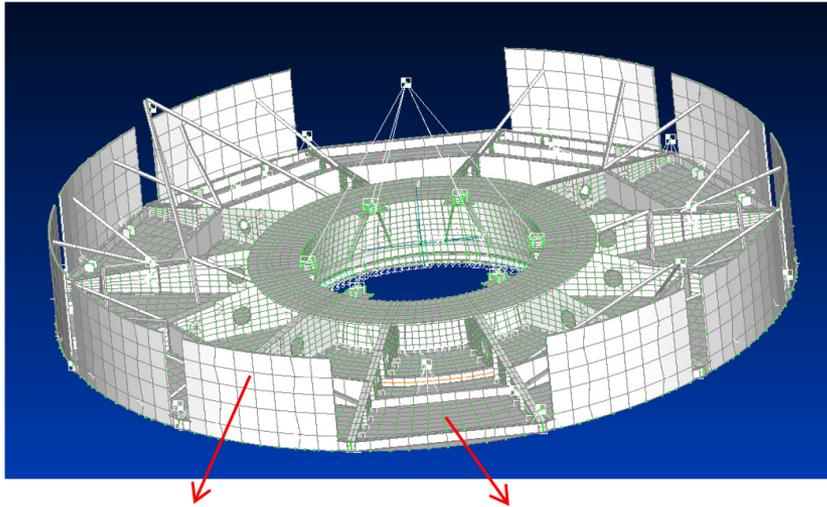
Average SPL from the Control Mics versus MSL PF Requirement





Boundary Element Modeling (BEM) of the MSL CS

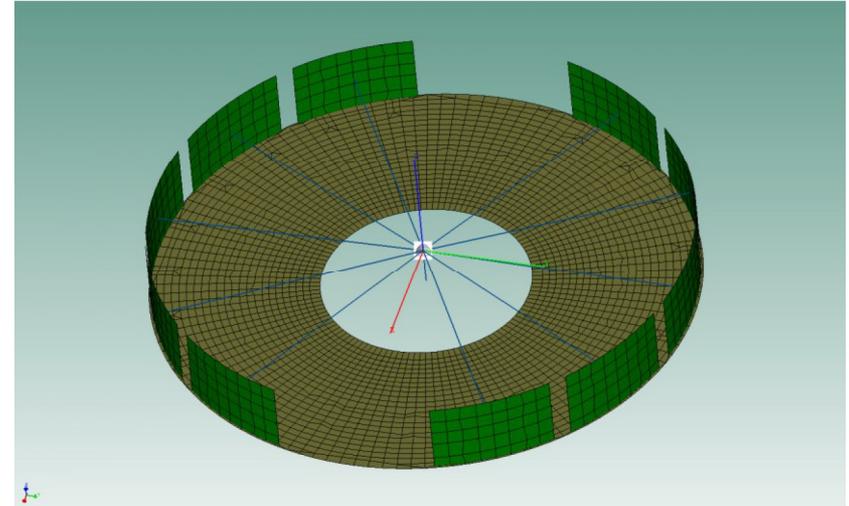
NASTRAN FE Model of the CS



HRS Radiators (10x)

Solar Array substrate (6x)

BEM Model of the CS in VA ONE

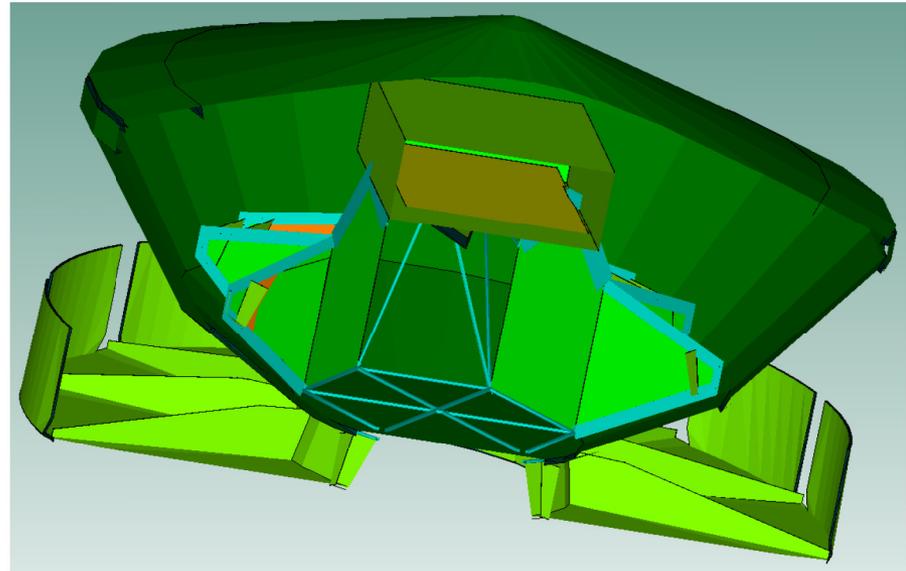
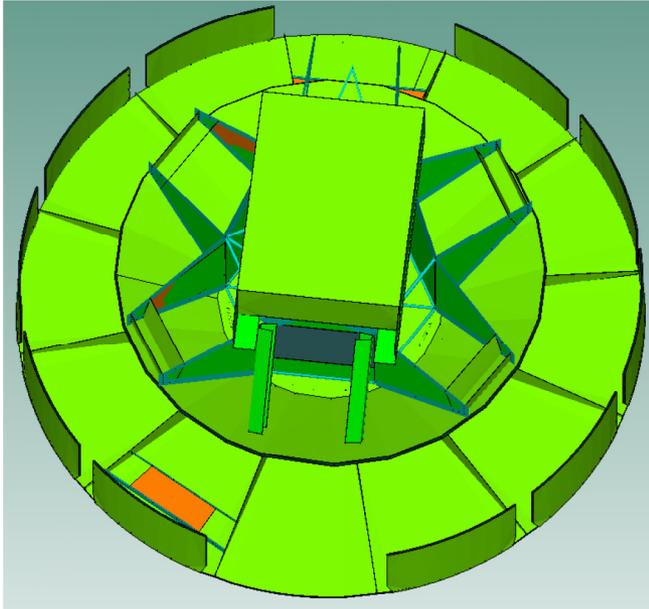


Modeling Considerations:

- The BEM analysis was performed in 1/12 octave bands up to 400 Hz.
- BEM mesh quality: the BEM Mesh size was reduced to include at least 12 points per wavelength at 400 Hz.
- There are 614 structural modes up to 400 Hz.
- RAYON BEM Solver in VA ONE 2008.5 was used.
- 1% critical damping ratio was assumed for all structural modes (2% DLF).
- The air acoustic absorption was assumed to be zero.

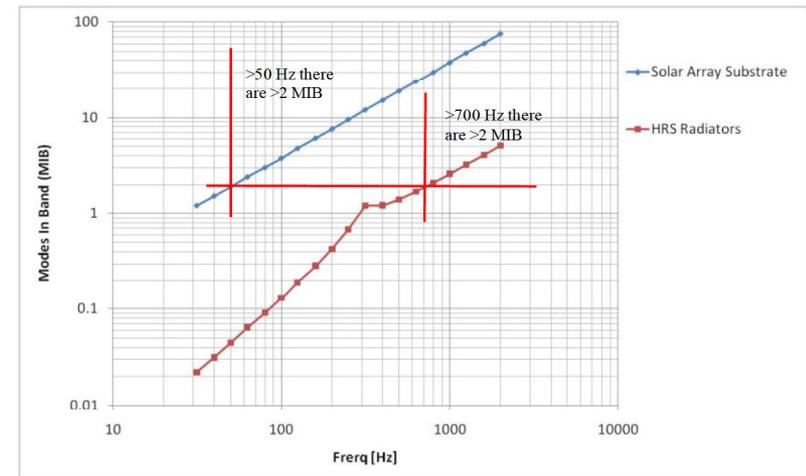


SEA Model of the MSL Spacecraft



SEA Modeling Considerations:

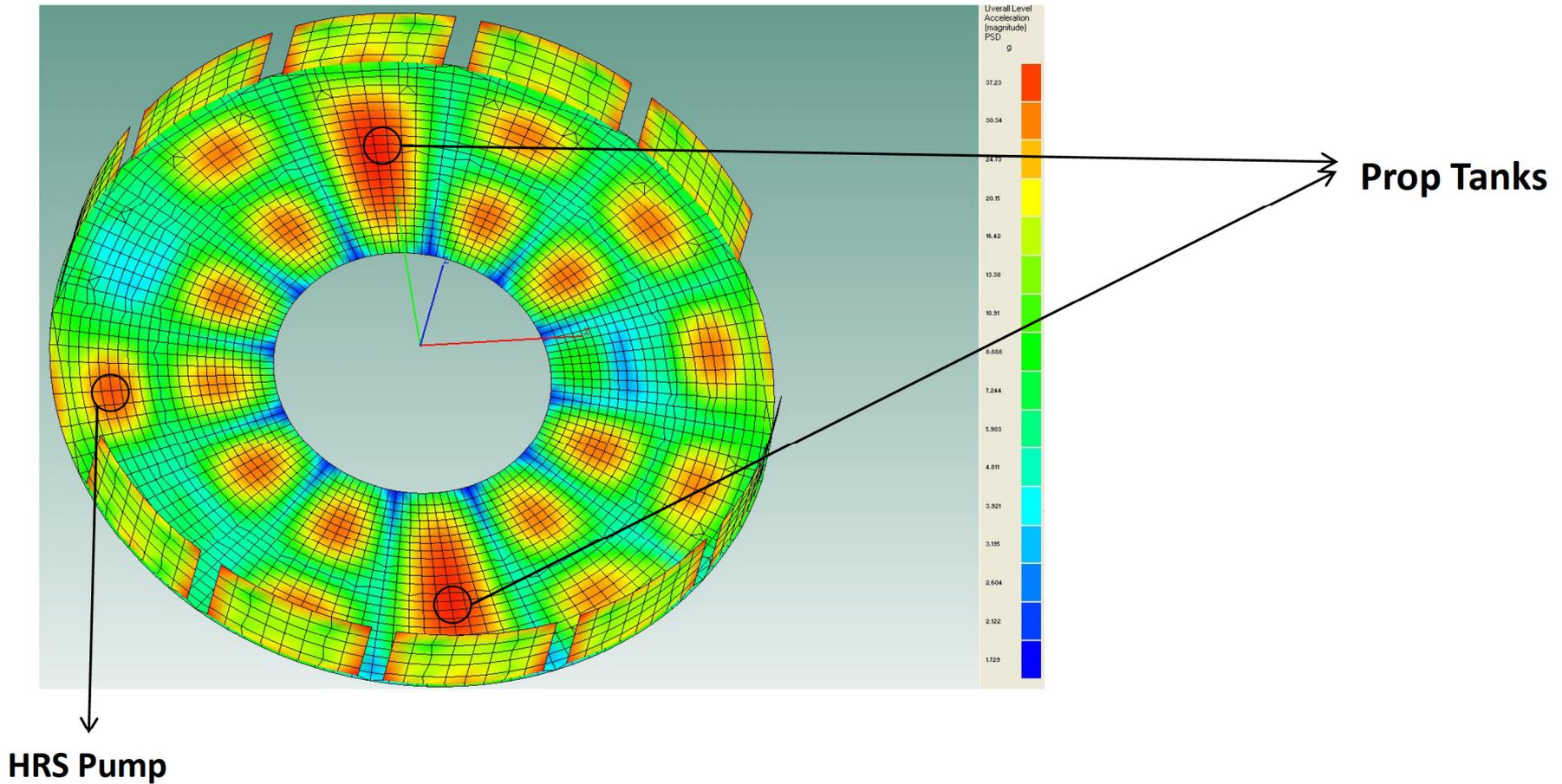
- For all structural members, **2% Damping Loss Factor (DLF)**
- +3dB adjustment was added to the Diffuse Acoustic Fields directly applied to the Solar Array and HRS Radiators' surfaces.
- Mass Loading: McNelis PATH49 radiation efficiency was used.





BEM Results: Response Acceleration Contour Plot

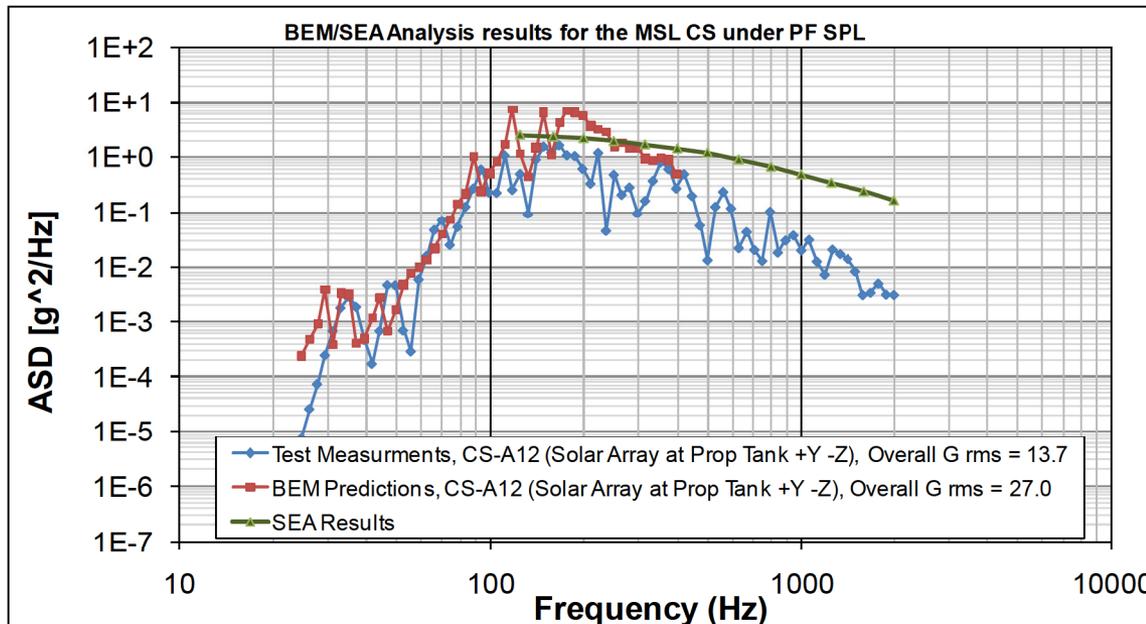
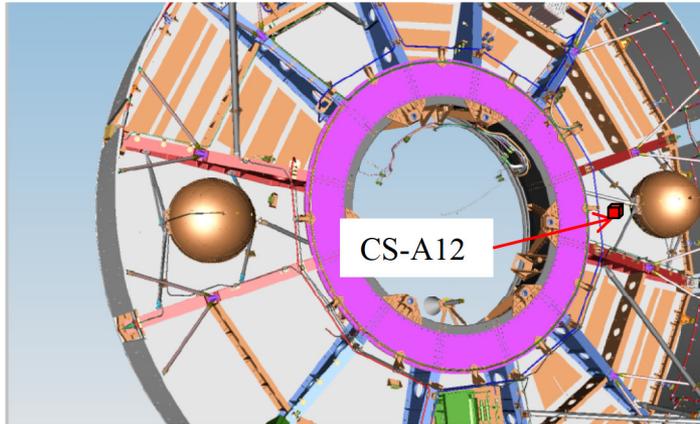
Contour Plots for the overall Grms





BEM/SEA Accel Predictions at Accel CS-A12 and Comparison with Measurements

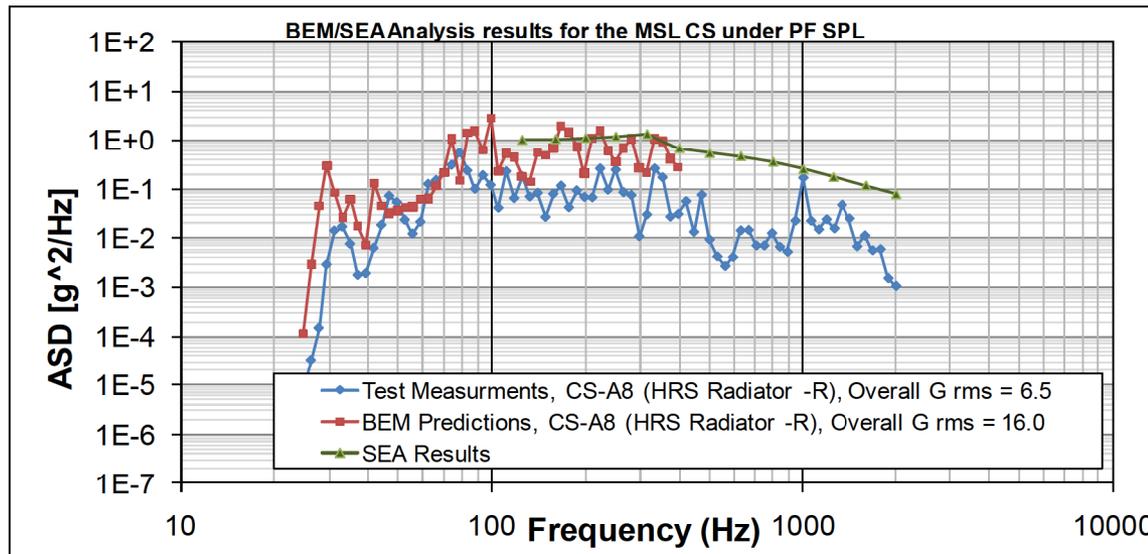
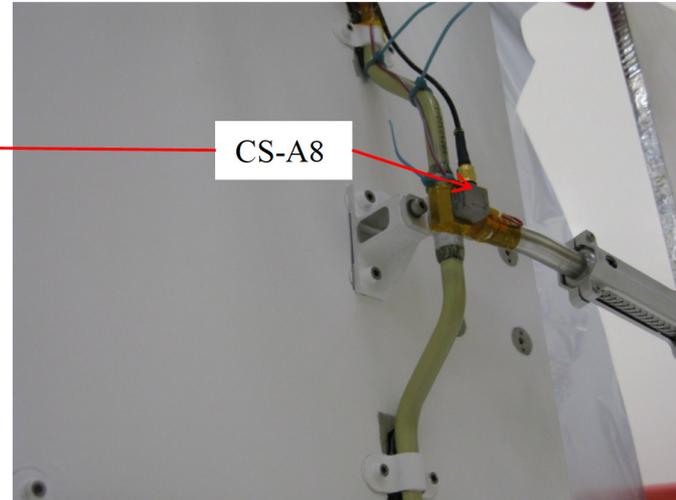
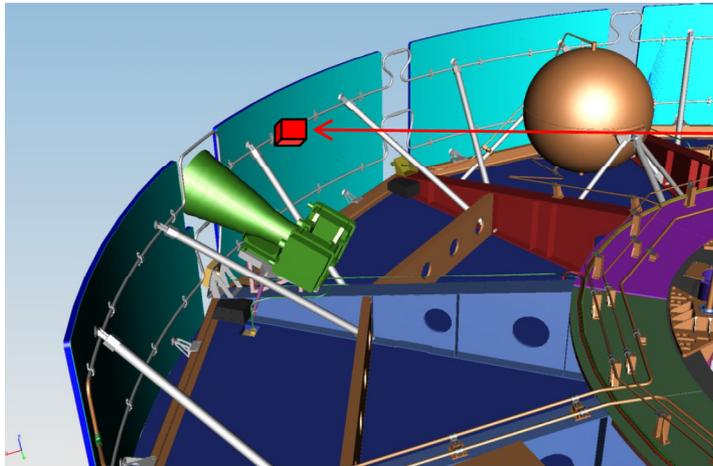
CS-A12 placed on the Solar Array Substrate, right underneath the Prop Tanks





BEM/SEA Accel Predictions at Accel CS-A8 and Comparison with Measurements

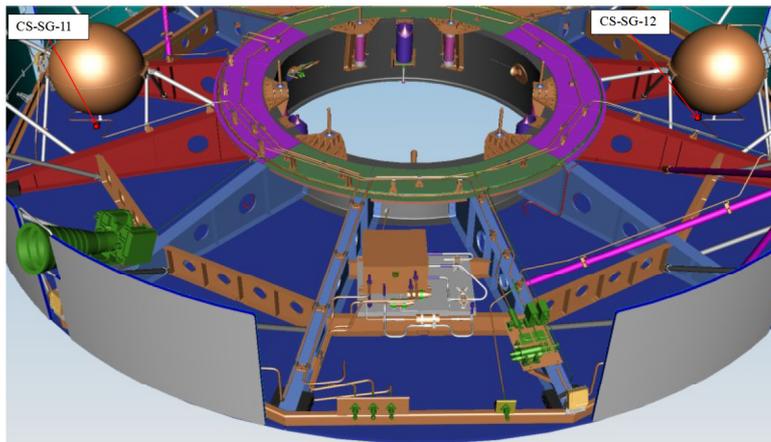
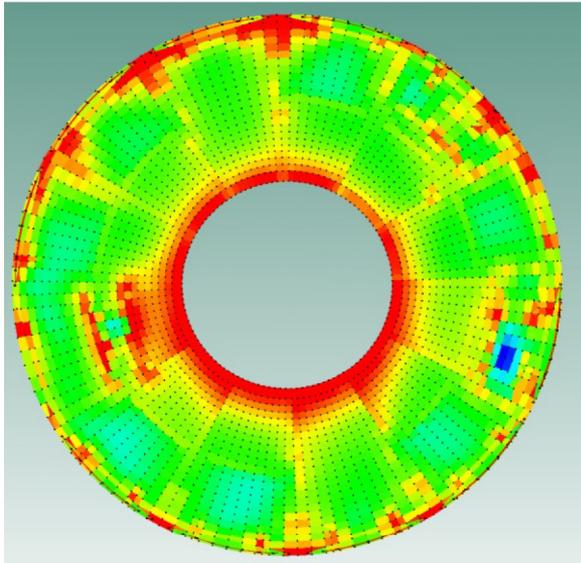
CS-A8 placed on the CS HRS Radiator Lines



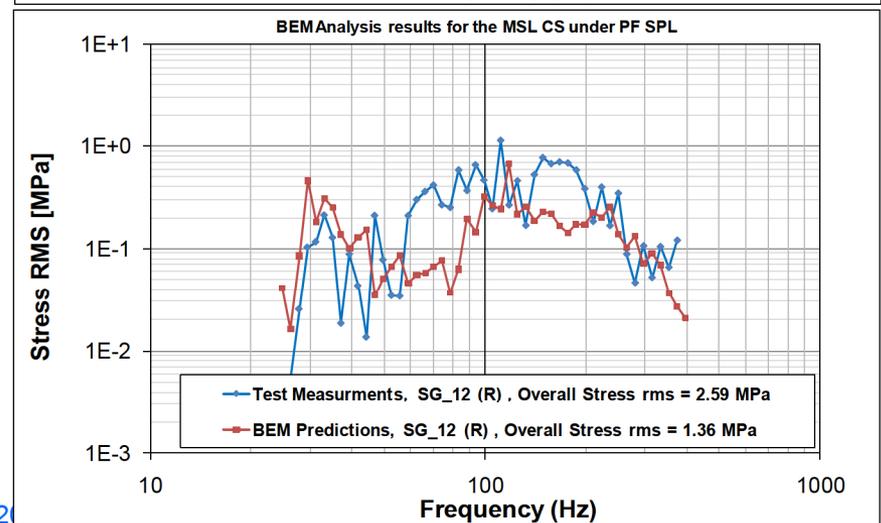
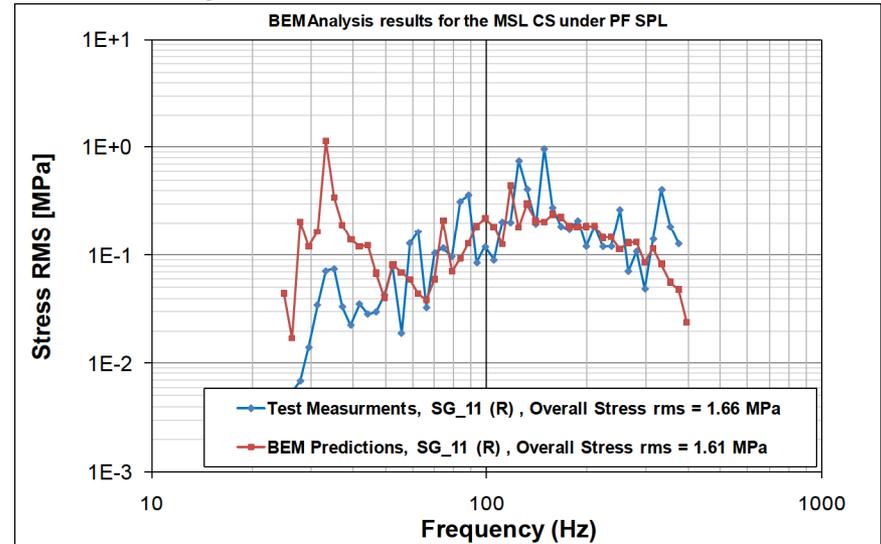


BEM Stress Predictions

BEM Contour Plots for the CS Overall Stress



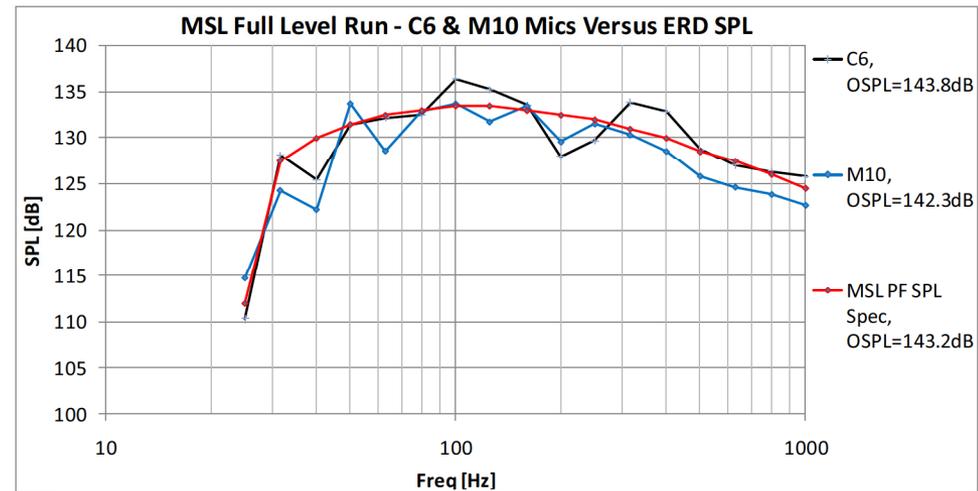
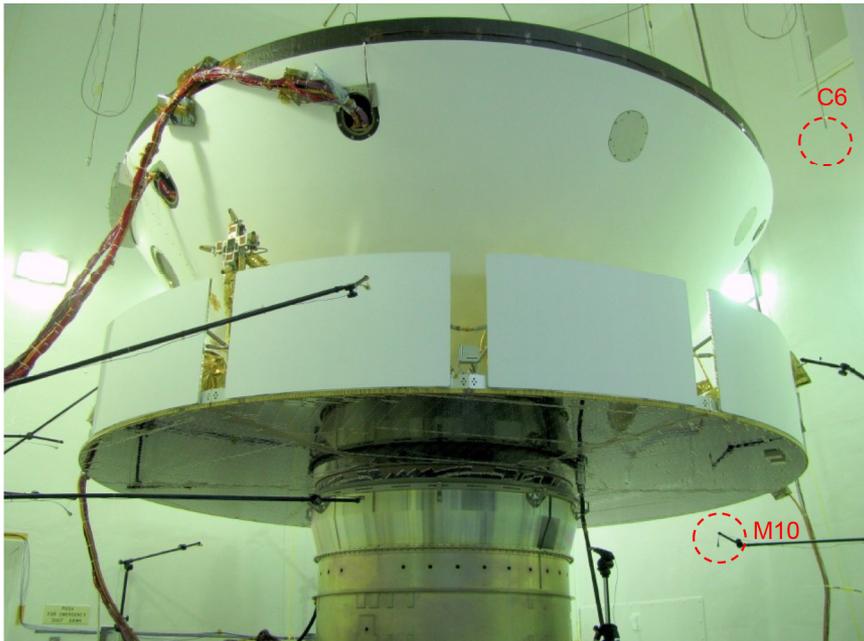
BEM Stress Predictions at CS-SG-11 & 12 and Comparison with the Test





BEM Predictions Improvements Using the Test Operational SPL (1/2)

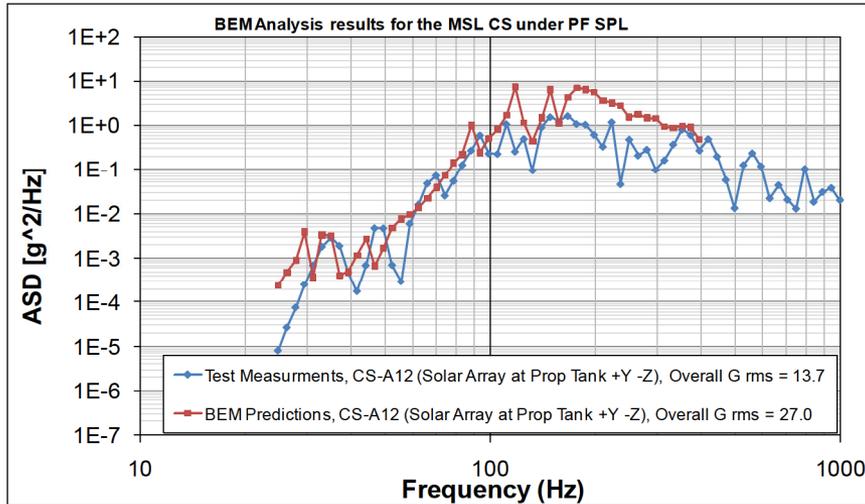
- Prior to the acoustic tests, we used the MSL PF requirement SPL (the red curve) as input to the BEM/SEA analyses.
- Post test analysis can be performed using input SPL based on the actual measured pressure time histories from the Mics in the chamber.
- To that end, the SPL measurements from the M10 & C6 Mics are used (M10 is relatively closer to the CS).



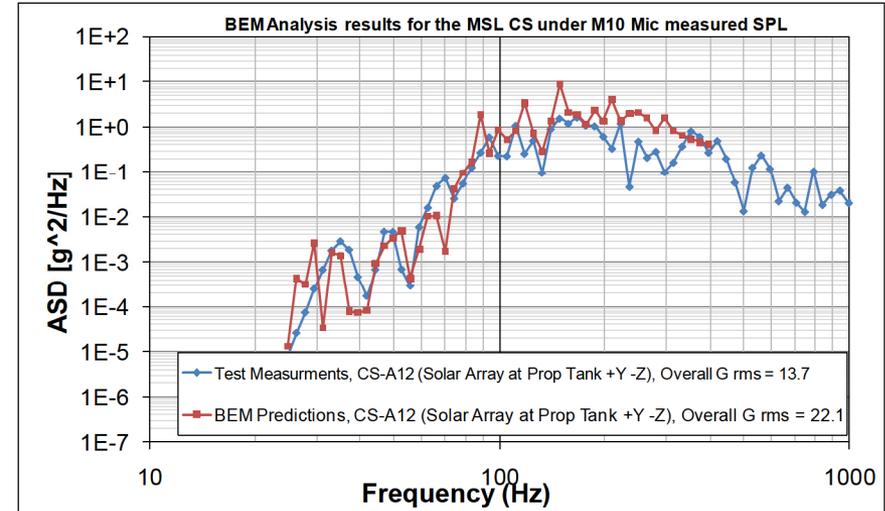


BEM Predictions Improvements Using the Test Operational SPL (2/2)

BEM Results for the MSL PF SPL



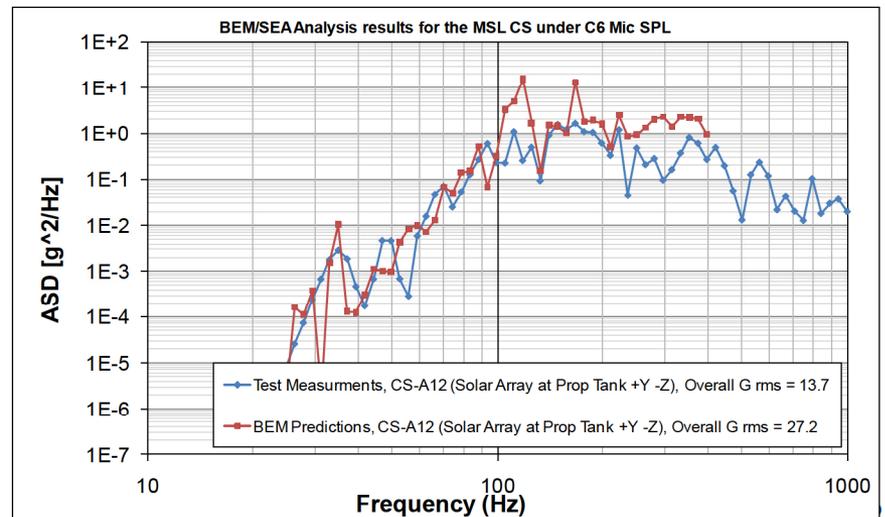
BEM Results for the Test SPL measurement from M10 Mic



➤ Improvements in the BEM predictions is made by incorporating the operational SPLs from the test, *especially at low freq and in the overall Grms*

➤ The BEM results with the M10 Mic SPL as input, is in a better agreement with the measured responses, since the M10 Mic is closer to the CS, and is more representative for the sound pressure that the CS experienced during the test.

BEM Results for the Test SPL measurement from C6 Mic





Modeling Deficiencies

- In general, FE model fidelity is good for the first several global modes, and lacks the fidelity/accuracy at higher frequencies.

- The 1% critical damping factor used for all modes may not be realistic.
 - modal testing/measured response time histories may provide more representative damping constants.

- Aeroshell not modeled in BEM, but present during the acoustic test.
 - The acoustic absorption may have some effects.

- The SPL is assumed to be diffuse in our analyses. However the MSL spacecraft's large volume compared to the chamber size may impact the diffusivity assumption made in this analysis.

- The Sensor locations could not be precisely pinpointed in the analysis (important for the stress recovery).



Summary

- The acoustically-induced stress and acceleration responses for the MSL Cruise Stage were computed via BEM/SEA analysis and compared with measurements from MSL S/C acoustic test.
- The BEM analysis of the CS was conducted in VA ONE using 614 Structural modes in the FE model (up to 400 Hz).
- The SEA Analysis of the CS was performed in VA ONE using McNelis PATH49 radiation efficiency.
- The BEM predictions of the acceleration & stress responses for the CS Solar Array substrate and HRS Radiators were presented and compared with the test measurements. The comparison showed a reasonable agreement between the predictions and the measured data.
- The SEA and BEM results matched at mid frequencies (200 to 300 Hz) which is a good indication of consistency of these predictions.
- There are some modeling deficiencies that affects the predictions' accuracy and can be improved in the future iterations.

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Thank You



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