A Review of Mass-Loaded Support Structures Random Vibration Prediction Methodologies

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Overview

- **Random vibrations at component/vehicle structure interfaces can be greatly attenuated by the mass of heavy components**
- **Historically, knock down factors based on Barrett method applied to the unloaded structure vibration predictions have been used to account for the attenuation due to the component masses**

$$PSD_L / PSD_{UL} = W_S/(W_S + W_C)$$

  - **The knock down factor has a few technical issues**
- **The methodologies for predicting mass loading effects on random vibration levels are reviewed**
  - **A series of acoustic tests using panels with different configurations and components were performed to examine:**
    - **An improved Barrett Method for estimating mass attenuation effects to be used in early design phase**
    - **An impedance method using the frequency dependent apparent masses of the support structures with components to be used in more advanced design phase**

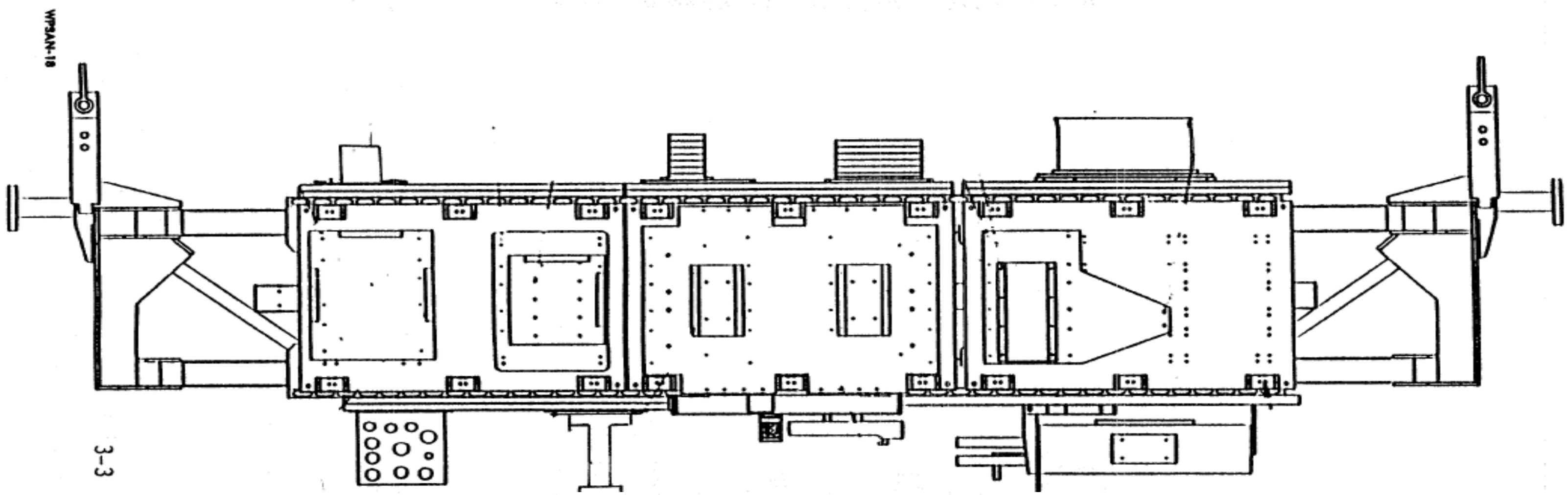
$$PSD_L / PSD_{UL} = |M_S/(M_S + M_C)|^2$$

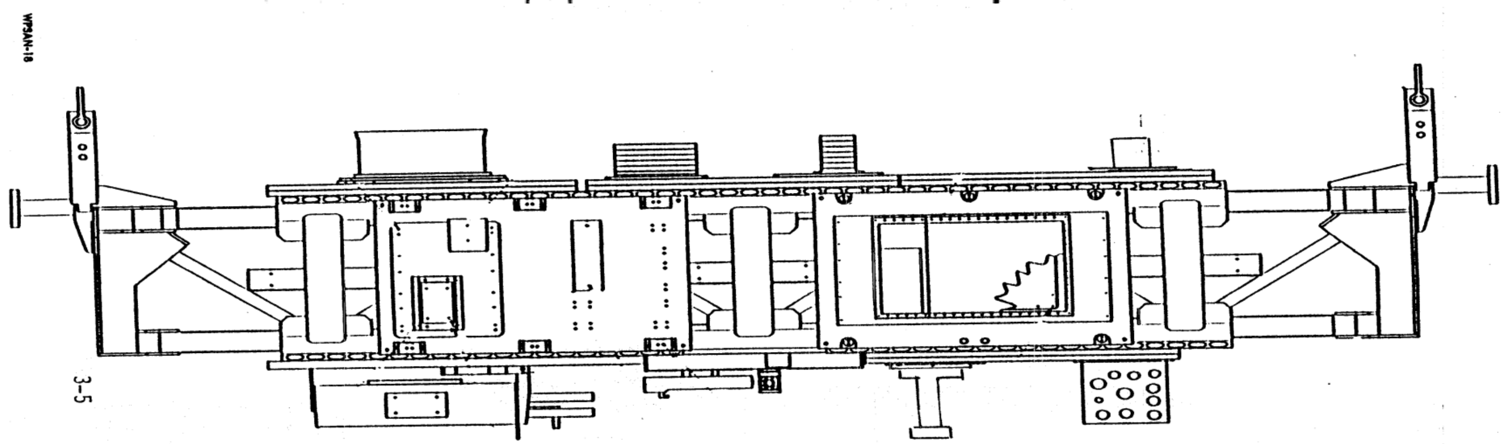
    - **BEM/FEM analytical method to be used before qualification tests of the components**
- **Progress are reported in these areas**

Acoustic Tests

- Mission Peculiar Equipment Support Structure (MPESS) Ground Acoustic Test
  - *Test performed in early 1990's*
  - *Several different loading configurations examined*
  - *Data analyzed based on limited information*
- A simple Aluminum Panel with flight-like components
  - *Several different configurations tested*
  - *Panel suspended (free-free boundary condition)*
  - *Detailed measurements using sound pressure levels, acceleration and force responses were made*
  - *Tap tests with calibrated hammer and force gages for acoustic test used to measure detailed impedances at each component interfaces*
- MSL rover ramp with flight-like components
  - *Different configurations tested*
  - *Panel attached to a frame (fixed boundary condition)*
  - *Detailed measurements using sound pressure levels, acceleration and force responses were made*
  - *Tap tests with calibrated hammer and force gages for acoustic test used to measure detailed impedances at each component interfaces*

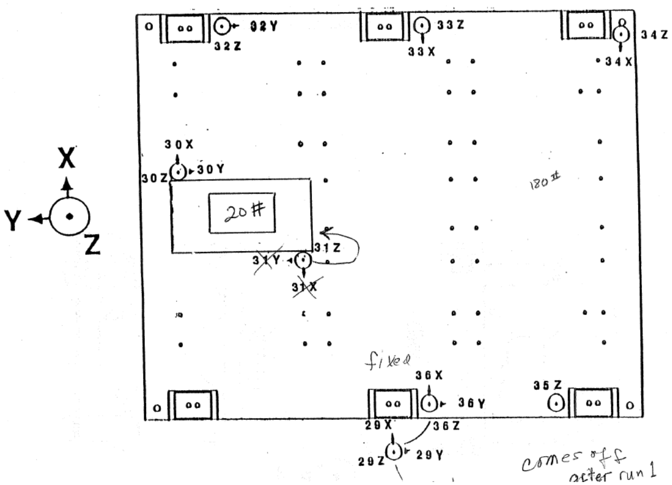
MPESS Acoustic Test Configurations



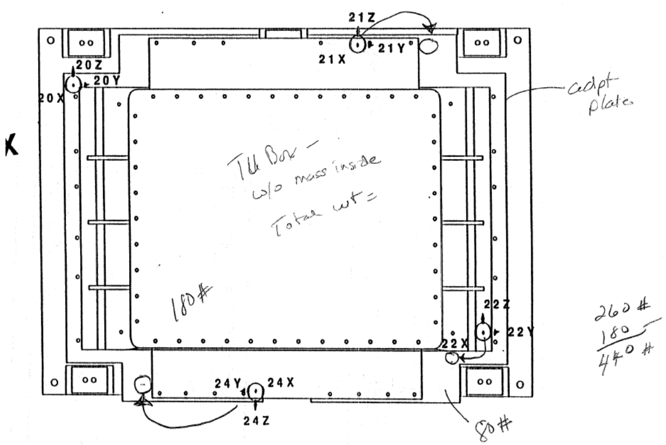


Acoustic tests on several MPESS configurations were performed to define the random vibration environments

MPESS Loaded and Unloaded Panels (Case 1)

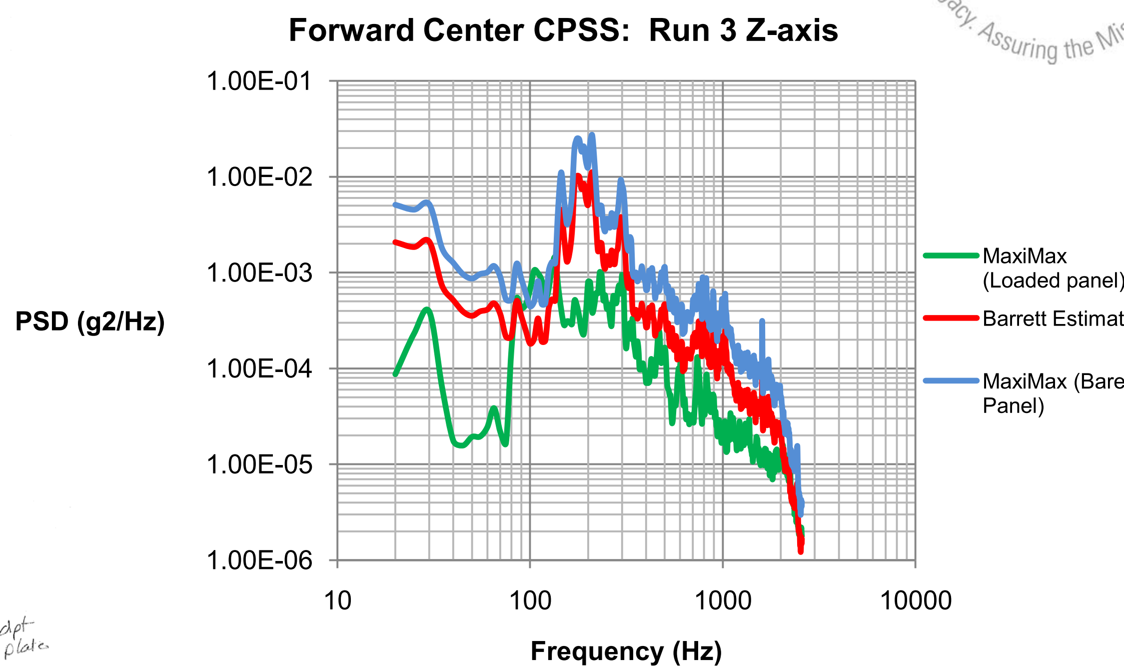


StarBoard



Forward Center

FIGURE 2-28. ACCELEROMETER LOCATIONS FOWARD CENTER CPSS RUN 3

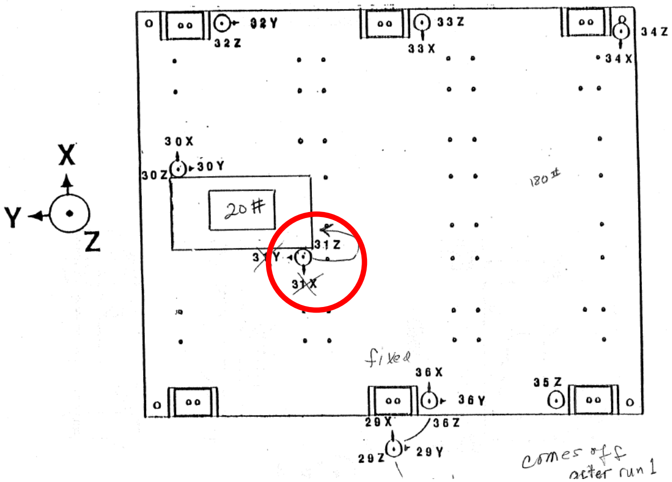


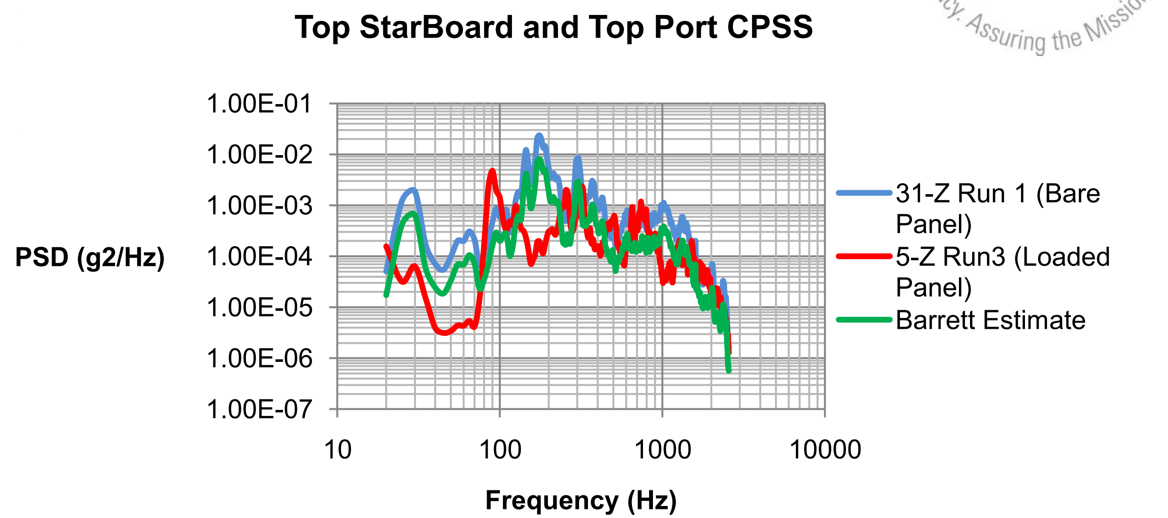
Support Structure: 180 lbs

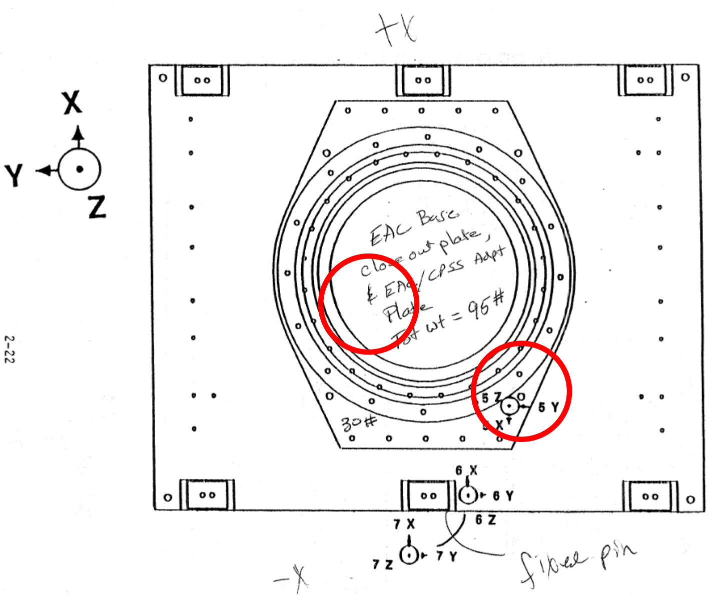
Components and Support Structures: 420 lbs

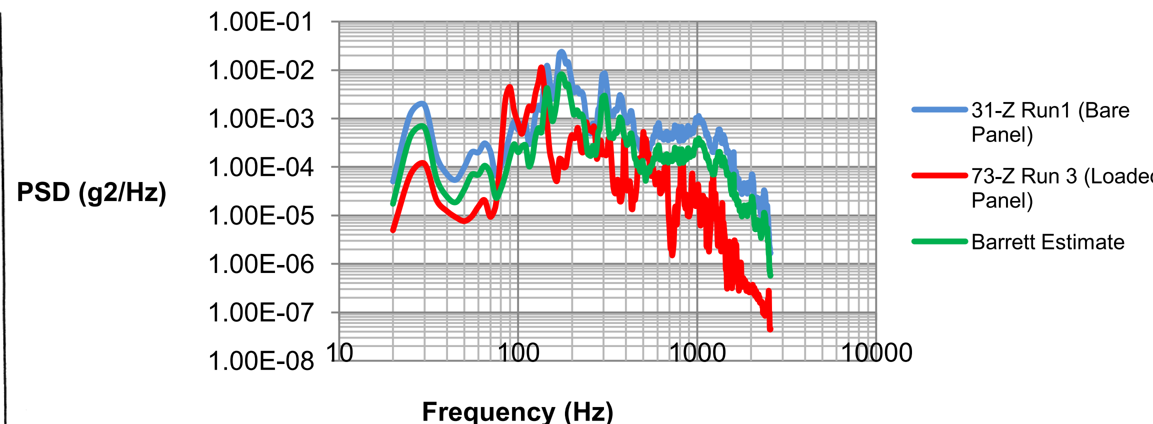
PSDs averaged over several accelerometers

MPESS Loaded and Unloaded Panels (Case 4)









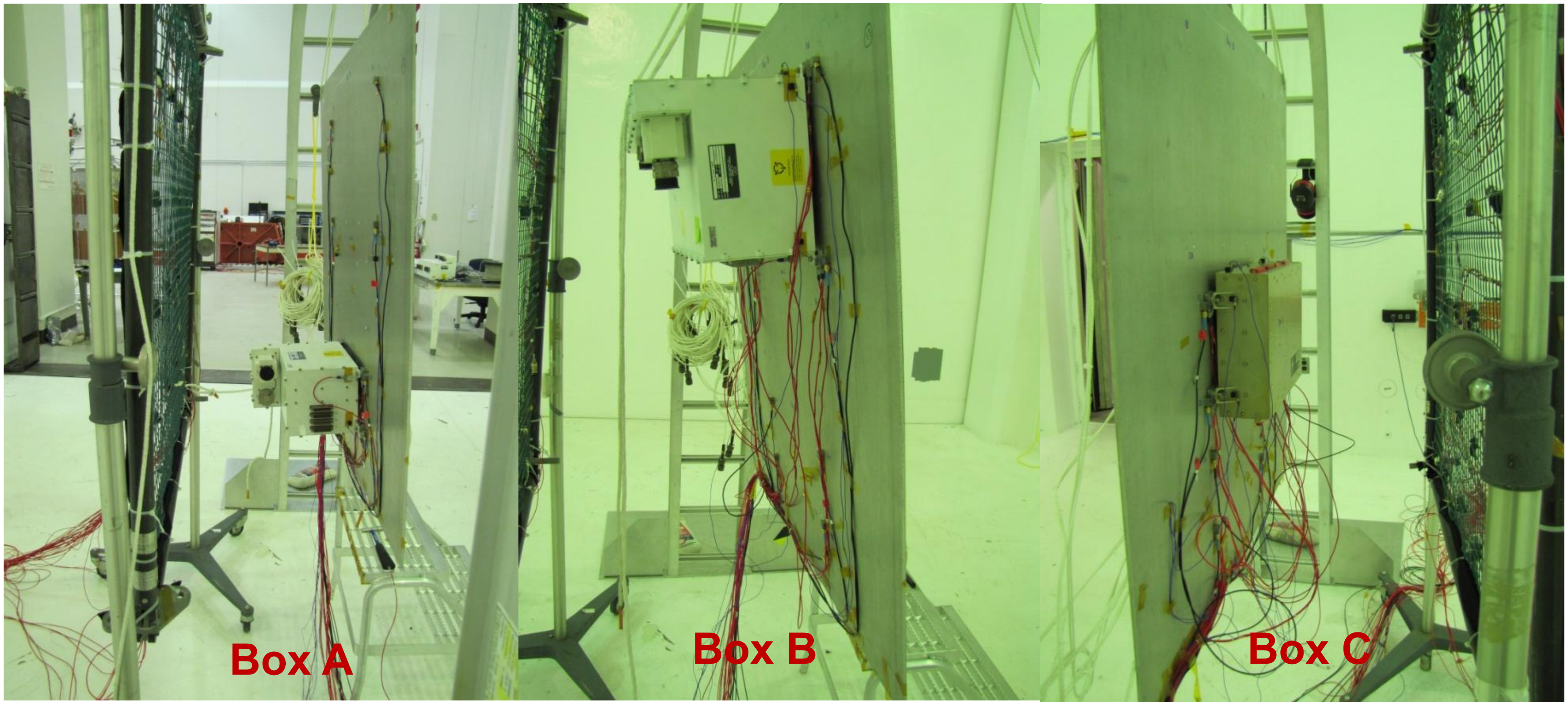
Support Structure: 180 lbs

Components and Support Structures: 525 lbs

AL Panel Acoustic Test

Al Panel Test Configurations

- Acoustic Test Setup
  - *Bare panel suspended (free-free Boundary Condition)*
  - *Different panel and components configurations (Box A: 17.4 lbs, Box B: 45 lbs, Box C: 8.4 lbs, Panel 42.6 lbs, including cables)*
  - *Instrumentations: Accels on both sides of IFs, Force gages at IFs, Microphone array, Reverberant acoustic test with OASPL of 145 dB*



AL Panel Acoustic Test Configuration

AL Panel and Box A+B

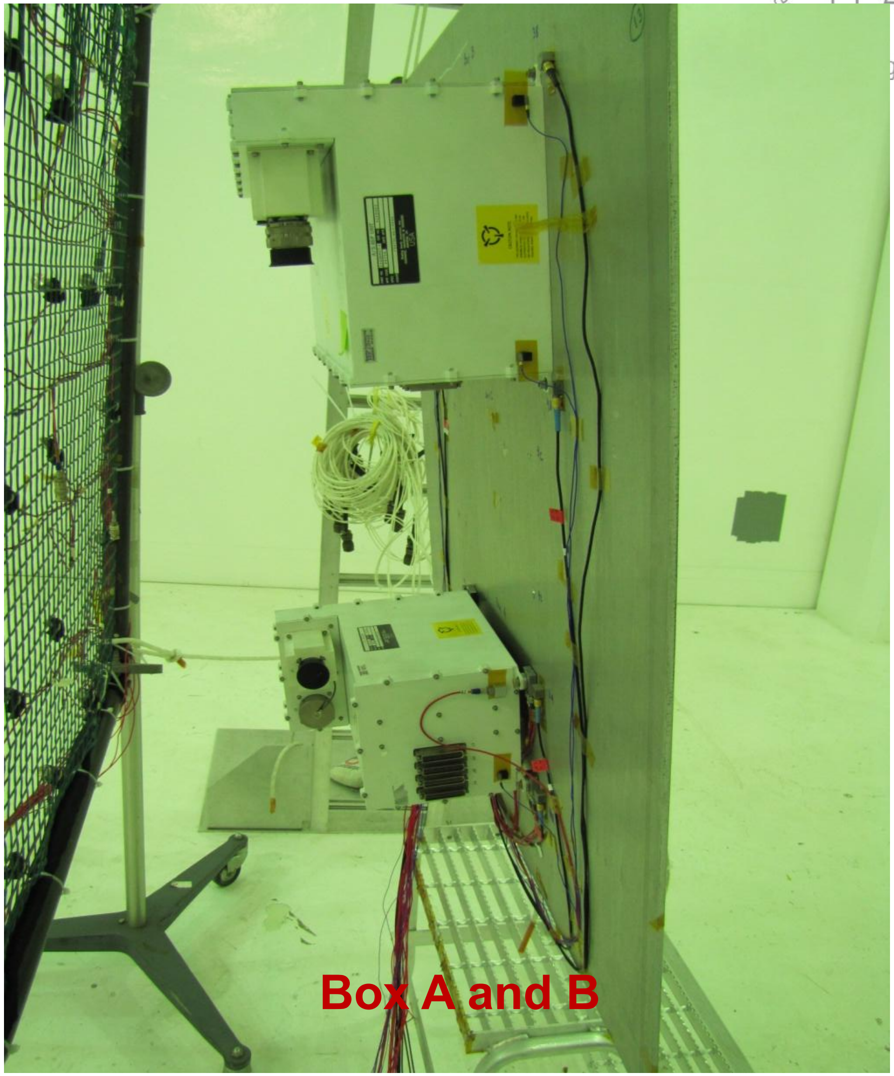
Total Weight: 105 lbs

Instrumentations:

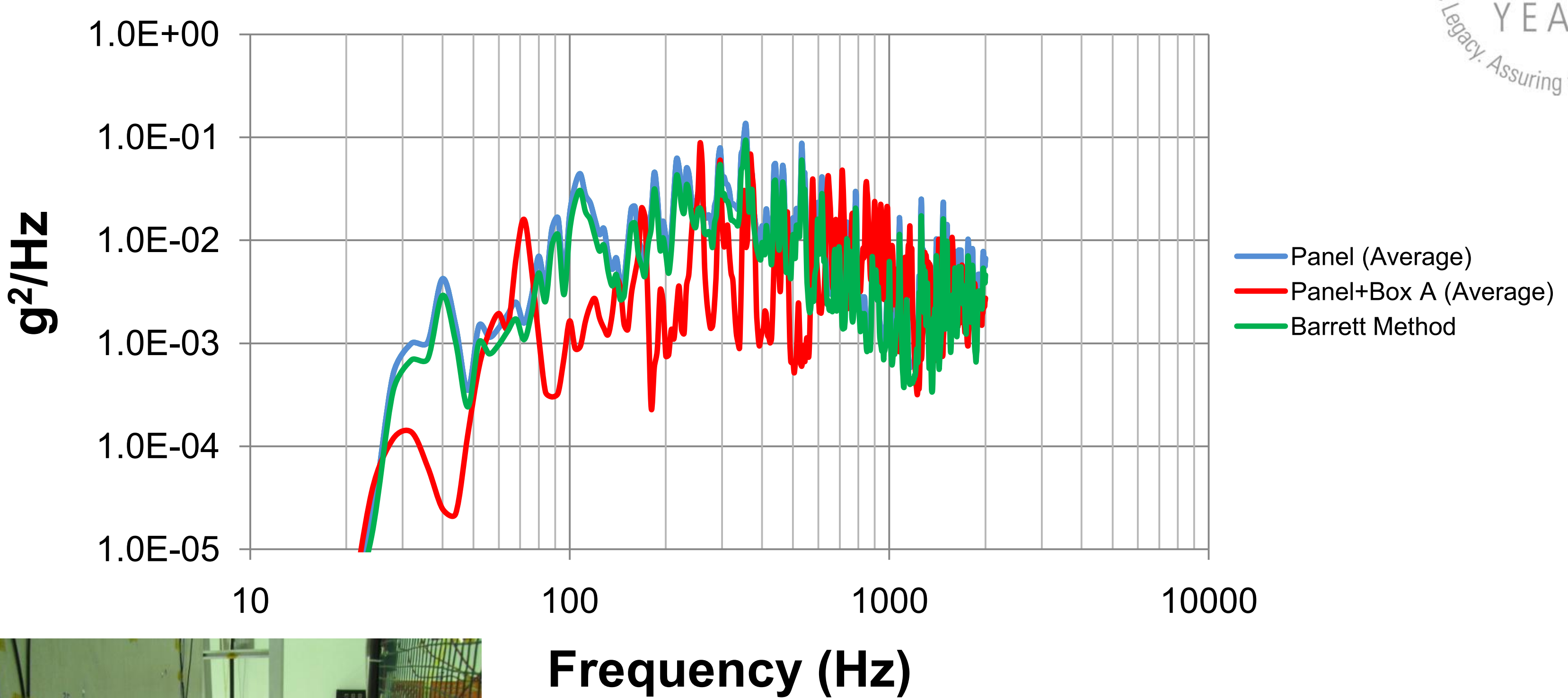
•Accelerometers on both sides of interfaces,

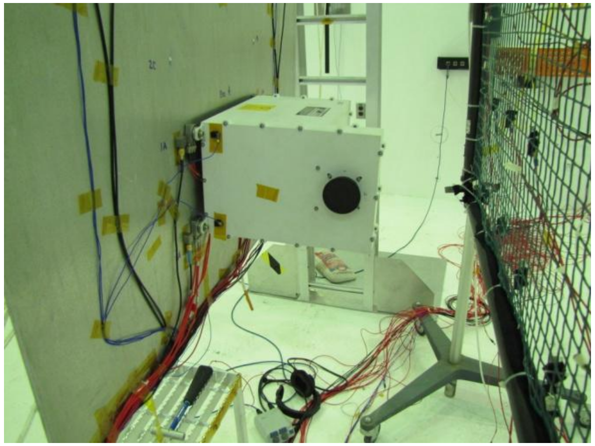
•Force gages at interfaces

•Microphone array to obtain detail acoustic field in front of the panel



AL Panel +Box A





Support Structure: 42.6 lbs
Component and Support Structure: 60 lbs

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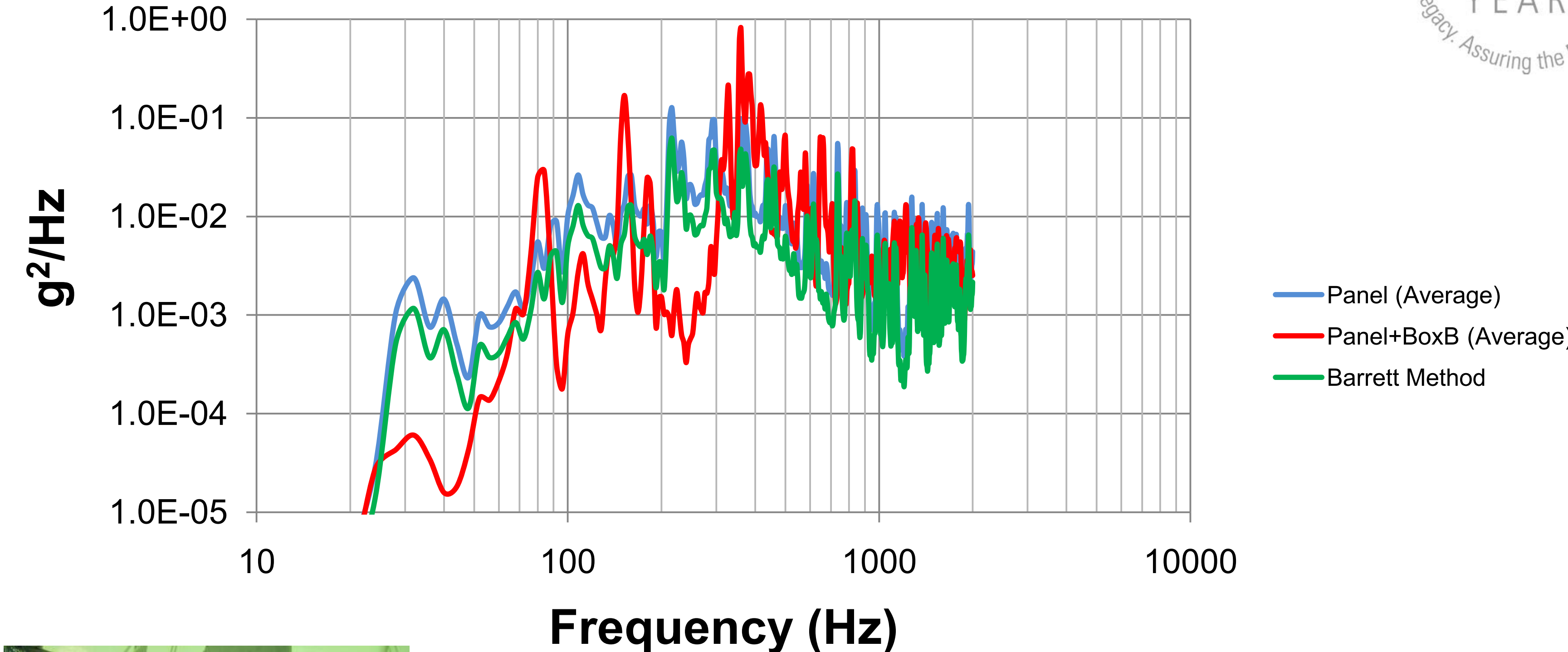
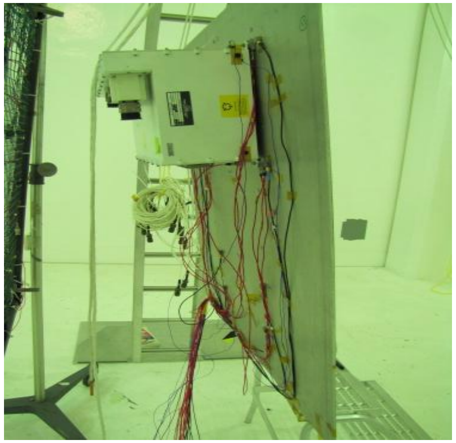
AL Panel +Box B



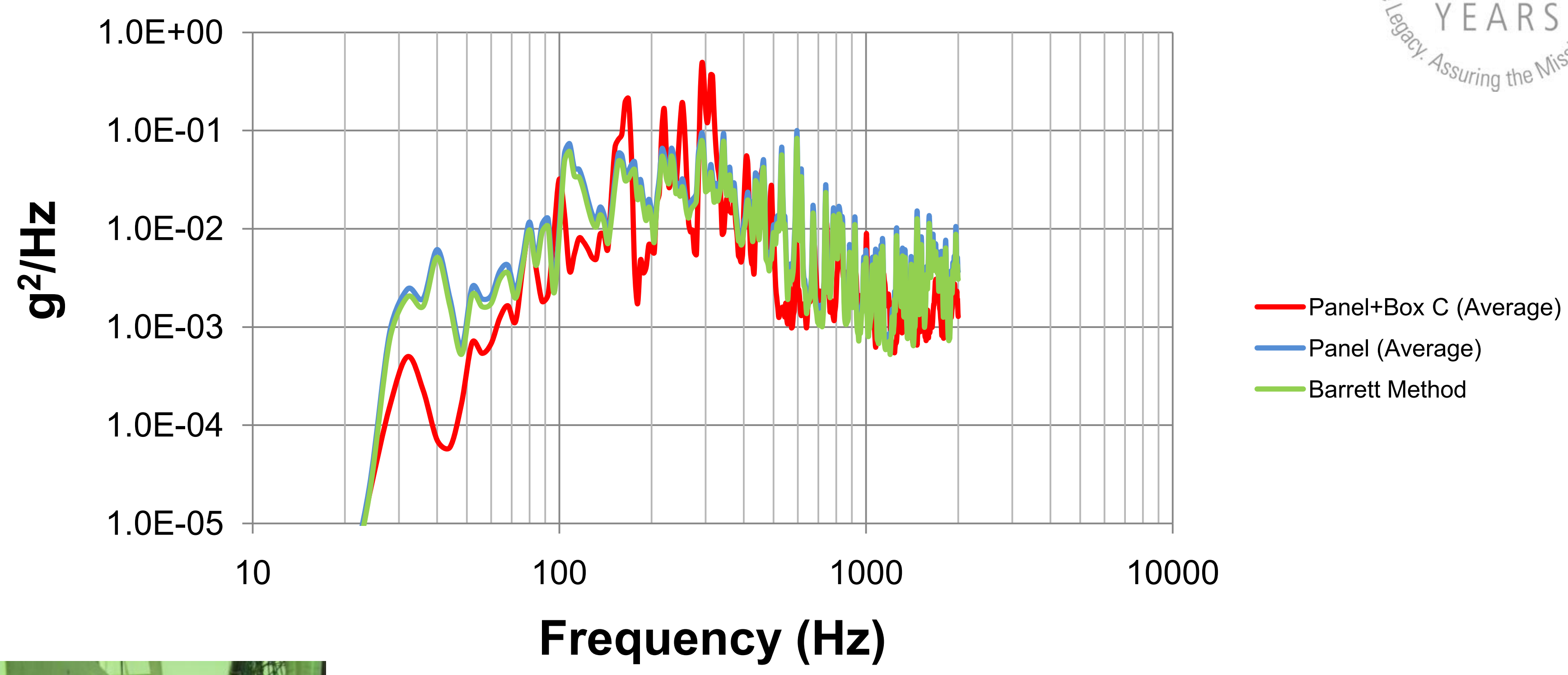


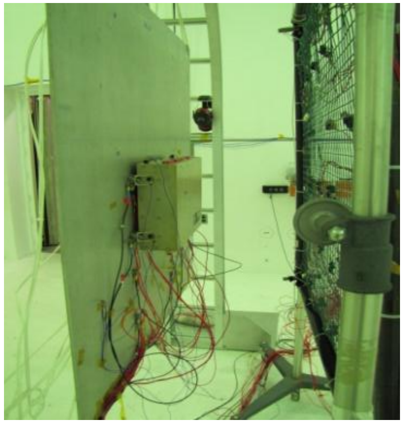
Support Structure: 42.6 lbs

Component and Support Structure: 87 lbs

Panel+Box responses @ ~ 80 Hz, ~170 Hz, and 300 to 400 Hz several dB higher than Bare panel responses

AL Panel +Box C

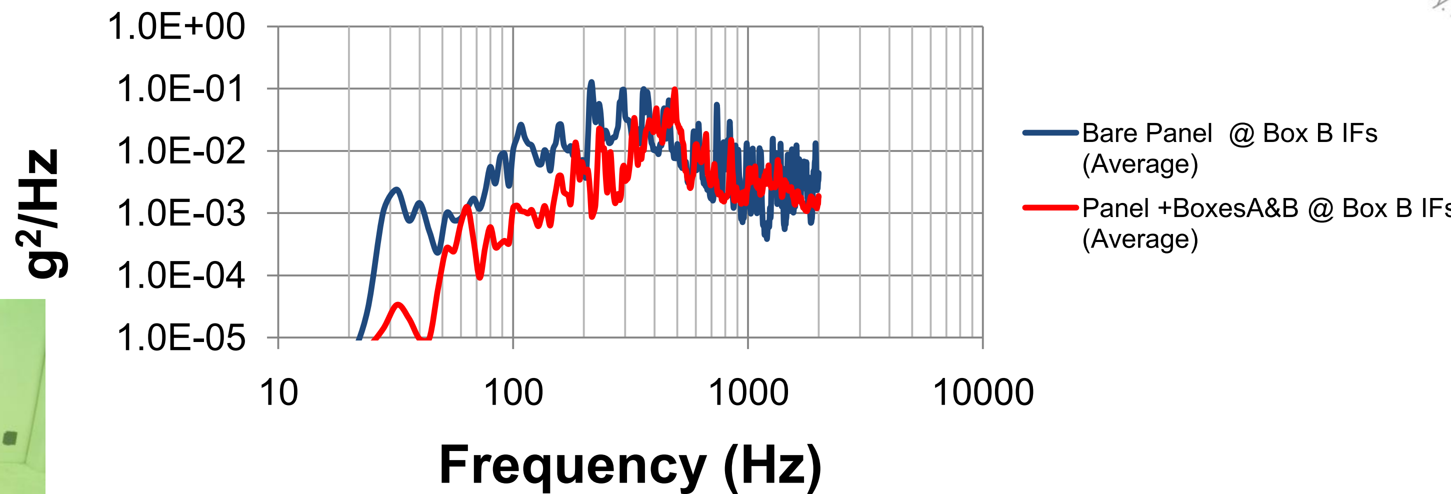


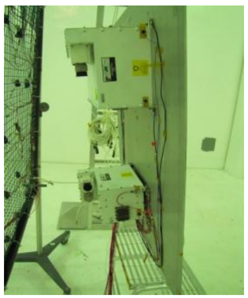


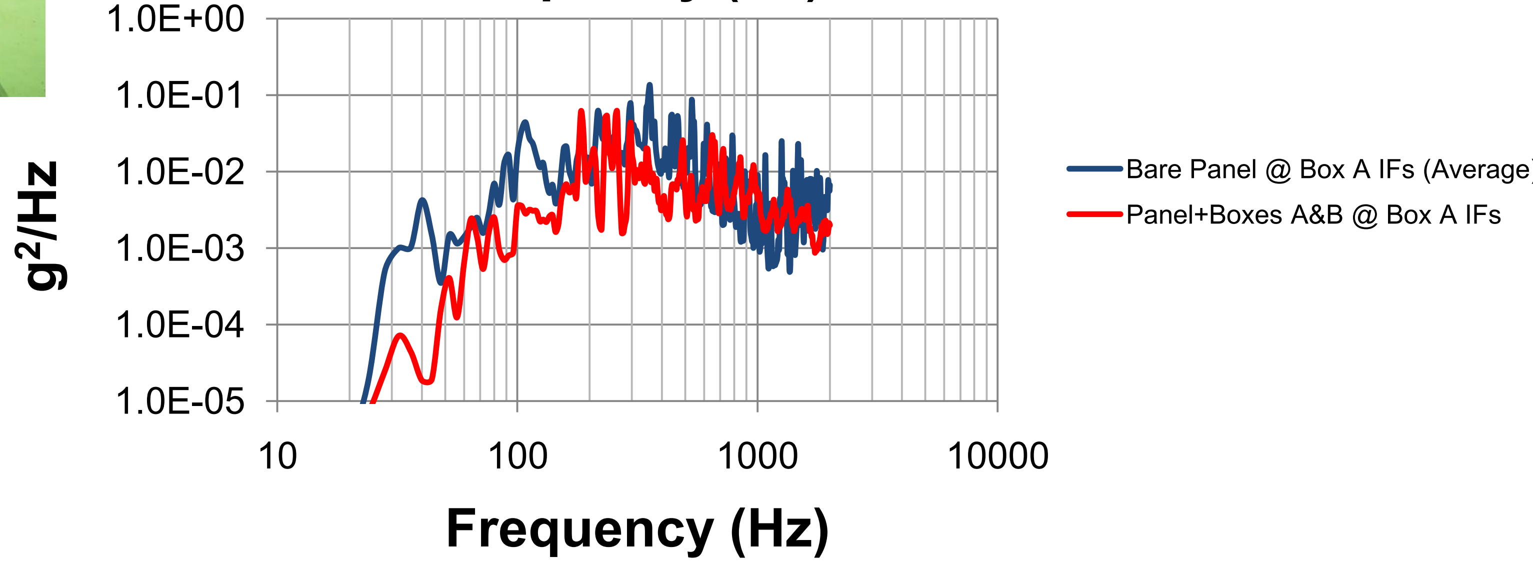
Support Structure: 42.6 lbs

Component and Support Structure: 51 lbs

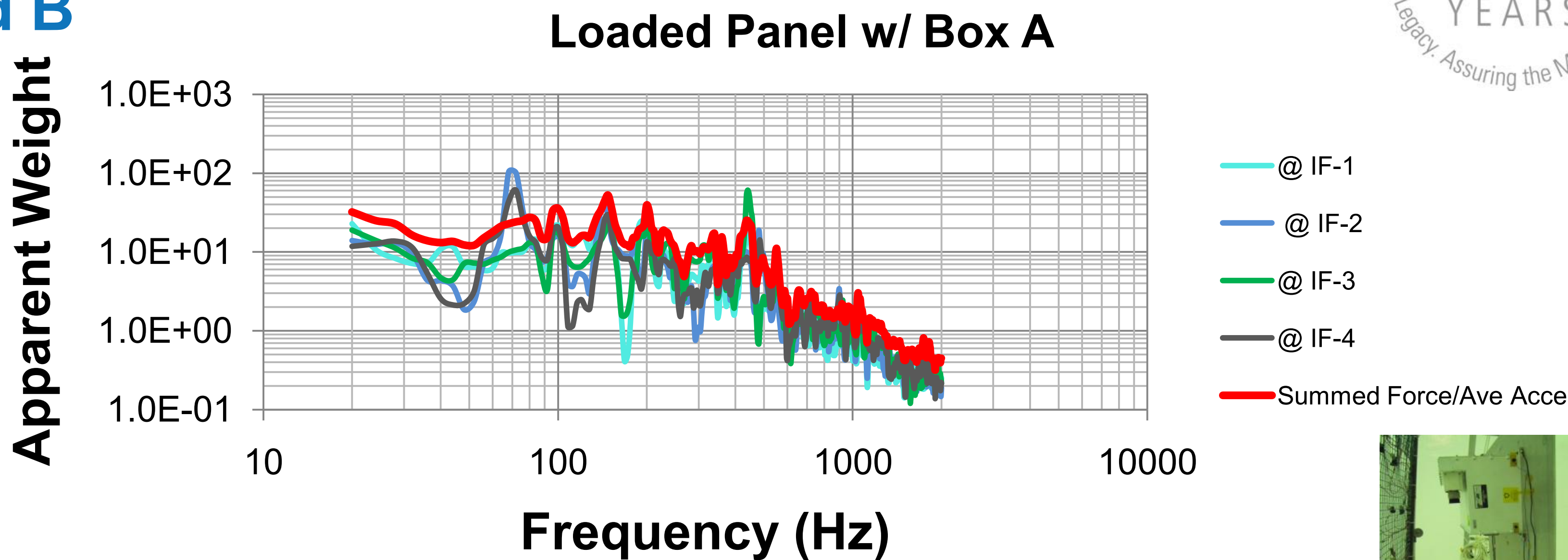
AL Panel + Boxes A and B

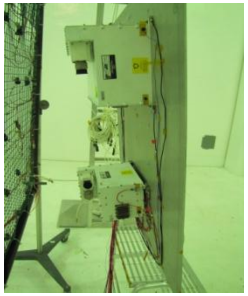


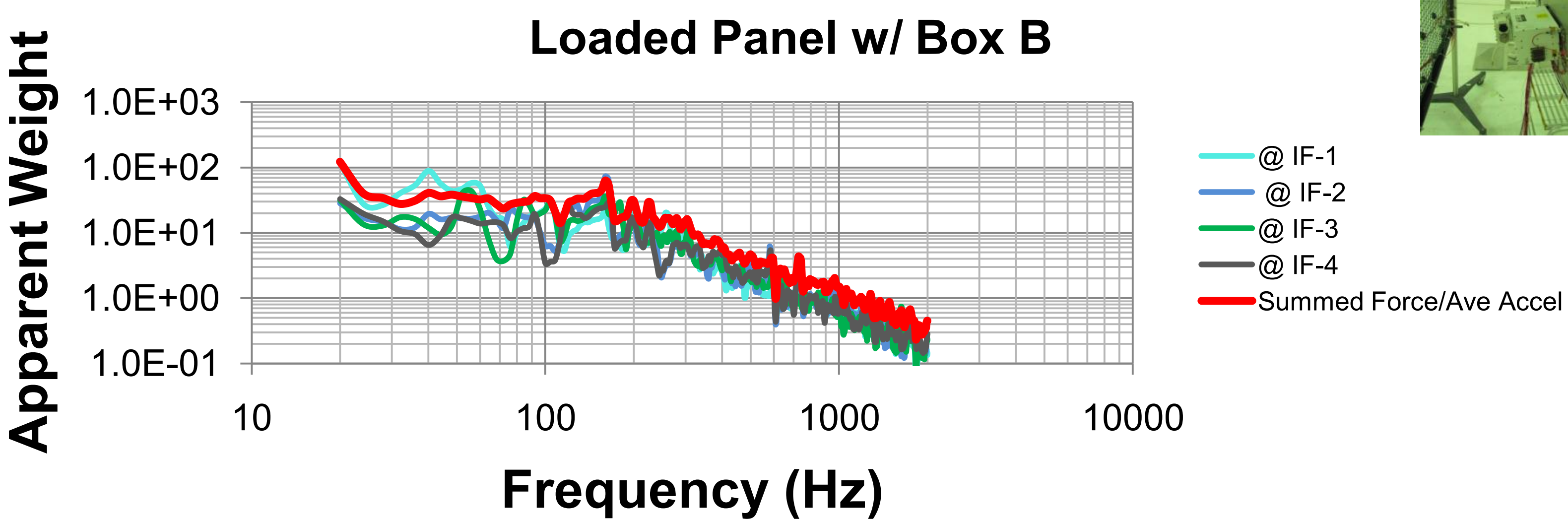




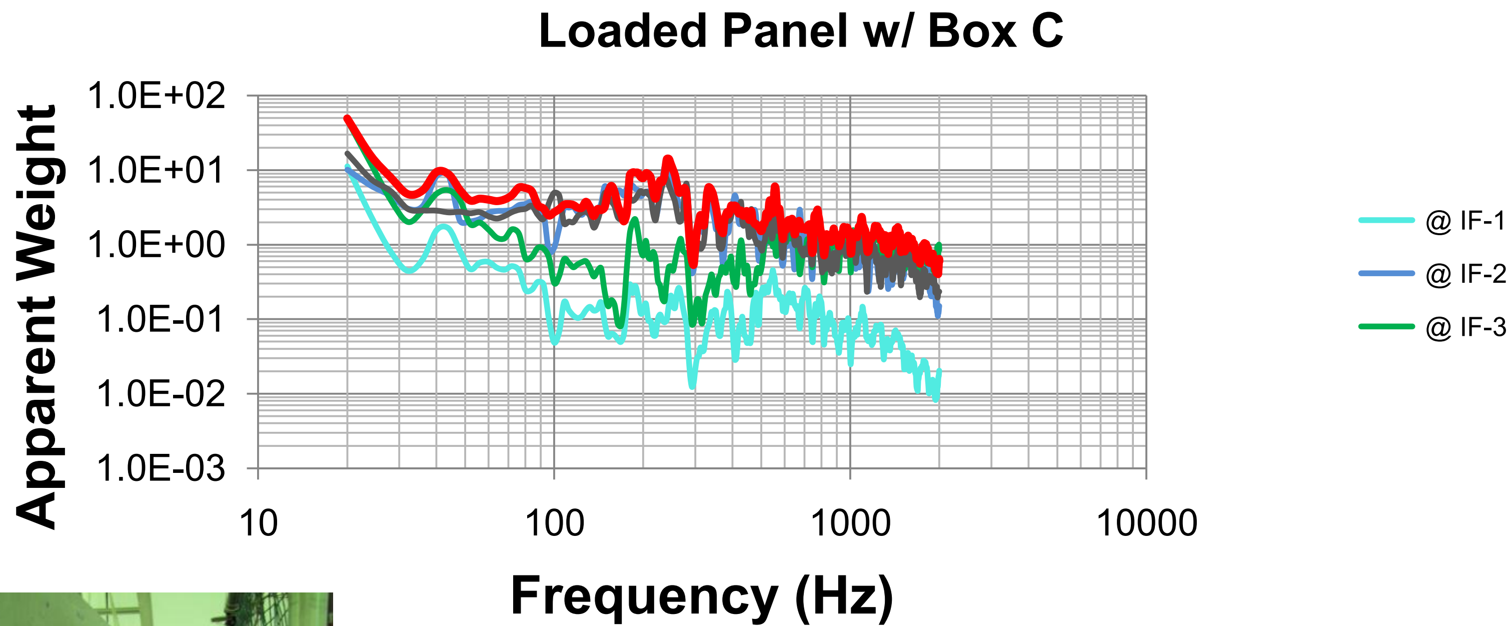
Measured Apparent Mass of Al Panel with Box A and B

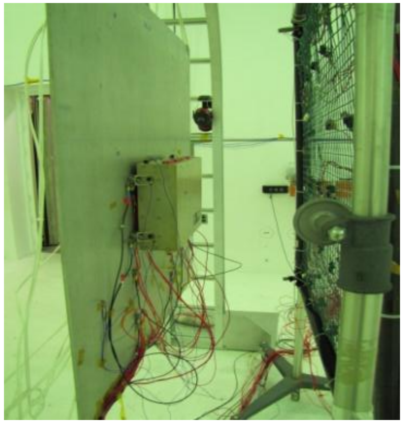






Measured Apparent Mass of Al Panel with Box C





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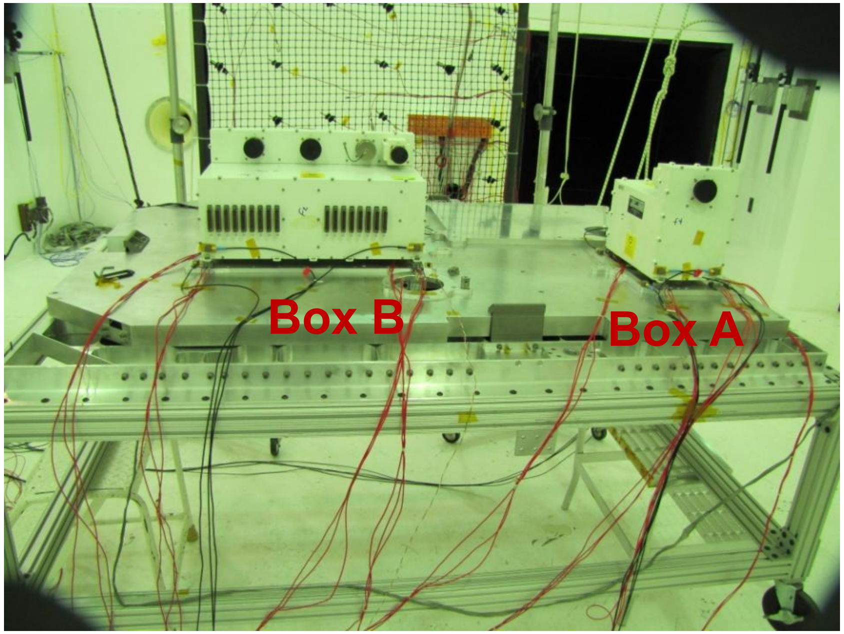
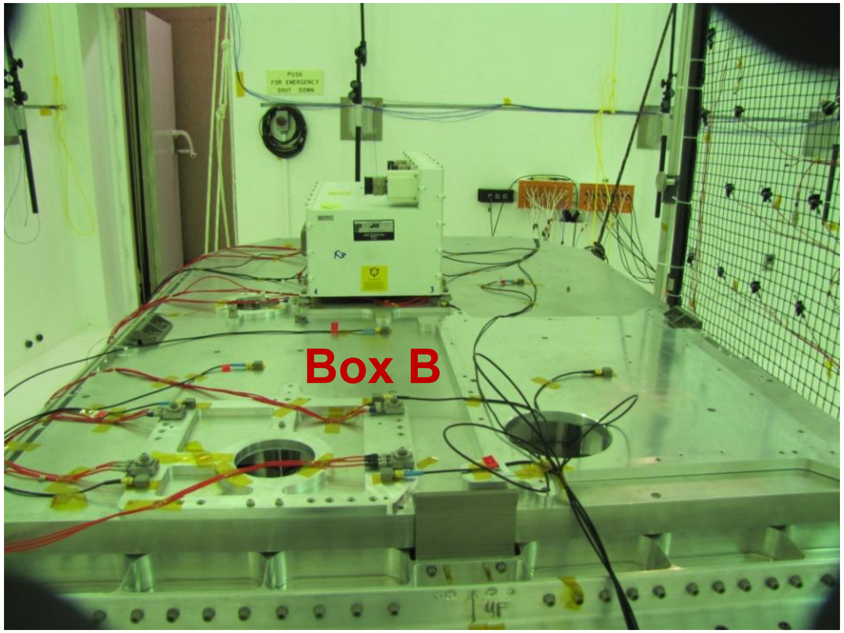
MSL Rover Top Deck Acoustic Test

Rover Ramp Acoustic Test Configurations

- Acoustic Test Setup
  - *Bare panel, anchored to a frame (fixed-fixed Boundary Condition)*
  - *Panel and components with different configurations (Box A: 17.4 lbs, Box B: 45 lbs, Ramp 155 lbs)*
  - *Instrumentations: Accels on both sides of IFs, Force gages at IFs, Microphone array, Reverberant Acoustic Test with OASPL of 145 dB*





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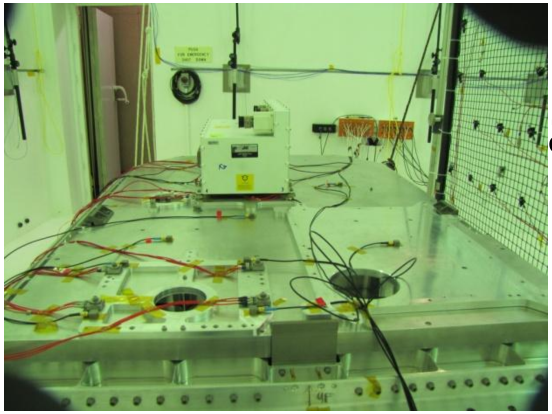
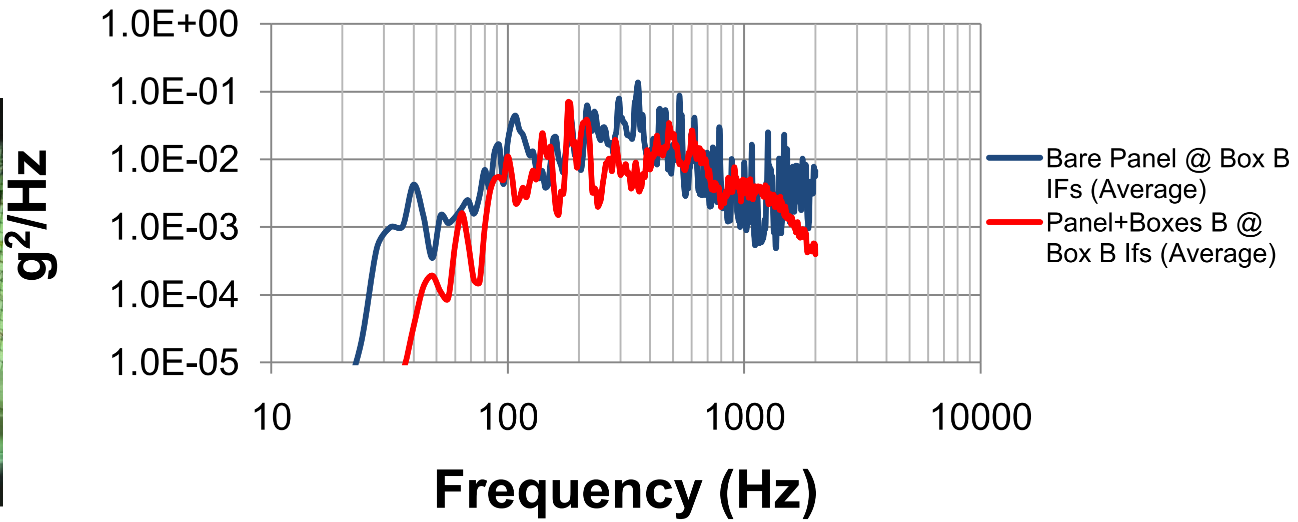
Rover Top Deck+Box B
Interface acceleration Responses



Rover top Deck with Box B acoustic test setup

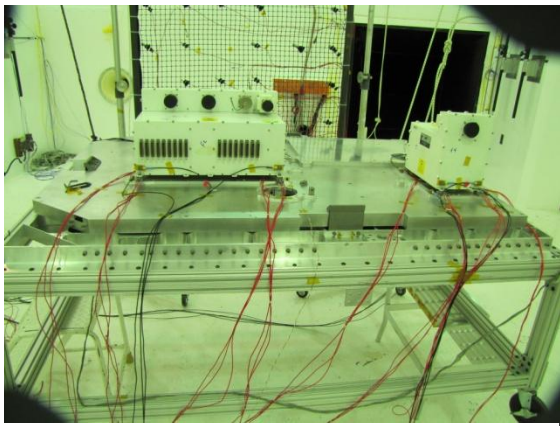


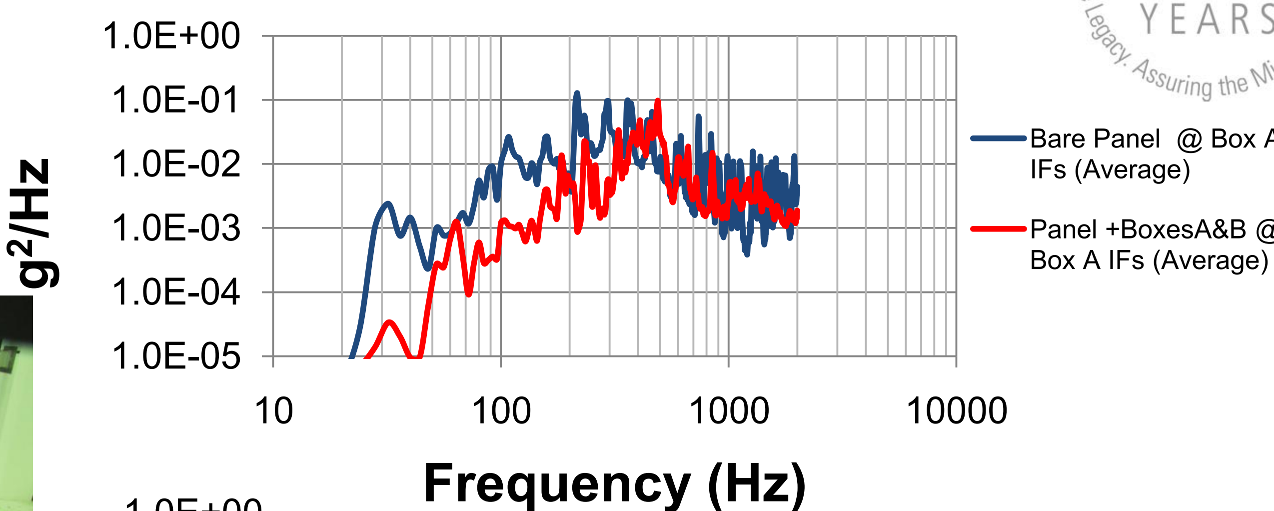
Support Structure: ~150 lbs

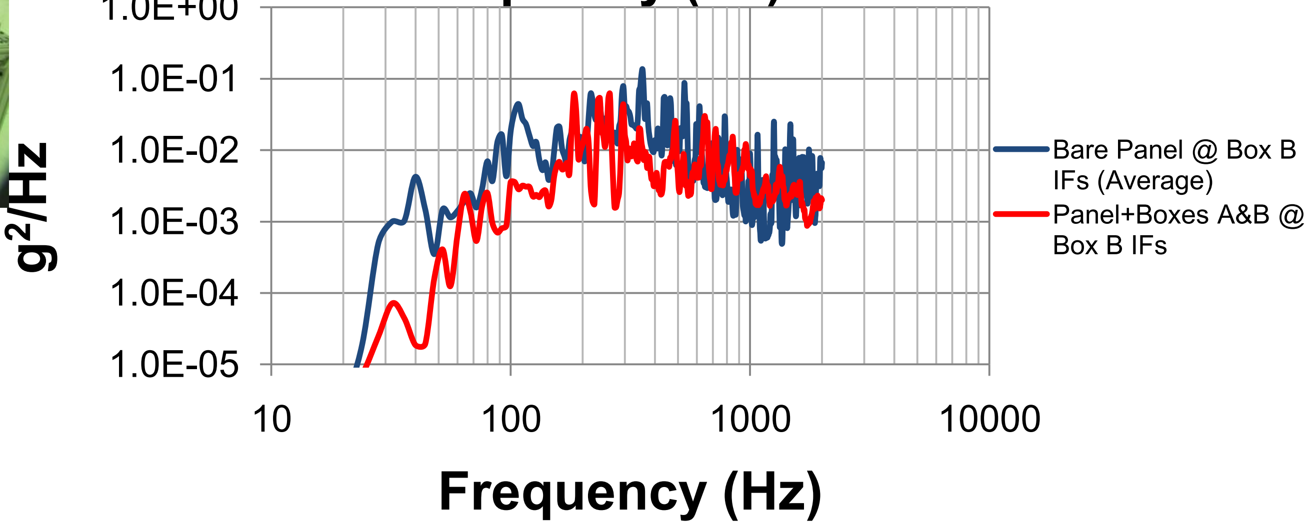
Component and Support Structure: ~195 lbs

Rover Ramp +Boxes A+B

50 YEARS
Honoring the Legacy. Assuring the Mission.







Support Structure: ~150 lbs

Components and Support Structures: 212.5 lbs

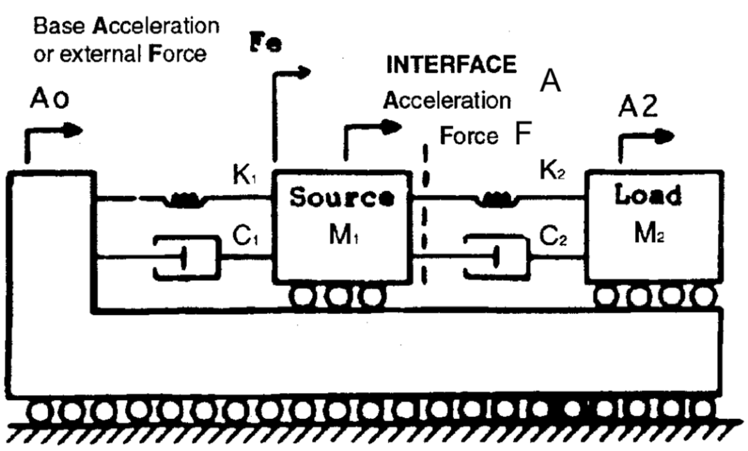
Impedance Method Example: Simple TDFS

Using Norton's equivalent circuit theorem, the ratio of the interface acceleration (A) to the free acceleration of the source (A_s), which is again defined at the interface, is:

$$|A(f)/A_s(f)| = |M_s(f)/[M_s(f)+M_l(f)]|$$

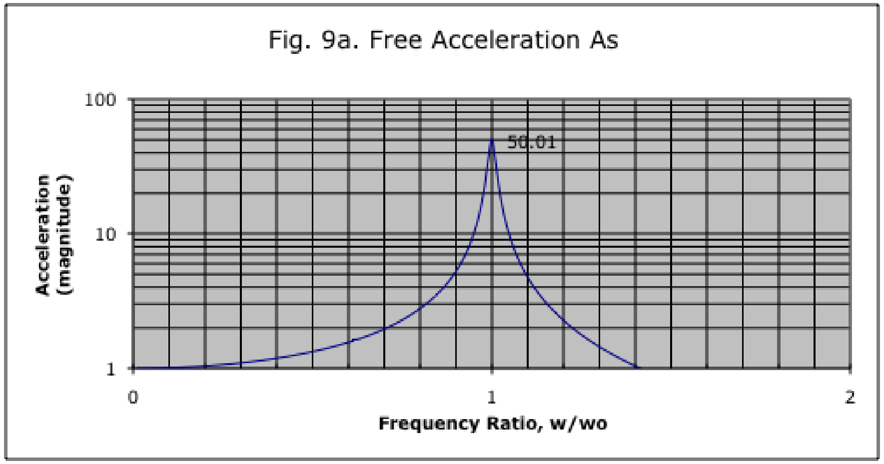
where: M_s and M_l are the apparent masses of the source and the load, and the ratio of the interface force (F) to the free acceleration (A_s) is:

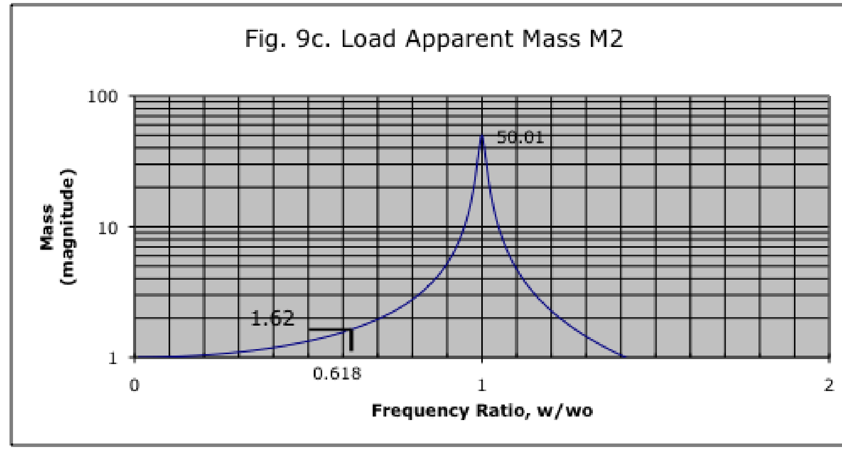
$$|F(f)/A_s(f)| = |M_s(f)*M_l(f)/[M_s(f)+M_l(f)]|$$

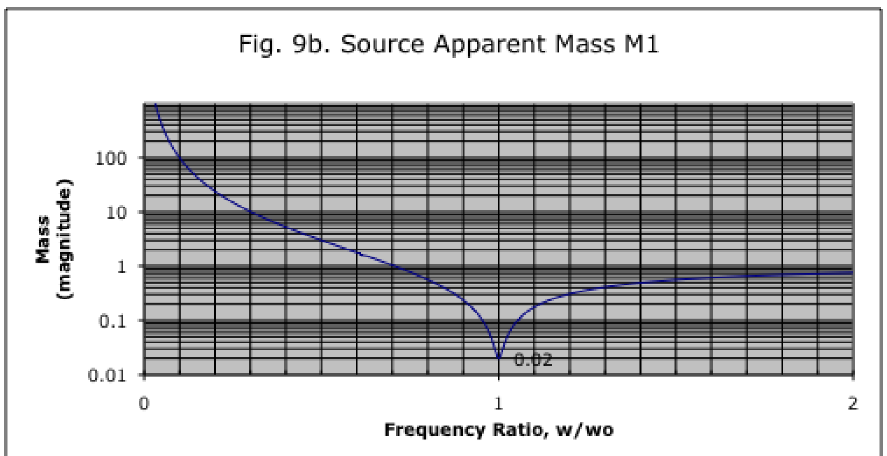


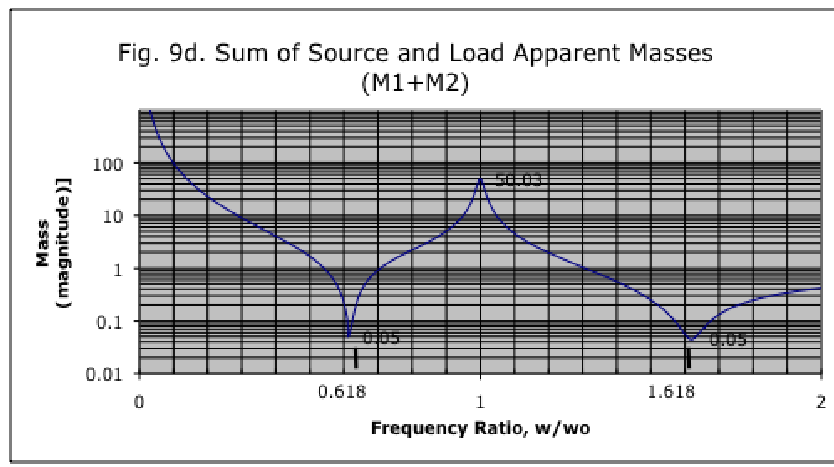
In the following numerical example, these two oscillators are identical with: A_o= 1, M_1 = M_2 = 1, $K_1/M_1 = K_2/M_2 = \omega_o^2 = 1$, $C_1/M_1=C_{2/}M_2= \omega_o/Q = 1/Q = 0.02$ (Q=50).

Source and Load Apparent Masses For TDFS Example









Impedance Method Calculation of Interface Acceleration and Force for TDFS Example

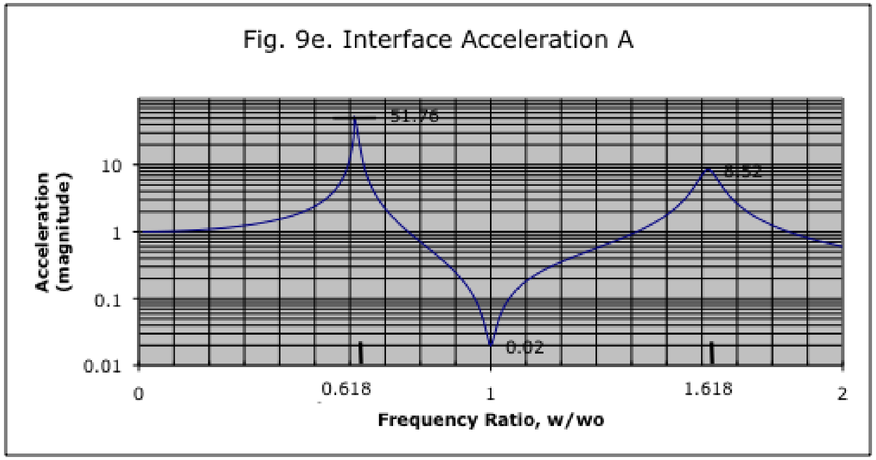


Fig. 9e. Interface Acceleration A

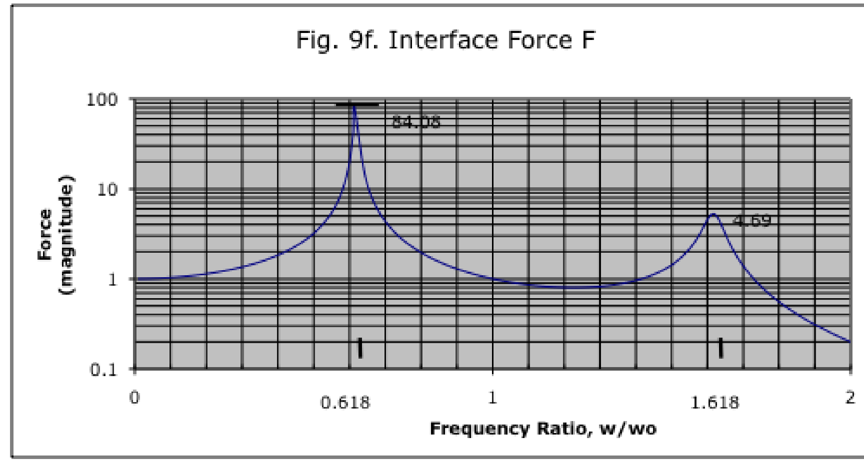


Fig. 9f. Interface Force F

- The ratio of the peak interface force (84.18) to the peak interface acceleration (51.76) is 1.62, which is the same value obtained with the Simple TDFS Method of predicting force limits (NASA –HDBK-7004B)
- And, the peak response of the load (A_2= 84.18), which has the same numerical value as the interface force because M_2=1, is only **1.68** times the free acceleration of the source (the vibration test specification), even though Q=**50**!

Summary

- Random vibration data obtained from acoustic tests performed on panels with components suggest a strong frequency dependence of the loaded panel interface responses
  - *A knock down factor using the Barrett model may not be adequate to predict loaded panel acceleration responses*
    - In general this method is very conservative at certain frequencies,
    - It under predicts at frequency ranges where the component dynamics influence the panel
    - A frequency dependent Barrett method is more appropriate
  - *Impedance method, using the frequency dependent apparent masses, with exponent of 2 provides an improved method in predicting the loaded accelerations at the interfaces*
    - *A simplified TDFS model that takes into account of the component/panel coupling dynamics may be used to obtain the impedances the interfaces*
      - *may not accurately predict the responses for a system with multi modes and multi-degree impedances*
    - *A FEM model of the coupled system to predict multi-degree impedances is required*
- The BEM analysis of panels with components should provide accurate multi-degree impedances (this effort is underway)