CUBESAT
California Polytechnic State University

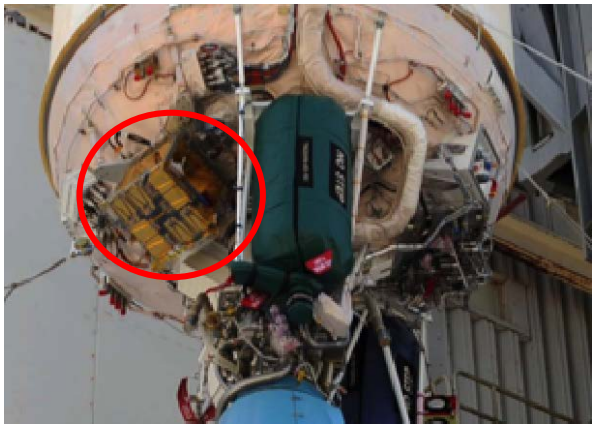
Update on Improving Launch Vibration Environments for CubeSats

Dave Pignatelli
California Polytechnic State University, San Luis Obispo

Small Satellite Conference, Logan, Utah
August 8th, 2018

CubeSat Launch Environments

- CubeSat launch environments are typically bounded by random vibration environmental loads
  - Shock, acoustic, and quasi-static environments are typically considered non-damaging and only rarely require testing
  - Environments are defined at the payload dispenser interface
  - Actual CubeSat interface levels are not typically defined
- This is different from typical primary spacecraft environmental loads
  - Bounding environments: vibroacoustics, quasi-static loads, sine vibration
  - Environments are defined at the primary spacecraft interface

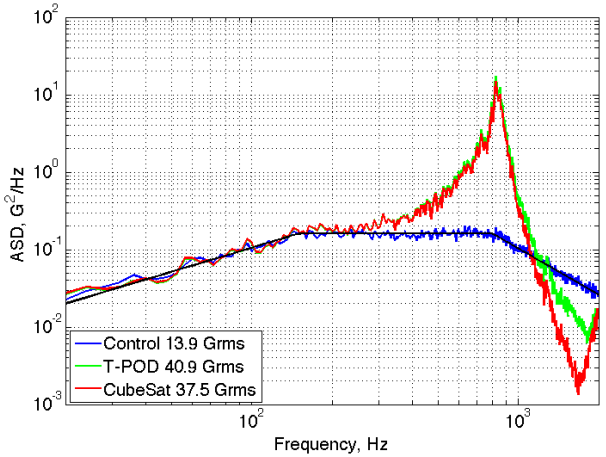


Credit: ULA

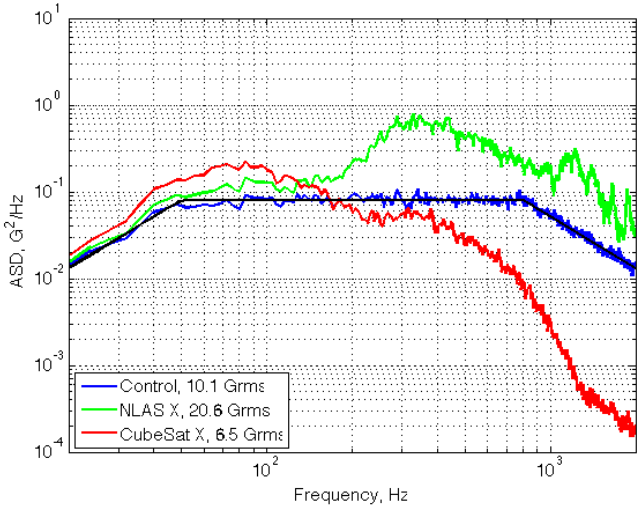
Credit: ULA

Review from Last Year

- Actual levels experienced by CubeSat vary due to a number of factors:
  - Launch vehicle/test specification
  - Dispenser and constraint method
  - Isolation implementation
- Free-constraint dispenser response is often 2-3 times higher than input levels, but CubeSat levels remain 1:1 or less
- Internal isolation demonstrated on the 3U P-POD
  - Consists of damping material embedded in dispenser to CubeSat interface contact points (rails)
  - Internally isolated CubeSat levels ranged from 3.7 G_{rms} to 4.4 G_{rms}
  - Similar results expected with the 6U NLAS



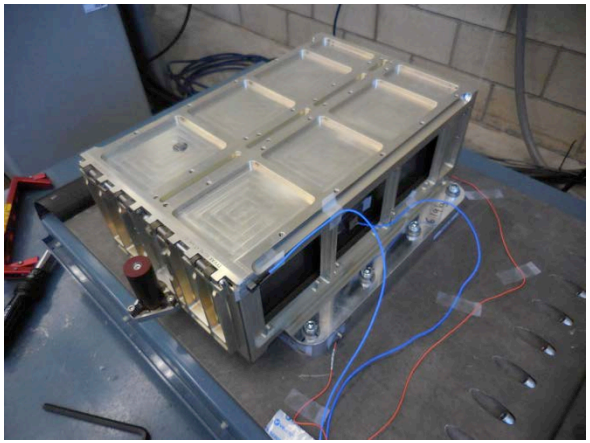
Dispenser and CubeSat Response almost 1:1!



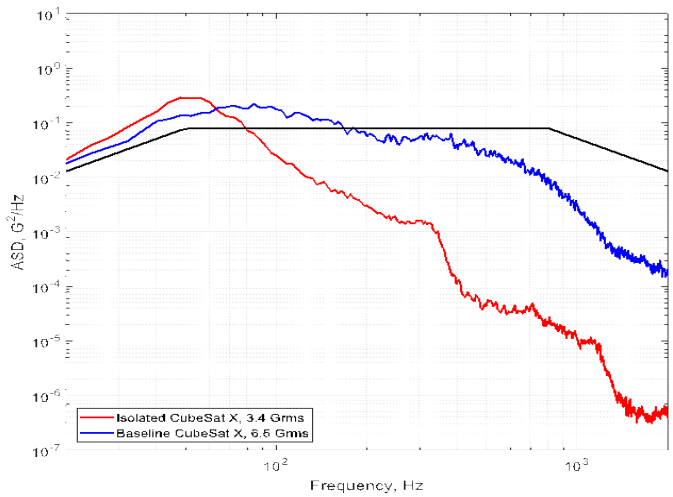
CubeSat Response in NLAS X-Axis

6U Isolation Testing Results

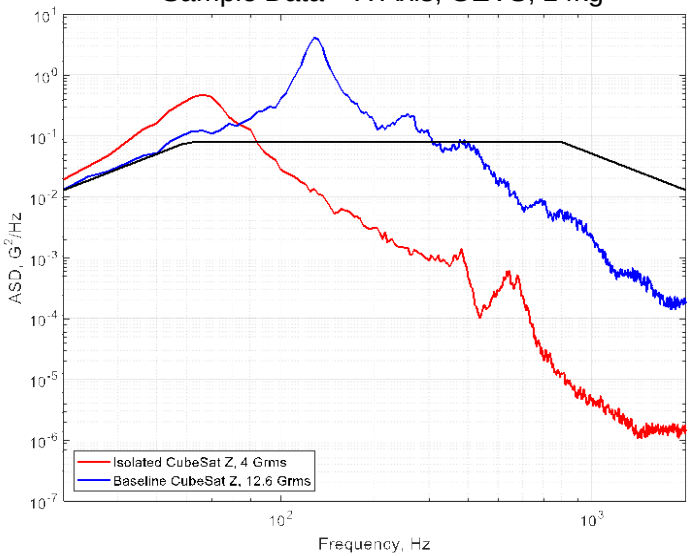
- After isolation incorporation, reduced environments were measured in all axis
  - Overall G_{rms} levels reduced by 17% - 71%
    - GEVS CubeSat response overall level ranged from 3.1 G_{rms} to 4.0 G_{rms}
    - Performance is sensitive to input spectrum. Better performance at higher frequency loading
  - Low first mode (between 50-60Hz)



Test Setup



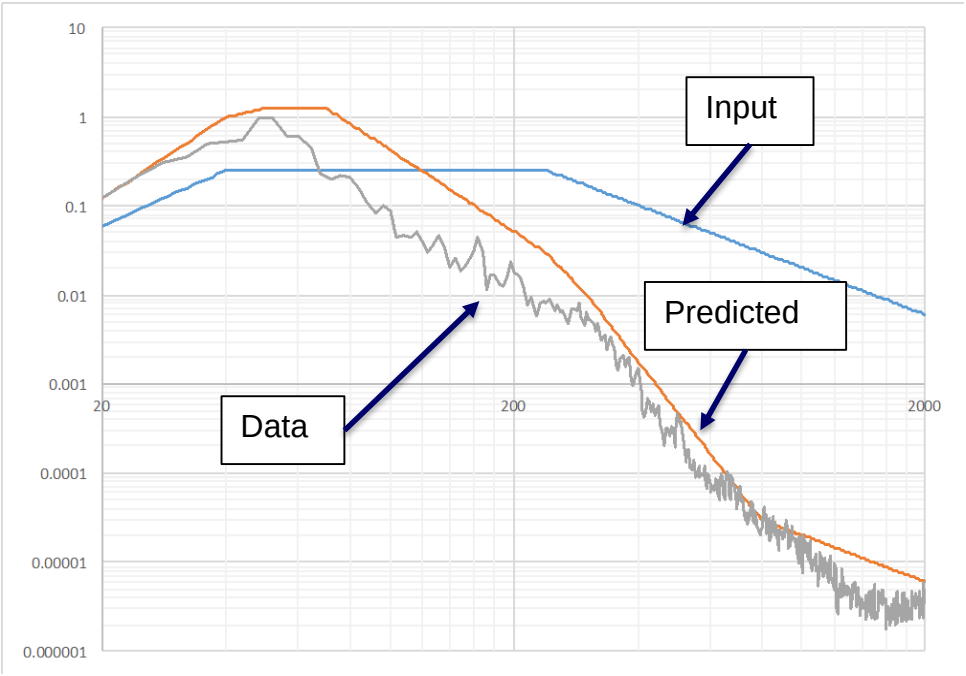
Sample Data – X Axis, GEVS, 14kg



Sample Data – Z Axis, GEVS, 14kg

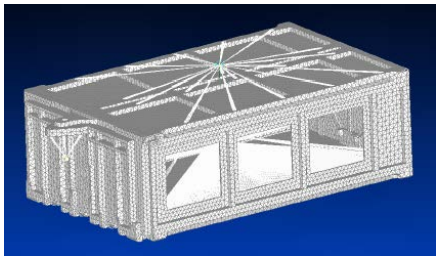
6U Payload Transfer Function

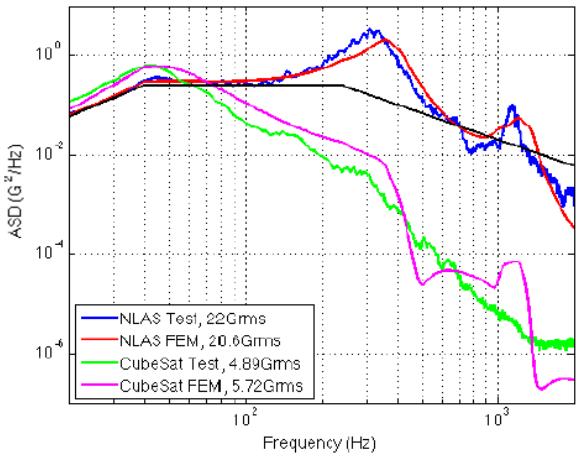
- Analyzing data sets for the 6U testing, a transfer function was developed which can be used to estimate payload environments for a variety of launch vehicle inputs
  - To leverage this capability, simply multiply the launch vehicle input by the transfer function to obtain the estimated payload environment
  - Enables rapid evaluation of environment, no need for complex analytical models.
- Low frequency amplification is seen as a result of the isolators. Roll off begins at 60-70 Hz and reduces vibe inputs by a factor of 10-100x starting at ~200Hz



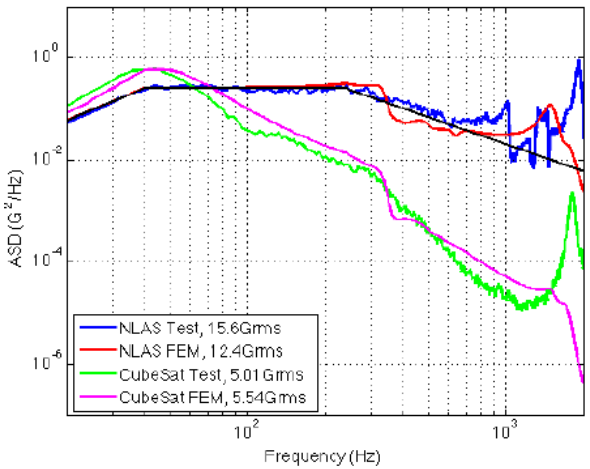
6U Finite Element Modeling

- A finite element modeling approach was used to investigate the ability to perform complex predictions
  - CubeSat is modeled as point mass at CG to simulate CubeSat simulator used in test
  - CubeSat is tied to dispenser using spring/damper elements
- Analytical response of CubeSat is extracted in PSD format and compared to measured response
  - Tuned model correlates to test data
  - Divergences in high frequencies due to mass model modes and not perfectly capturing high frequency dynamics when using point mass assumption

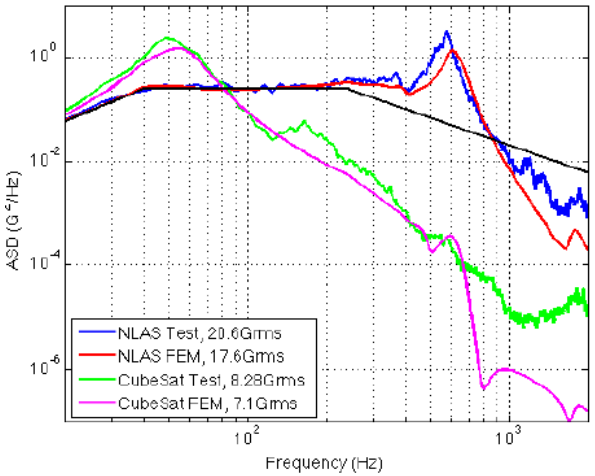




X-Axis



Y-Axis

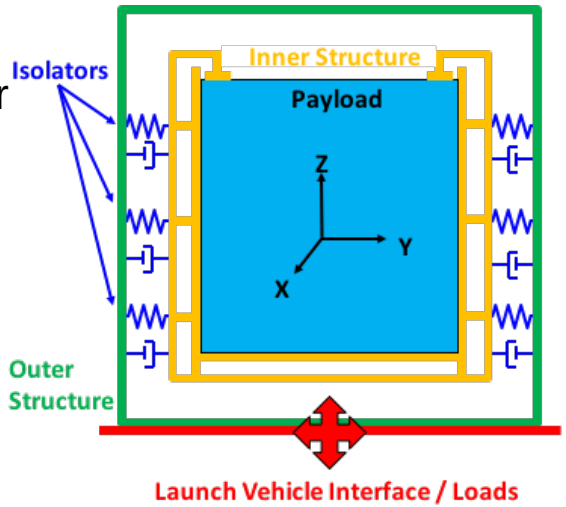


Z-Axis

12U Implementation

- Tyvak's 12U Rail Based Dispenser
  - Designed around internal isolation
- Retracting Rails allow for easier payload analysis
  - Contacts payload while integrated to reduce rail-to-rail free play
  - Analyzable boundary condition for payload developers
- Isolated Internal Structure
  - The 12U dispenser is unique in that it isolates the payload from the external dispenser structure through a unique load path approach
  - Utilizes bushings instead of constrained damping layer
  - Creates an analyzable boundary condition for payload developers

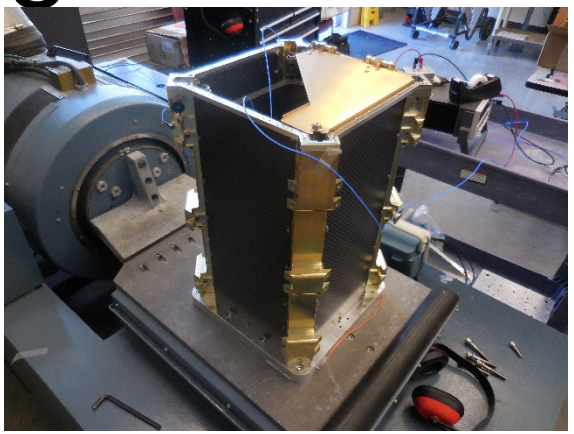
Credit: Tyvak



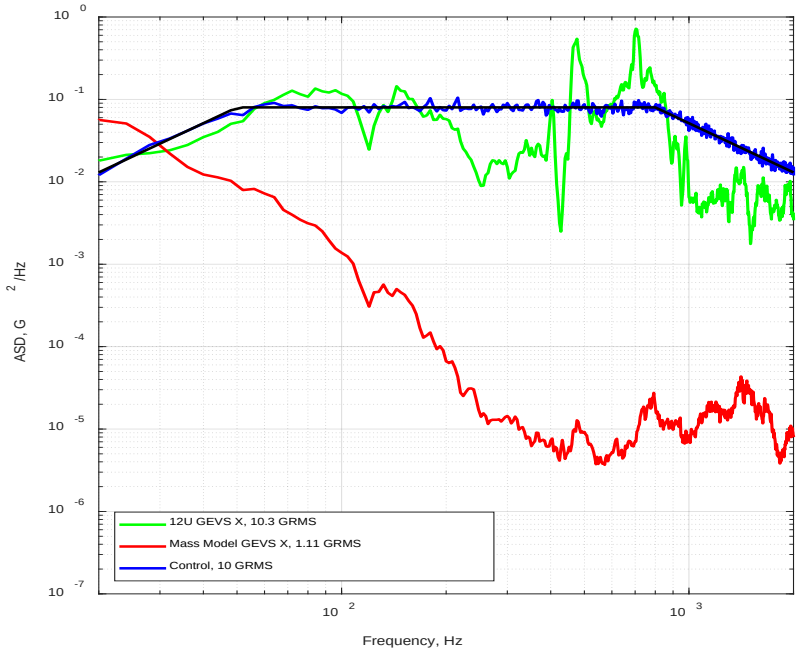
Internal Structure is Isolated from External
Credit: Tyvak

12U Isolation Testing Results

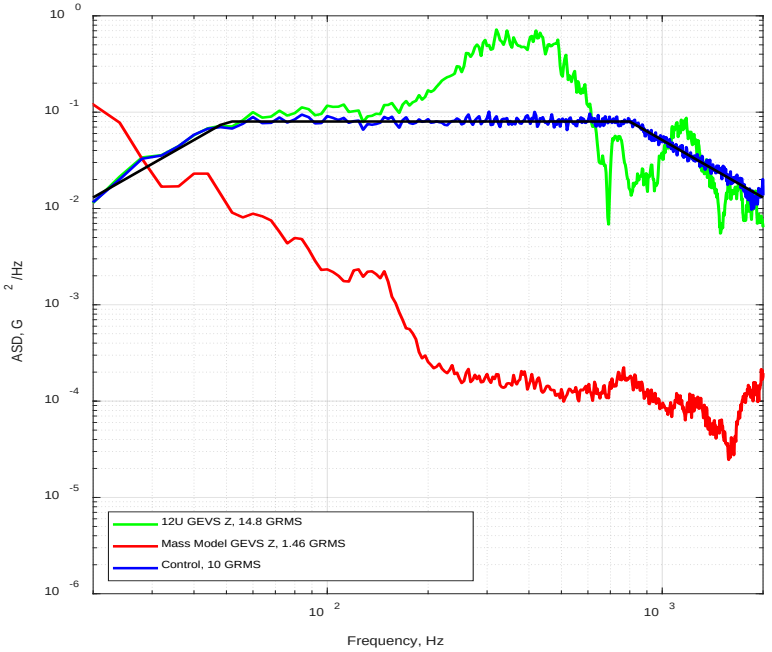
- Isolated design effectively reduces payload environments in all axis
  - Overall gRMS levels reduced by 77% - 93%
  - Low first mode (between 20 – 25 Hz)



Test Setup



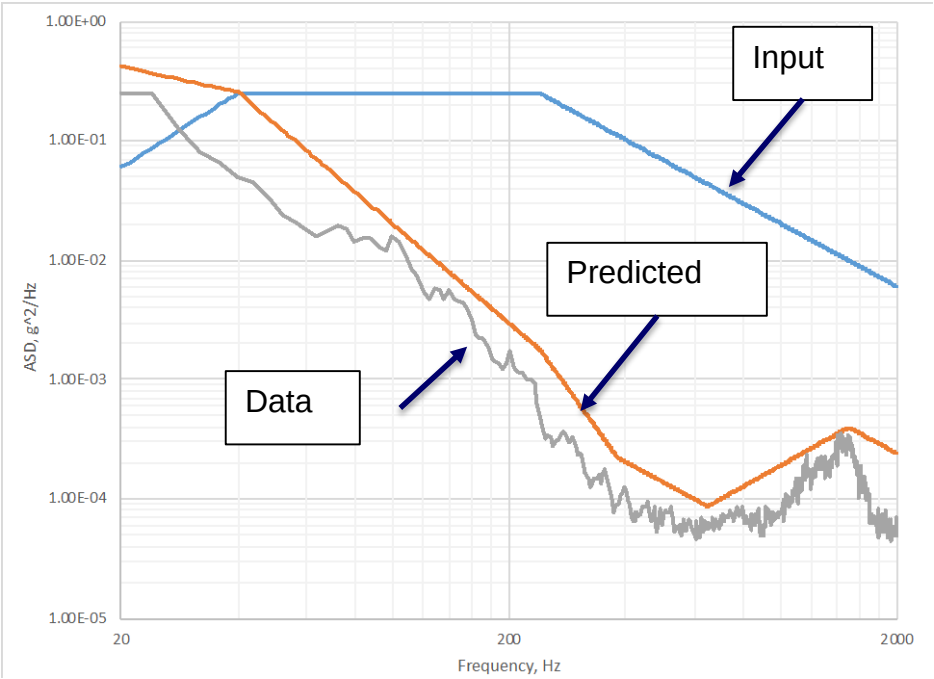
Sample Data – X/Y Axis, GEVS, 25kg



Sample Data – Z Axis, GEVS, 25kg

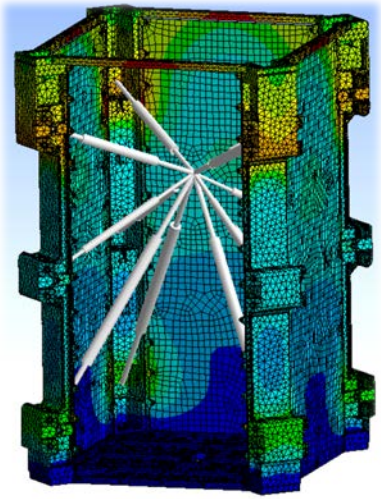
12U Payload Transfer Function

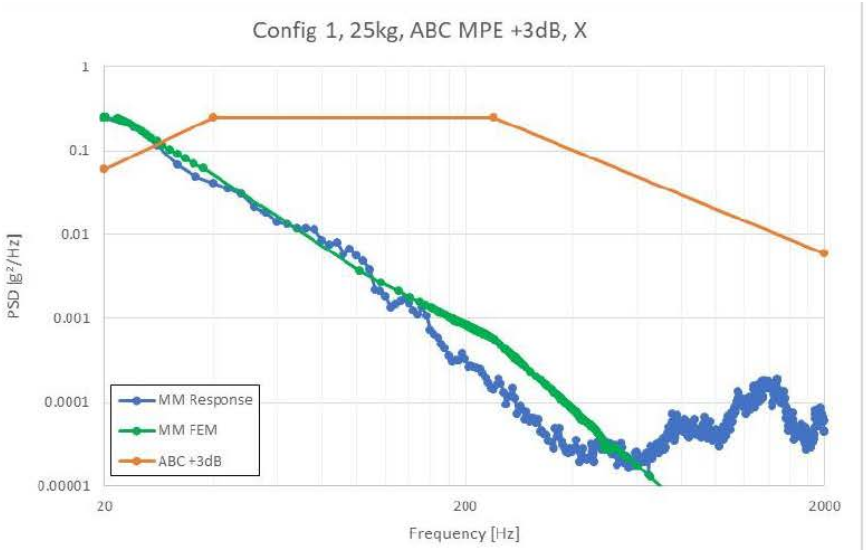
- Analyzing data sets for the 12U testing, a transfer function was developed which can be used to estimate payload environments for a variety of launch vehicle inputs
  - To leverage this capability, simply multiply the launch vehicle input by the transfer function to obtain the estimated payload environment
  - Enables rapid evaluation of environment, no need for complex analytical models.
- Low frequency amplification is seen as a result of the isolators. Attenuation begins at ~40Hz and reduces vibe inputs by a factor of 10-100x starting at 100Hz

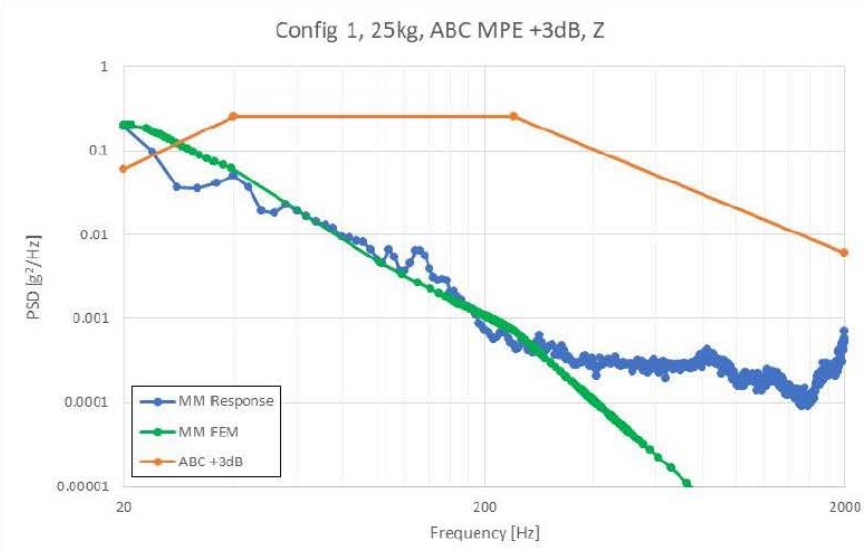


12U Finite Element Modeling

- A finite element modeling approach was used to investigate the ability to perform complex predictions
  - CubeSat is modeled as point mass at CG to simulate CubeSat simulator used in test
  - CubeSat is tied to dispenser using spring/damper elements
- Analytical response of CubeSat is extracted in PSD format and compared to measured response
  - Tuned model correlates to test data
  - Divergences in high frequencies due to mass model modes and not perfectly capturing high frequency dynamics when using point mass assumption

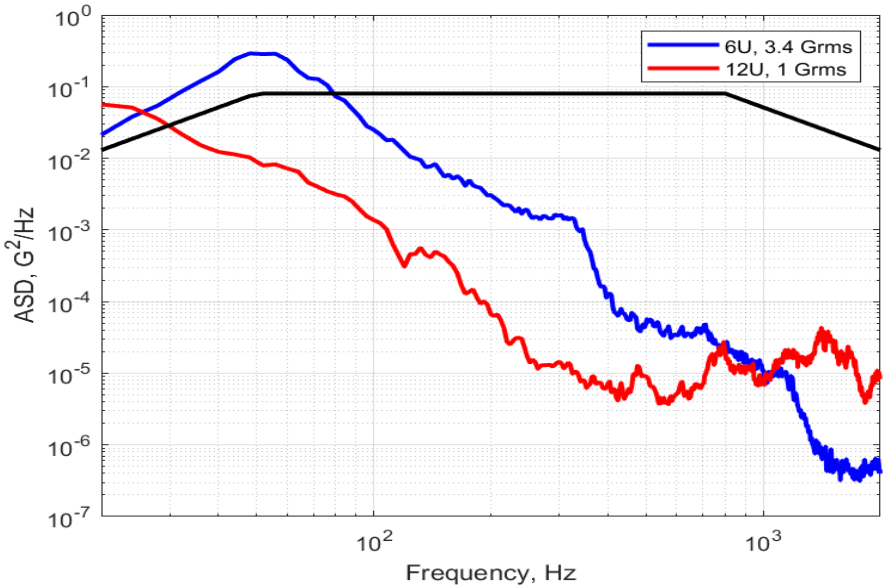






Conclusion and What's Next

- Internal isolation can be successfully implemented in multiple ways
  - 6U – modified rail type dispenser, constrained layer of damping material
  - 12U – built around bushing isolation system (dramatically improved results)
- Two methods for predicting loads exist
  - Compiling known test data to synthesize enveloping transfer functions
  - High fidelity FEMs to generate accurate response for a CubeSat
- Lower CubeSat loads, lower mass dispenser
- Dispenser is hard-mounted, less mass for coupled loads analysis



X-Axis Comparison of 6U to 12U Response