Evaluation of Isolation Systems for Controlling Dynamics Environments During Spacecraft Ground Transportation

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Outline

- Motivation and scope
- SMAP transportation fixture configurations
- Interpretation of measurement data sets
- Insights from 3 degrees-of-freedom (DOF) model
- Summary

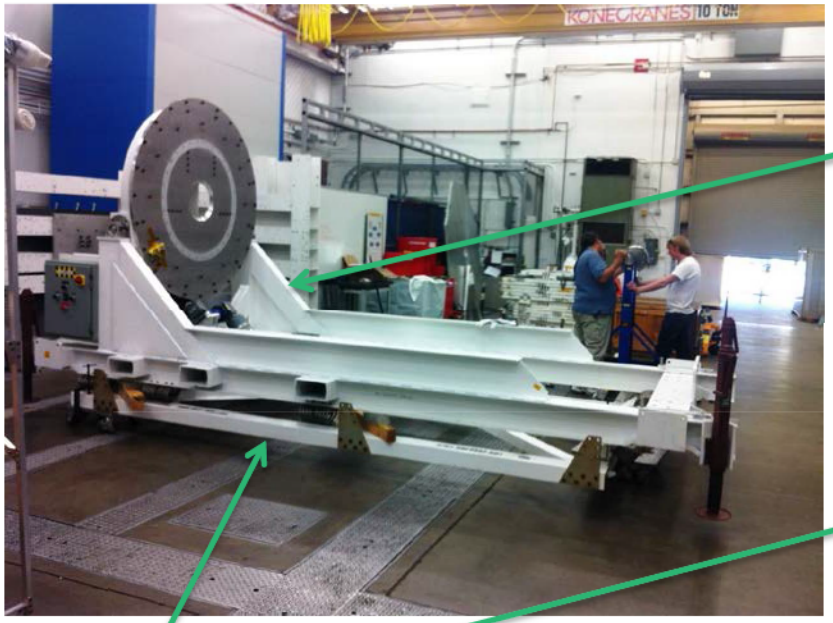
Image Credit: NASA/JPL-Caltech

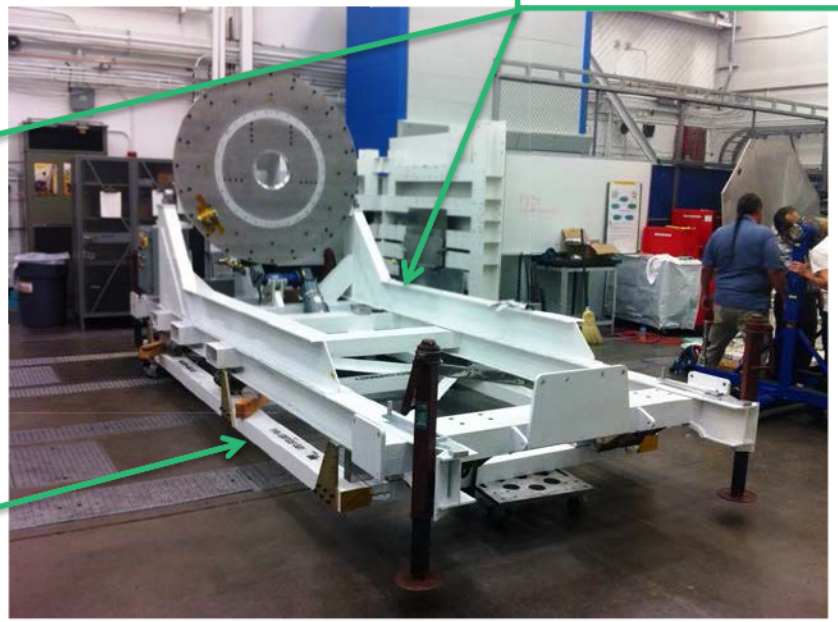
Motivation and Scope

- Ground transportation of flight hardware may exceed launch environments, therefore it is critical to assess the predicted loads
- Isolation systems may be needed to ensure transportation environments do not exceed launch environments
- SMAP transportation dynamics were investigated using available datasets from mass mock up and Observatory transportations
- Lumped-parameter analytical models are used to assess the isolation system dynamics characteristics

Image Credit: NASA/JPL-Caltech

Transportation Fixture





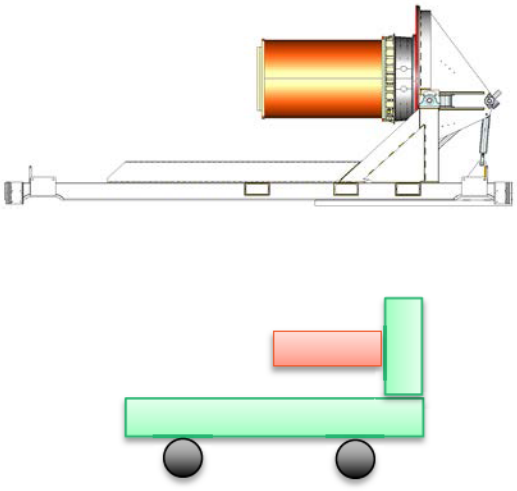
Transportation Fixture

Isolation Pallet

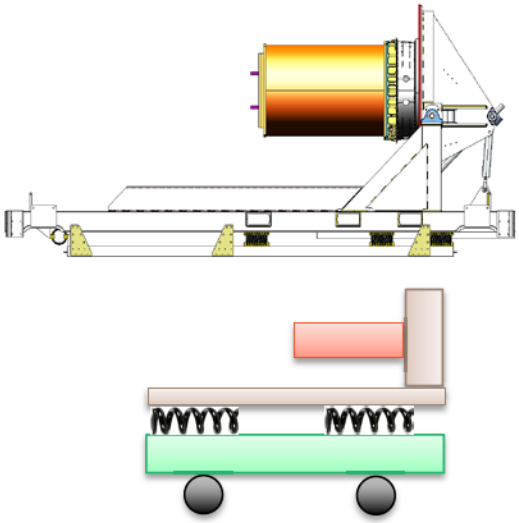
Coil Isolators

Test Configuration

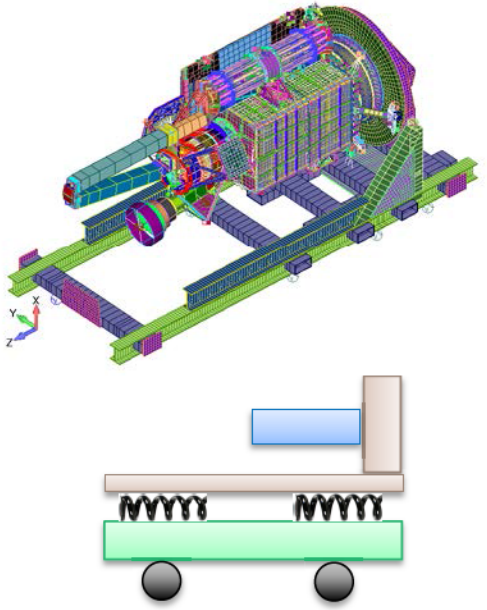
- **Test 1**: Consists of mass mockup, fixture, transported on air-ride van
- **Test 2**: Consists of mass mockup, fixture, and coil isolation, transported on air-ride van
- **Test 3**: Consists of Observatory, fixture, and coil isolation, transported on air-ride van
  - *It should be noted that the air-ride van of Test 1 is different than the ones in Tests 2 and 3.*
  - *Stiffeners were added to the fixture after Test 1.*
  - *Masses: Mockup = 2368 lbs., Observatory = 1881 lbs.*
  - *Uncoupled fn: Mass mockup = ~40Hz, Observatory = 18 Hz*



Test 1

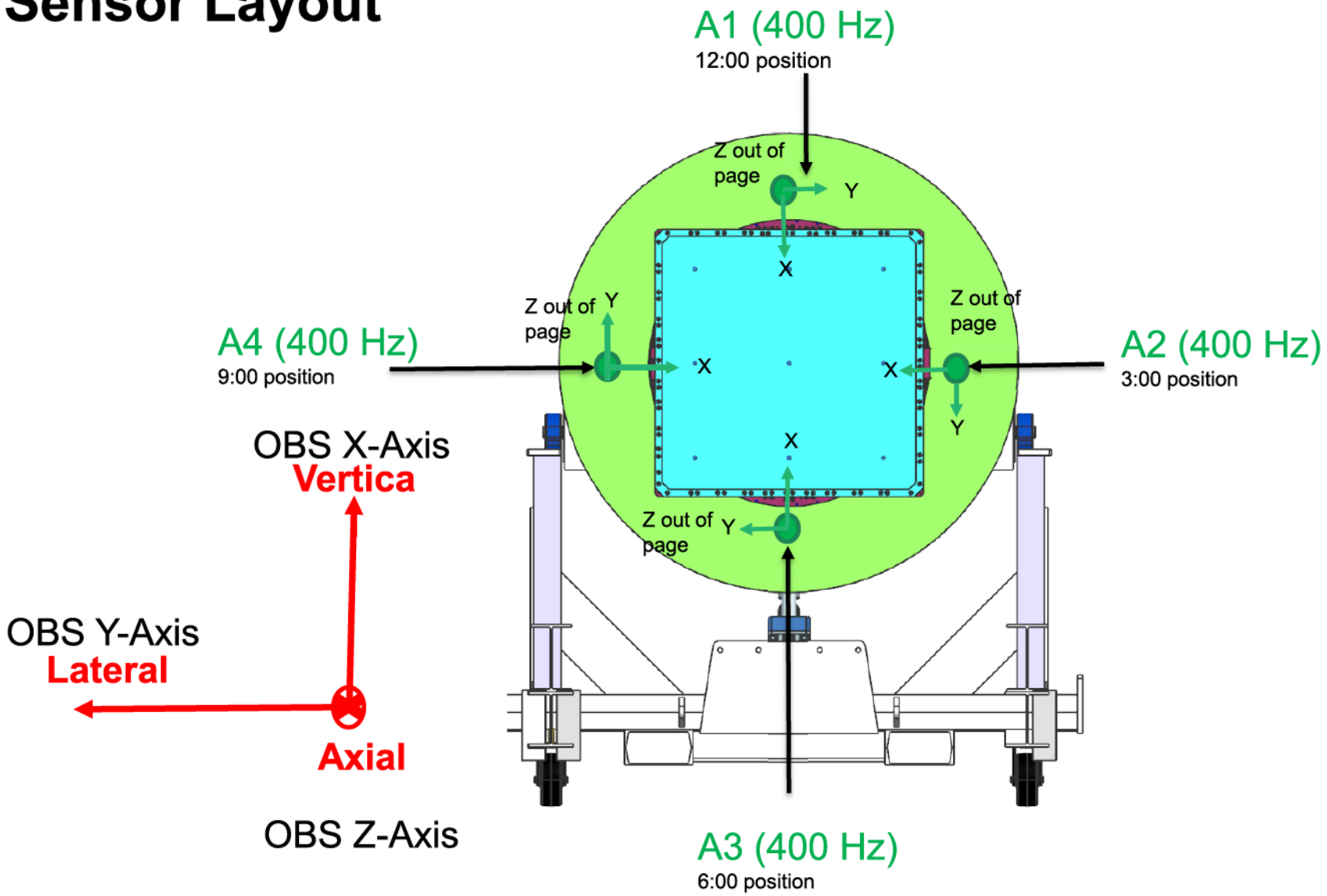


Test 2



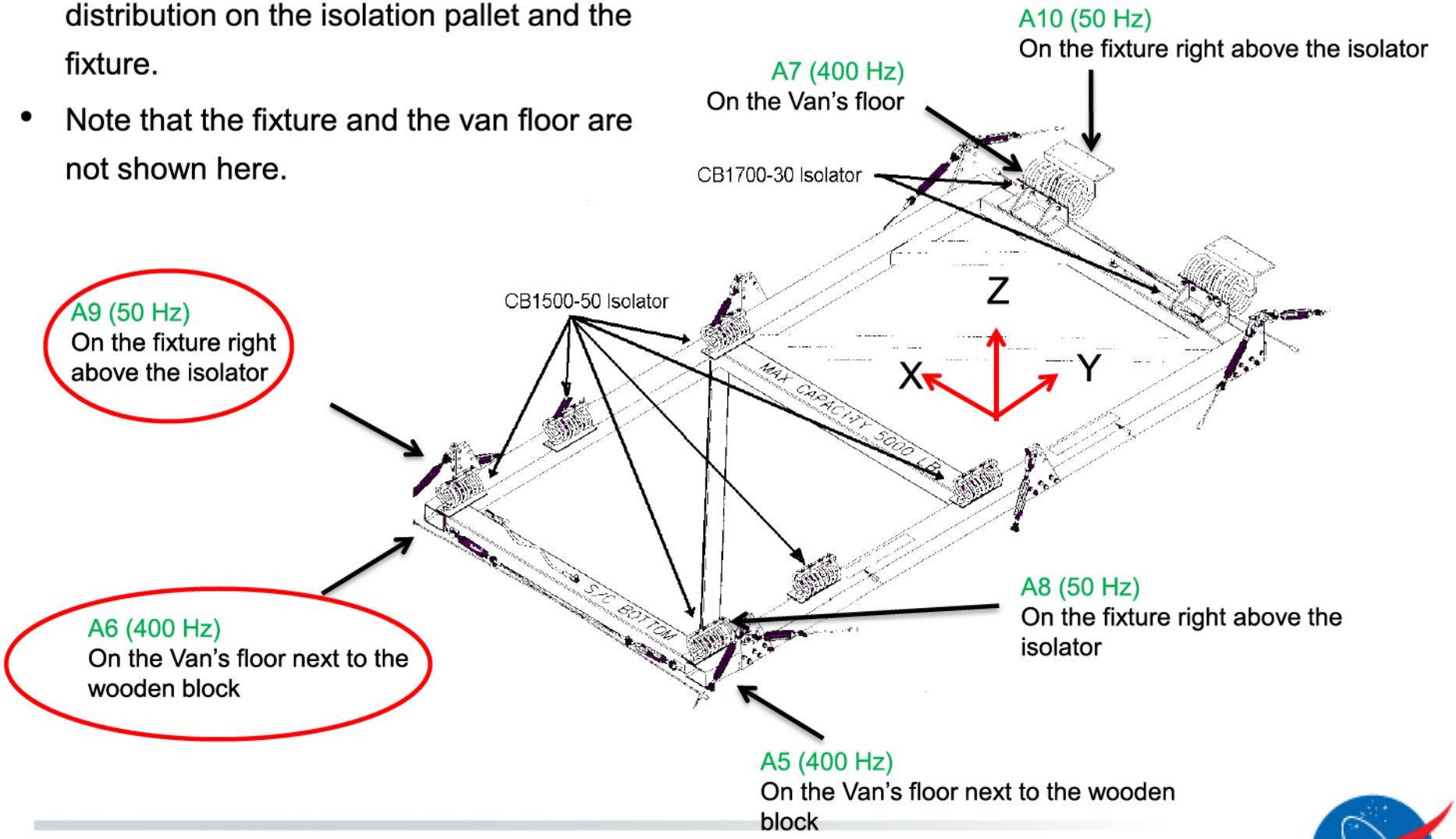
Test 3

Sensor Layout

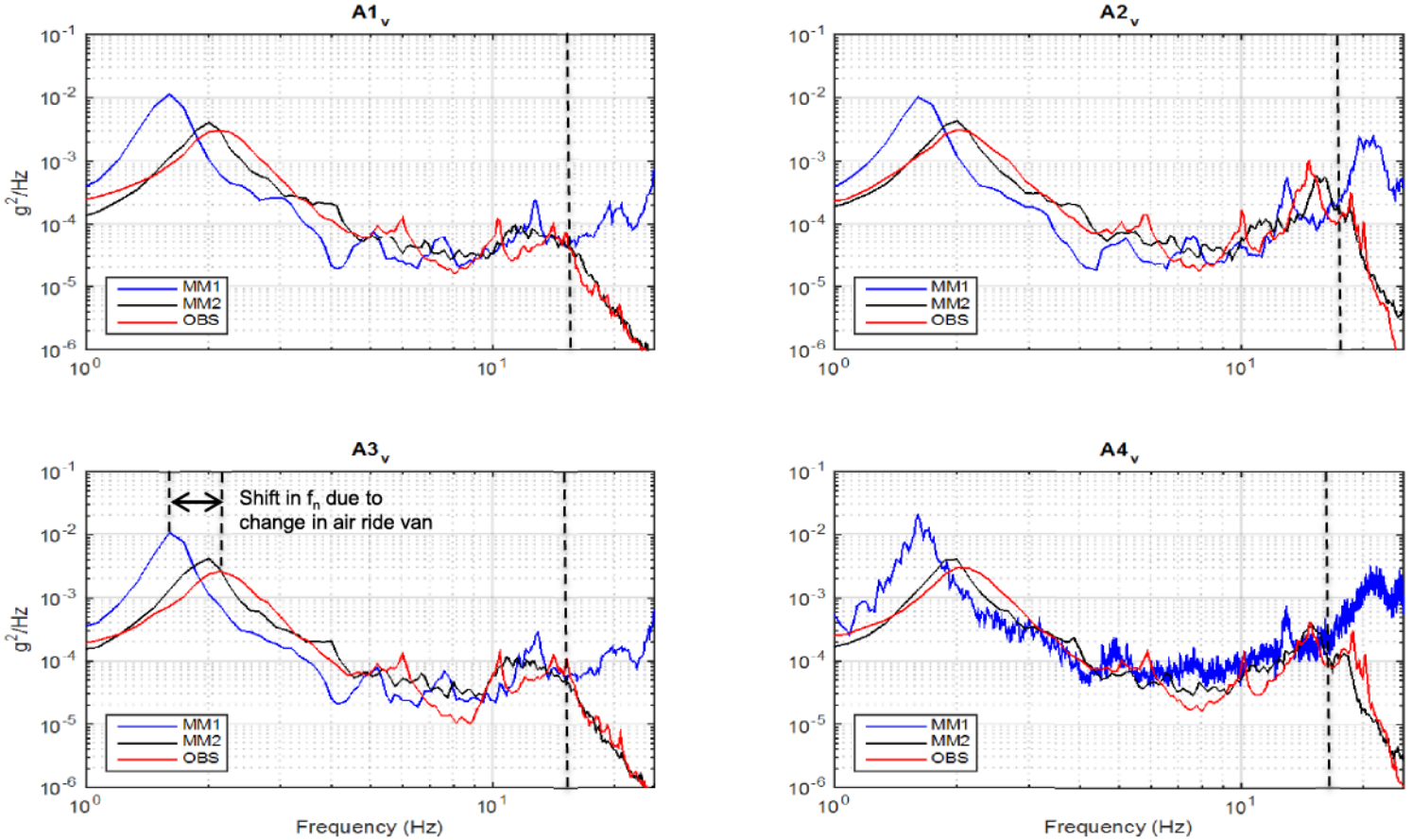


Sensor Layout

- The diagram shows the sensor distribution on the isolation pallet and the fixture.
- Note that the fixture and the van floor are not shown here.

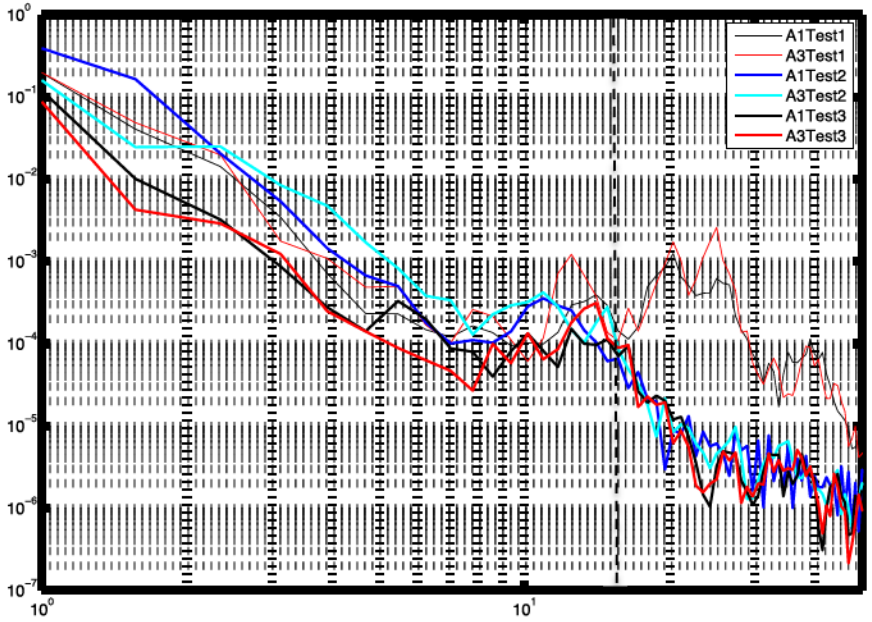


PSD Comparison of Structural Acceleration Responses in the Vertical Direction – All Tests

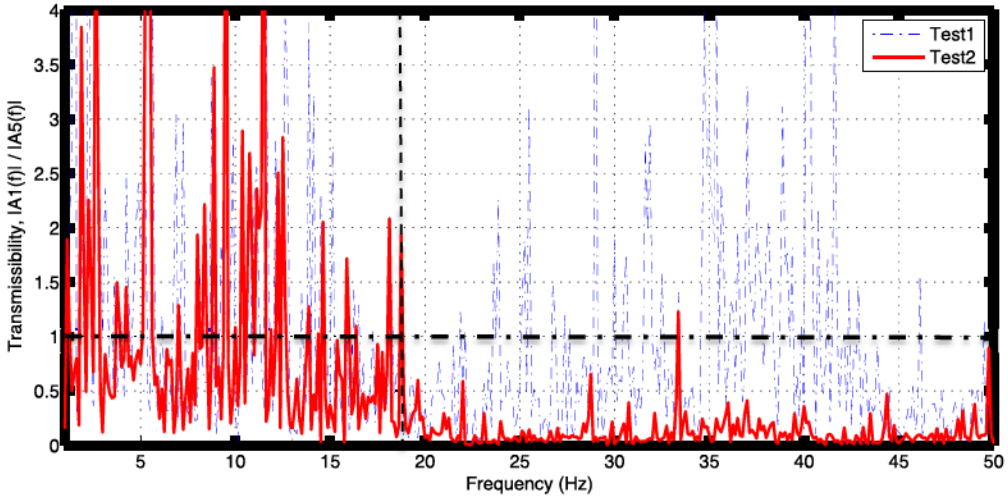


- Air-ride isolation system attenuated structural responses above 2-3 Hz
- Note the shift in the lower peak between MM1 compared to MM2 and OBS. This is most likely due to the different air ride van used for MM1
- Helical coil insolation system attenuated the structural responses above 15-16 Hz
- Test 1 (MM1) without coil isolation system indicate significant structural responses above 15-16 Hz

Transmissibility Analysis



Power Spectral Density (PSD) of Channels A1 and A3
Lateral Direction (OBS-Y Axis)
Test 1, Mass Mockup, No Coil Isolation
Test 2, Mass Mockup, With Coil Isolation
Test 3, Observatory, With Coil Isolation

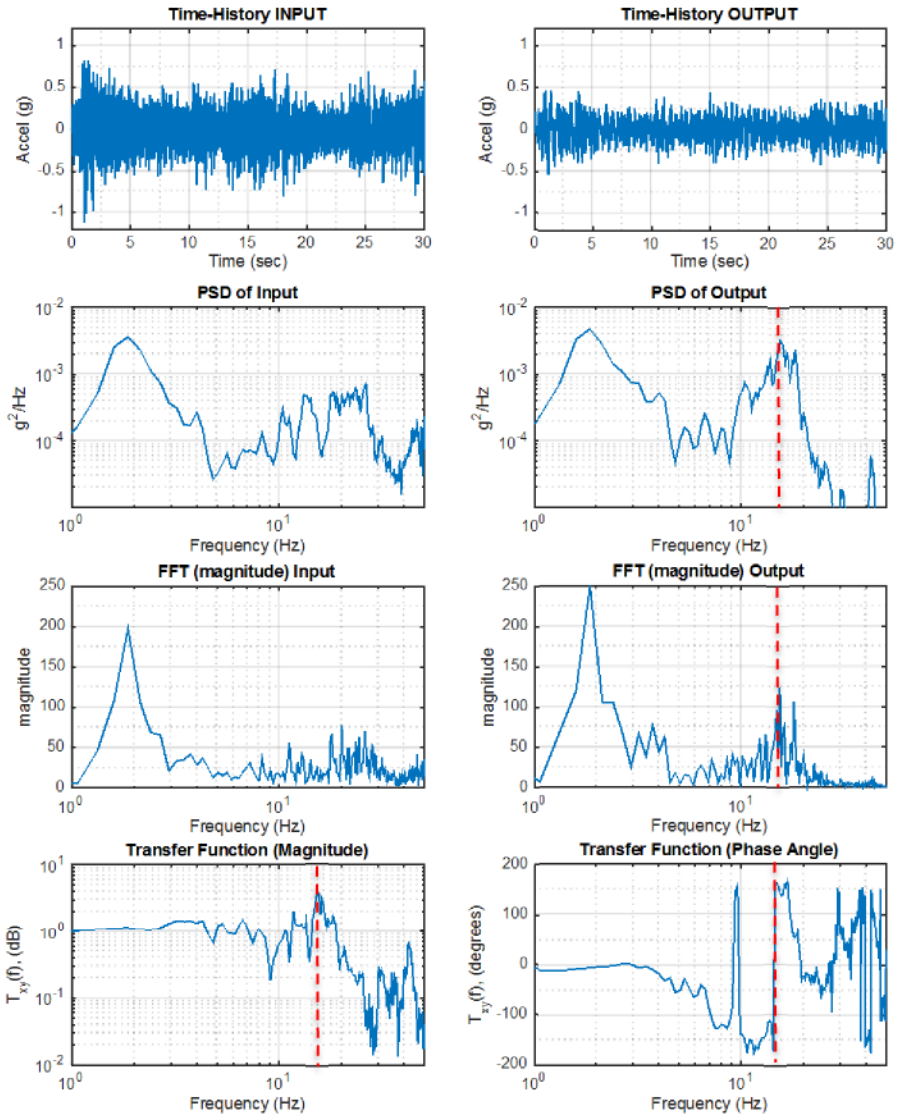


$$T_{rs} = \frac{Complex Harmonic Acceleration at R(response), \ddot{u}_r}{Complex Harmonic Acceleration at S(source), \ddot{u}_s}$$

For effective isolation:

$$|T| \ll 1.0$$

Transfer Function Analysis of Channels A6 & A9 (below & above coil isolator) – Test 3



- Transfer Function

$$T_{xy}(f) = \frac{P_{yx}(f)}{P_{xx}(f)}$$

$T_{xy}(f)$: Transfer Function
x: Input Signal
y: Output Signal
$P_{yx}(f)$: Cross Power Spectral Density of x and y
$P_{xx}(f)$: Power Spectral Density of x

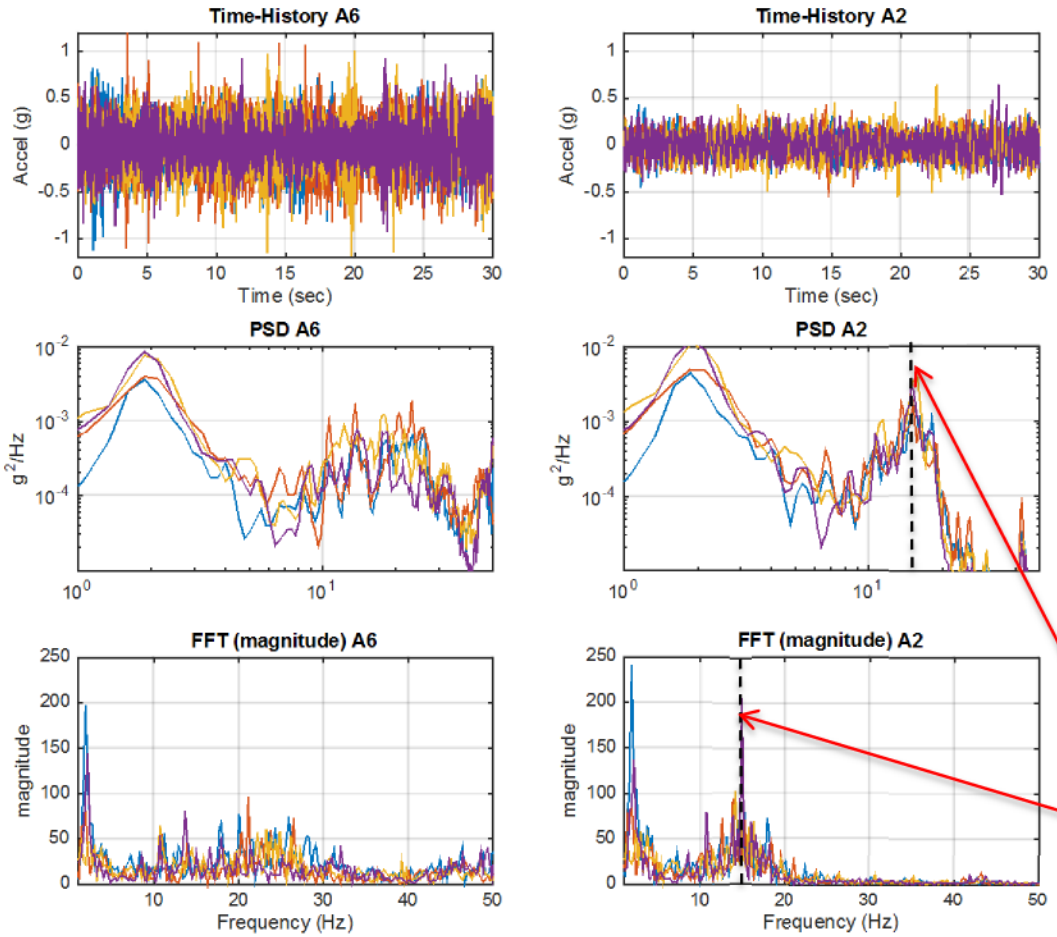
- Both channels in vertical direction:
  - *Input: A6-Output: A9*
- Test 3 is the only synced data set
- One 30 sec. segment
  - *NFFT = length/8*
  - *Overlap = length/12*

- Transfer function shows 2 phase shifts:
  - *@ ~ 10 Hz*
  - *@ ~ 14.5 Hz*

- OUTPUT FFT shows 3 peaks:
  - *~ 2 Hz*
  - *~ 15 Hz*
  - *~ 17.5 Hz*

- Note that there is no phase shift in the transfer function @ 2 Hz

Comparison of Spectral Characteristics of Four Different Time Segments - *Channels A6 & A2 – Test 3*

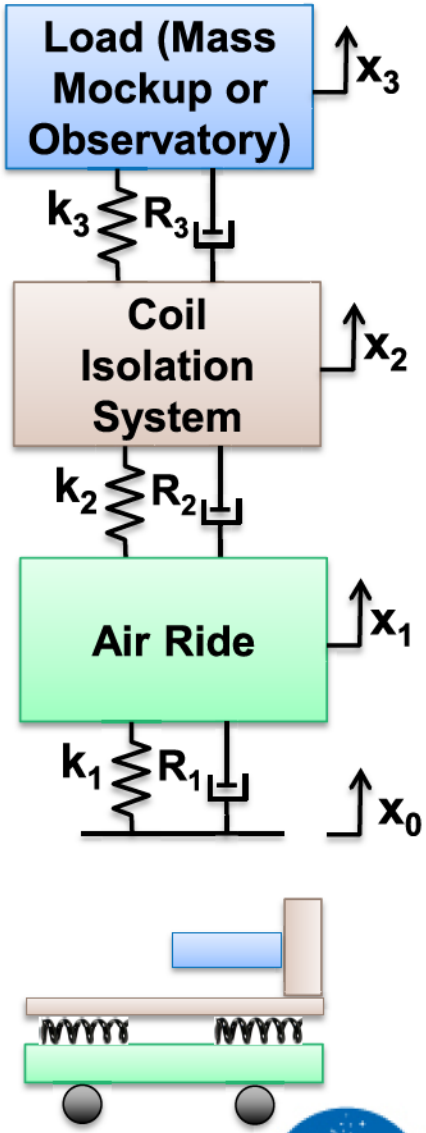


- Both channels in vertical direction
- FOUR 30 sec. segments selected to investigate transient effects
  - NFFT = length/8
  - Overlap = length/12
- Similar spectral behavior observed from all 4 segments

Responses attenuated above ~15 Hz

Three DOF Model: Air Ride + Isolator + Load

- Objective
  - *Assuming 3 DOF lumped parameter model is dynamically representative of an air ride/isolation fixture/load transportation system . . .*
  - *What insight can we apply from the coupled dynamic behavior of 3 DOF system?*
    - Effect load response when load natural frequency approaches isolation system natural frequency
- Note:
  - *Test data responses not measured at modal c.g. for the truck bed, isolation fixture, load*
  - *Therefore no direct correlation between 3 DOF model dynamics and transportation tests*
    - A1-A4 recorded at the base of the load, so can't be directly related to either the isolation system or the load *c.g.* response



Three DOF Model: Air Ride + Isolator + Load

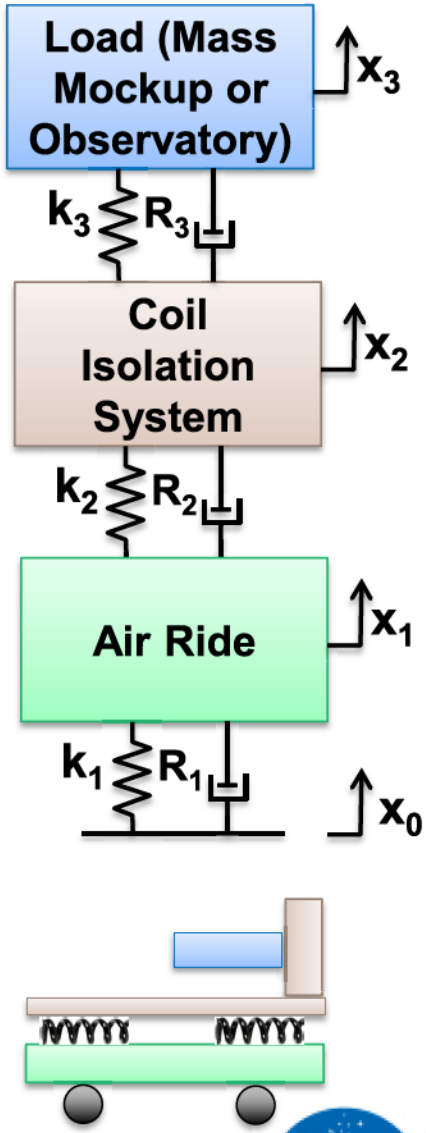
M1 = total mass of truck bed (assume 8000 lbs)
M2 = total mass of isolation fixture (assume 2500 lbs)
M3 = total mass of load (assume 2500 lbs)

$m_{3\_modal} = \alpha_3 M_3$
$m_{2\_modal} = \alpha_2 (M_2 + M_3 - m_{3\_modal})$
$m_{1\_modal} = \alpha_1 (M1 + M_2 + M_3 - m_{2\_modal} - m_{3\_modal})$

$$m_{\text{modal}} = \alpha\left(M_{\text{total}}\right)$$
$$m_{\text{residual}} = M_{\text{total}}\left(1-\alpha\right) = M_{\text{total}} - m_{\text{modal}}$$

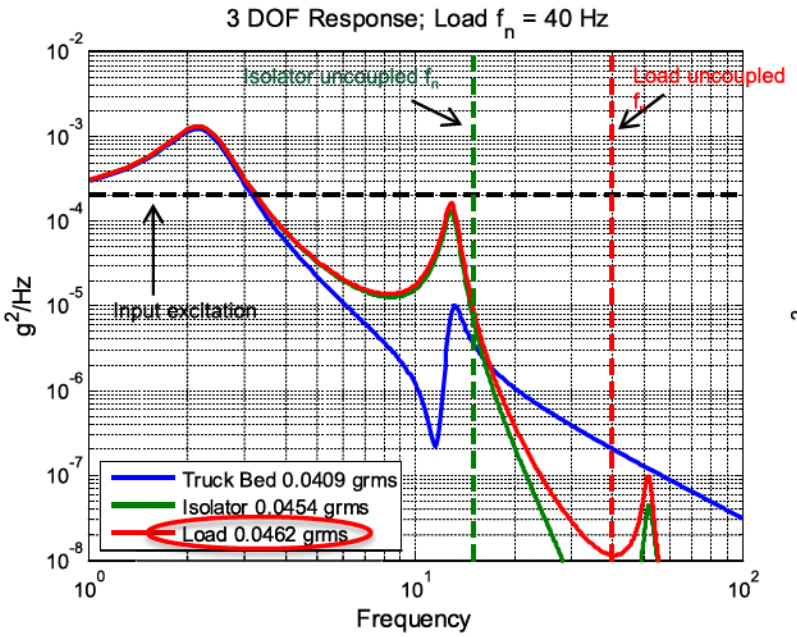
α = *modal mass participation factor*

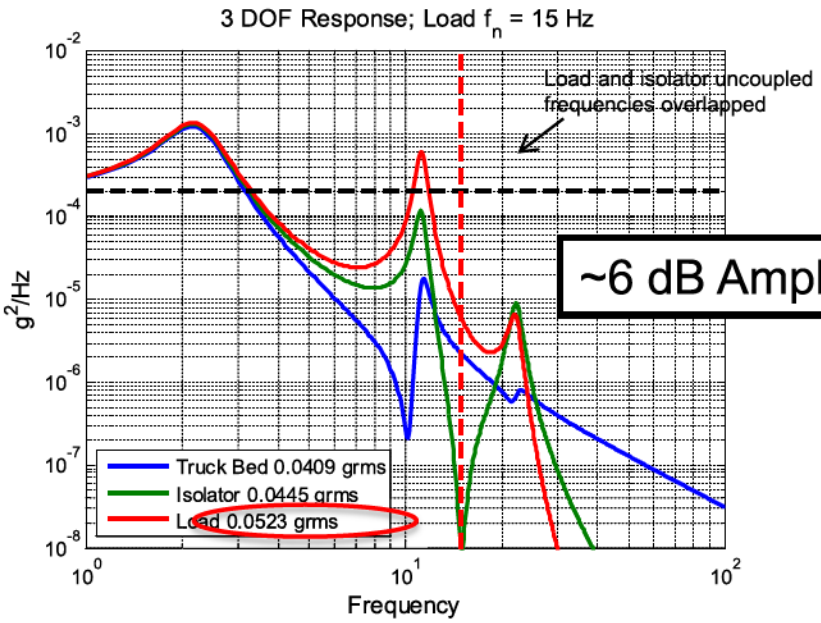
- *Based on total mass, approximate mode shape, mass distribution of represented structural element*



Case Study: Move Load Frequency closer to Isolation System Frequency (vary from 40-15 Hz)

Uncoupled Dynamic Parameters	$W_{\_Total}$	α	$W_{\_modal}$	f_n	Q_n
Truck Bed	8000	1.0	8000 lb	2.5 Hz	2
Isolator	2500	0.375	938 lb	15 Hz	10
Load	2500	0.375	938 lb	40 → 15 Hz	25





~6 dB Amplification

Summary

- Air Ride frequency at ~ 2Hz and has dominant effect in attenuating SMAP Observatory and Mass Mock fundamental frequencies
- Transmissibility, spectral density, and phase data analysis suggest air-ride and the coil isolation systems coupled with the load have frequencies of ~2 Hz and ~15 Hz, respectively
  - *Spectral attenuation and phase shift support this observation*
- Observations from 3DOF Model:
  - *Local frequency band response of load increases notably (~6 dB in this case) as load uncoupled f_n approaches uncoupled f_n of isolation system*
  - *This observation can explain the high accelerations (~2.5 g) experienced during the observatory transportation where strong coupling existed between the isolator and the load*
- Consideration should be made in placement of the accelerometers to better capture the coupled dynamics of the load/fixture/truck-bed
- Correlated models should be used for cases when the isolator mode and the load mode strongly couple, such as the one in this study

References

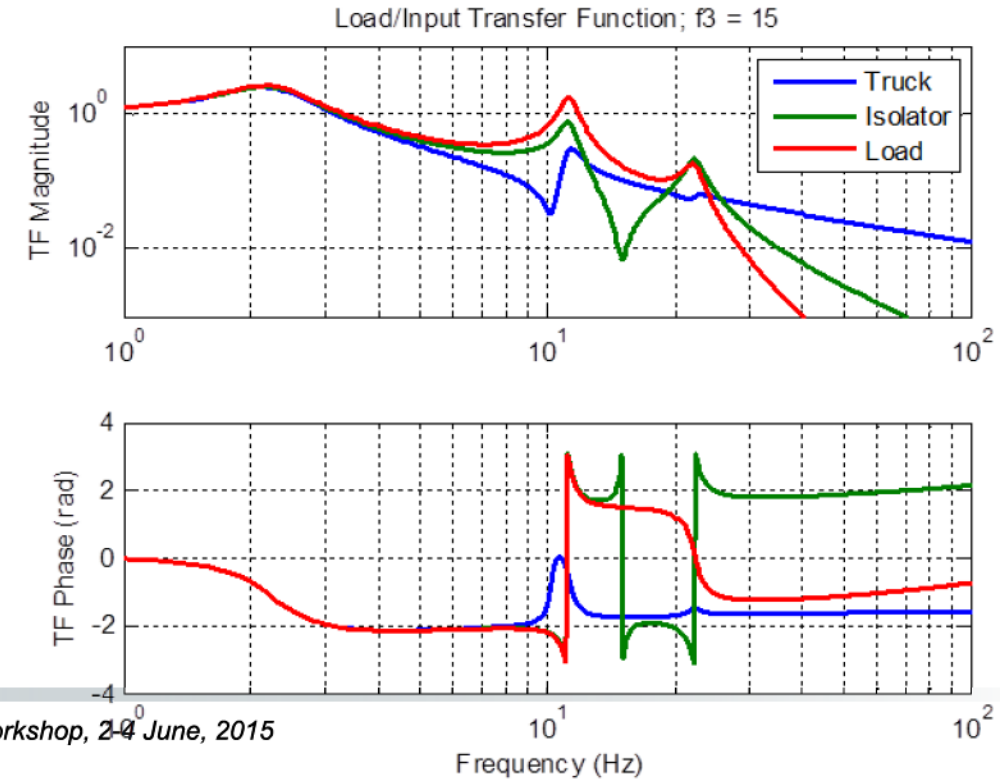
- Maed, Denys J., *Passive Vibration Control*. Wiley, 1999
- Bendat, Julus S., Piersol, Allan G., *Random Data Analysis and Measurement Procedures*, Third Edition, Wiley Series, 2000
- Meirovitch, L., *Fundamentals of Vibrations*. McGraw Hill, 2001

Back up

Case Study Continued: Load Frequency (15 Hz)

Transfer function between road and load

Uncoupled Dynamic Parameters	$W_{\_Total}$	α	$W_{\_modal}$	f_n	Q_n
Truck Bed	8000	1.0	8000 lb	2.5 Hz	2
Isolator	2500	0.375	938 lb	15 Hz	10
Load	2500	0.375	938 lb	15 Hz	25



PSD surface plots from Test 1