# Orion MPCV Service Module Avionics Ring Pallet Testing, Correlation, and Analysis

The NASA Orion Multi-Purpose Crew Vehicle (MPCV) is being designed to replace the Space Shuttle as the main manned spacecraft for the agency. Based on the predicted environments in the Service Module avionics ring, an isolation system was deemed necessary to protect the avionics packages carried by the spacecraft. Impact, sinusoidal, and random vibration testing were conducted on a prototype Orion Service Module avionics pallet in March 2010 at the NASA Glenn Research Center Structural Dynamics Laboratory (SDL). The pallet design utilized wire rope isolators to reduce the vibration levels seen by the avionics packages. The current pallet design utilizes the same wire rope isolators (M6-120-10) that were tested in March 2010. In an effort to save cost and schedule, the Finite Element Models of the prototype pallet tested in March 2010 were correlated. Frequency Response Function (FRF) comparisons, mode shape and frequency were all part of the correlation process. The non-linear behavior and the modeling the wire rope isolators proved to be the most difficult part of the correlation process. The correlated models of the wire rope isolators were taken from the prototype design and integrated into the current design for future frequency response analysis and component environment specification.

# Orion MPCV Service Module Avionics Ring Pallet Testing, Correlation and Analysis

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# Agenda

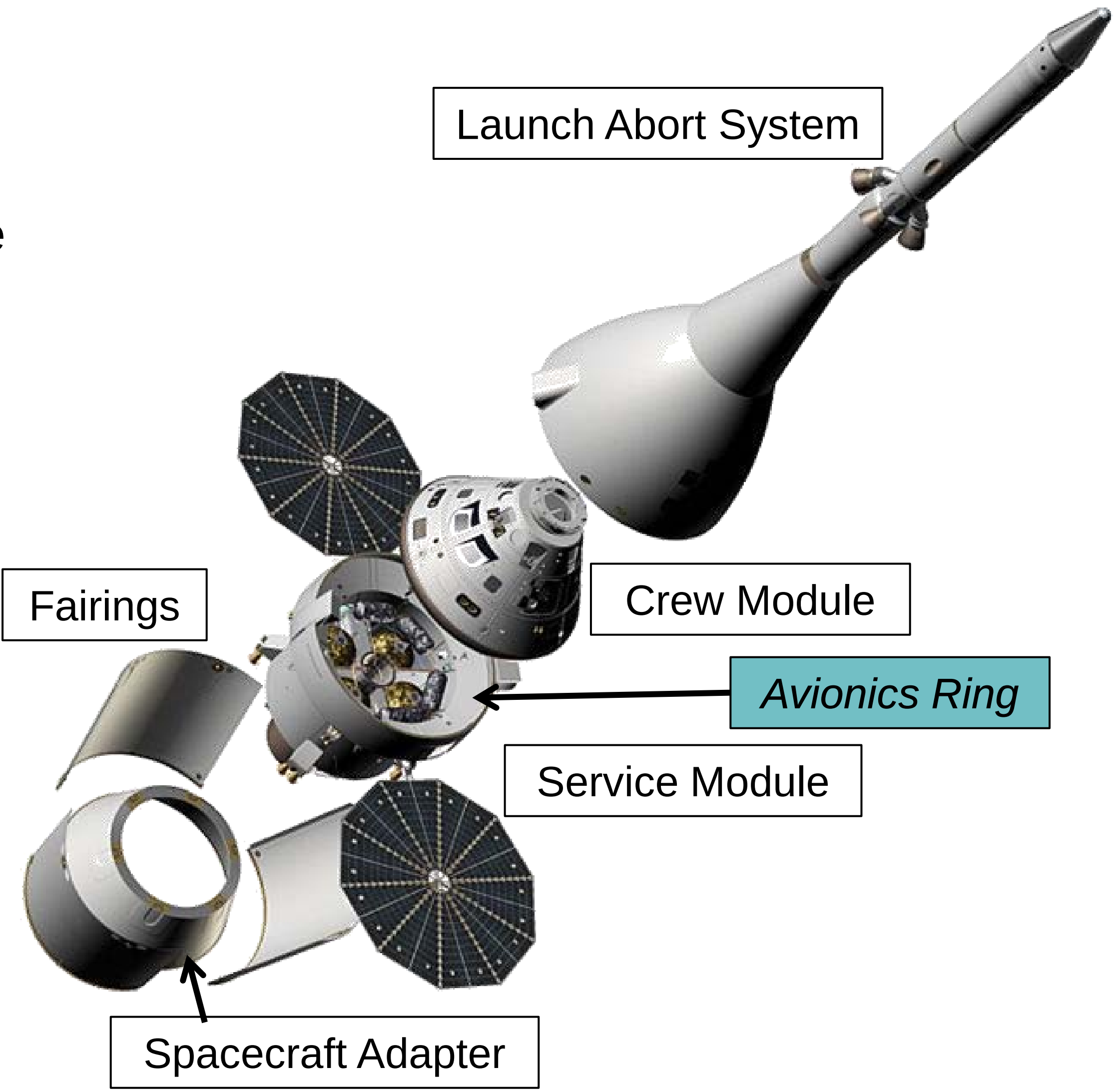
- Background
- Correlation
- EFT-1 Configuration
- Conclusions
- Acknowledgements

Spacecraft and Launch Vehicle Dynamic Environments Workshop

# Background

# Orion Multi-Purpose Crew Vehicle (MPCV)

- Orion MPCV is currently being designed as NASA's next human rated spacecraft
- Service Module Avionics Ring houses many important power, life support, communications, and navigation packages
- Predicted environments resulted in needing an isolation system design to protect sensitive avionics equipment in the SM Avionics Ring
- Development testing performed on a avionics pallet design, utilizing commercial (off the shelf) wire rope isolators to prove feasibility and potential performance of wire rope isolators and pallet design



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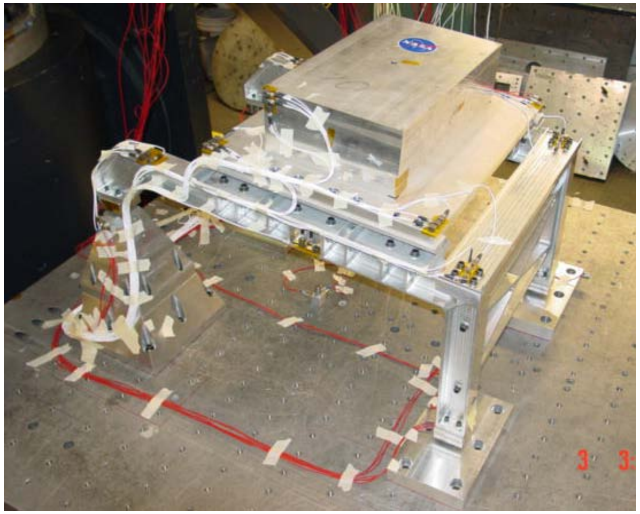
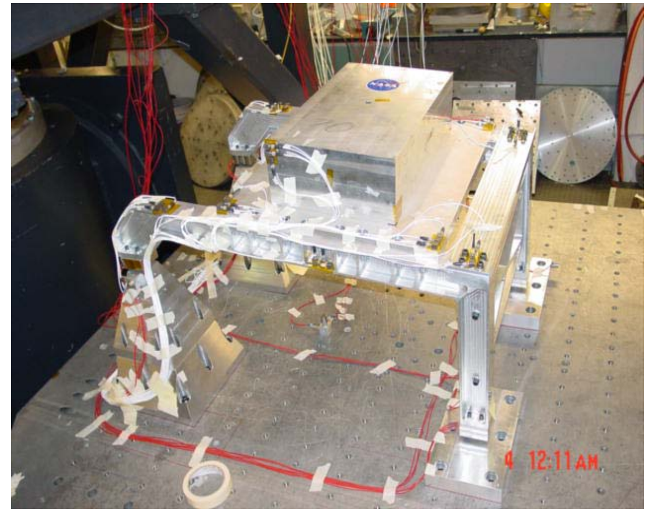
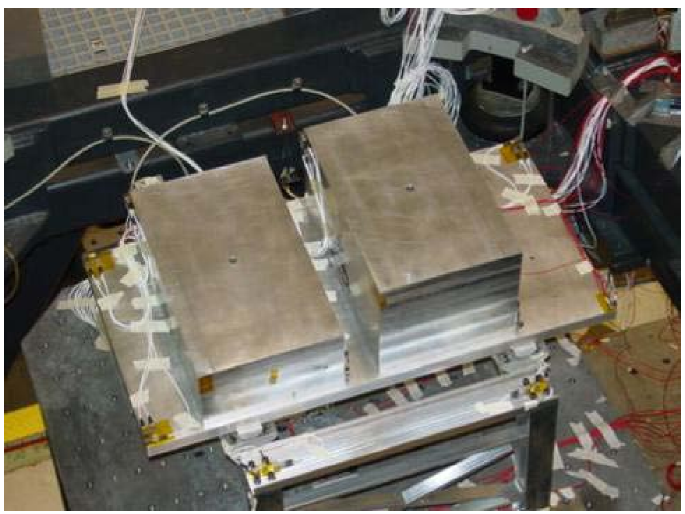
# SM Avionics Pallet Test Configurations



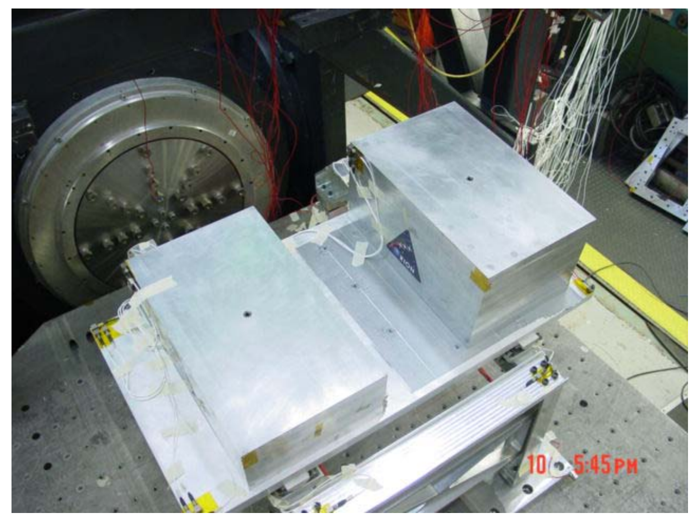
1) Small Pallet 70lb mass, isolated



2) Small Pallet 70lb mass, hard mounted



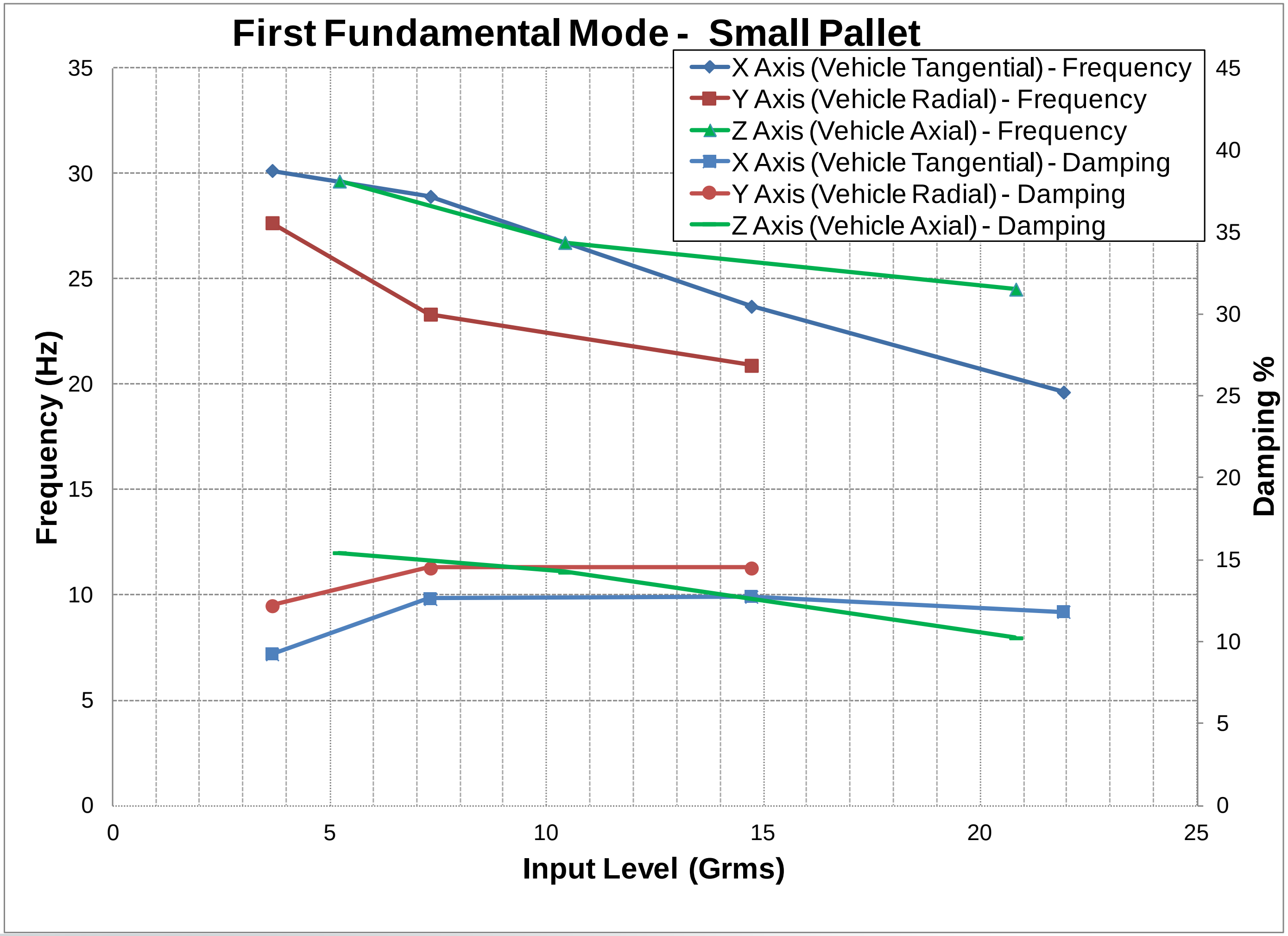
3) Large Pallet 70lb & 120lb mass, isolated



4) Large Pallet 70lb &120lb mass separated, isolated

# SM Avionics Pallet Test Results (1)

- Isolators displayed softening characteristics (i.e. modal frequencies of fundamental modes decreased as input levels increased).
- Isolator manufacturer provides a high damping value of $C/C_c \approx 0.20$ in literature for isolators → High modal damping also extracted from test data; expected to be lower



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# SM Avionics Pallet Test Results (2)

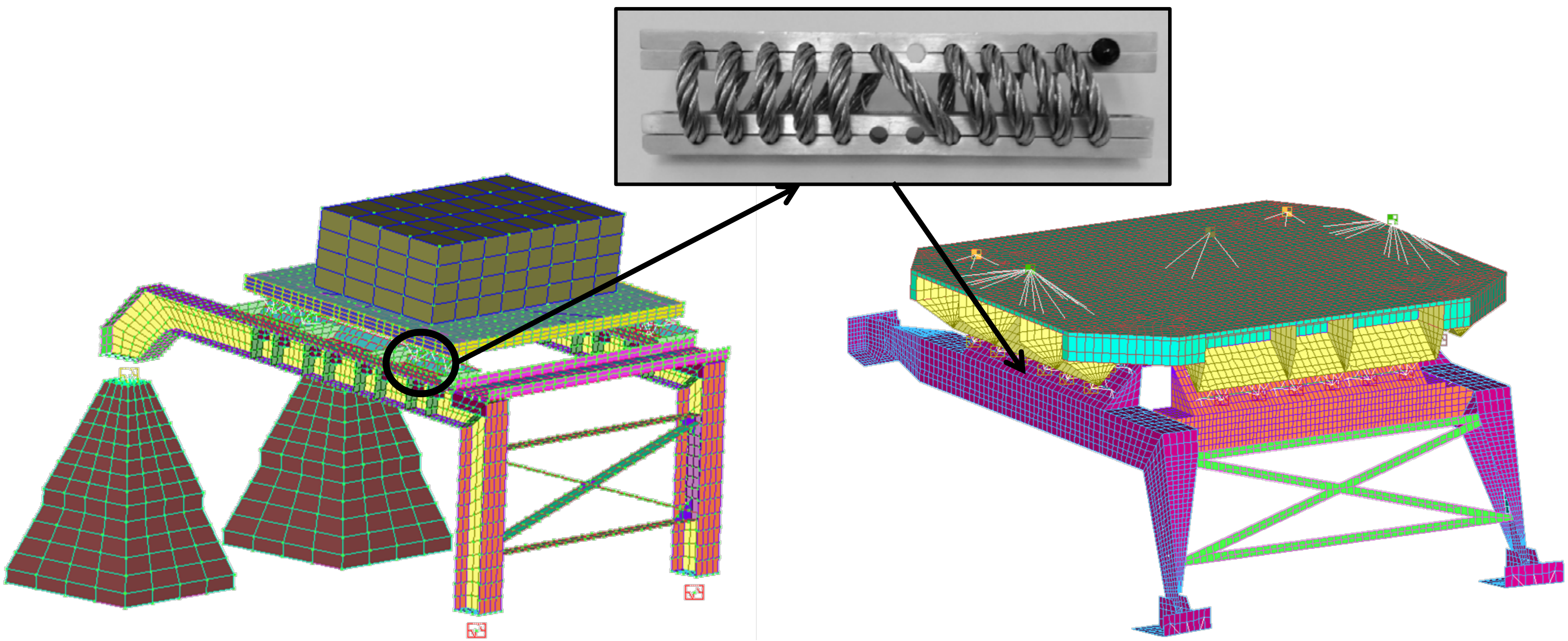
- Mass simulator had two accelerometers on opposite corners (front lower and rear upper corners)
- Accelerations were averaged to produce a representative C.G. mass response and used to create the results in the tables below → Hard Mounted vs. Isolated
- Large reductions in overall GRMS level seen at the avionics mass simulator

| Run | Axis | Mount | C.G. Response (Grms) | Percent Reduction (Isolated/Hard | Reduction in dB (Isolated/Hard) |
|---|---|---|---|---|---|
| 83 - 3.65Grms | X (Tangential | Isolated | 0.52 | **-72%** | **11** |
| 105 - 3.65Grms | X (Tangential | Hard | 1.86 | | |
| 91 - 3.65Grms | Y (Radial) | Isolated | 0.65 | **-90%** | **20** |
| 99 - 3.65Grms | Y (Radial) | Hard | 6.79 | | |
| 125 -5.2Grms | Z (Axial) | Isolated | 2.20 | **-88%** | **18** |
| 117 - 5.2Grms | Z (Axial) | Hard | 17.69 | | |

Development test proved feasibility and demonstrated potential performance of the wire rope isolator and pallet design

# In-Line Task Objective

- Orion MPCV project requested isolator test data from March 2010 development test be correlated and used to create new component environments → Exploration Flight Test - 1 (EFT-1) Pallet Configuration uses M6-120-10 wire rope isolators
- **<u>Objective:</u>** Correlate FEM's to the NASA GRC SM Pallet test data, which include models of the M6-120-10 wire rope isolators. Extract the correlated M6-120-10 models from these correlated FEM's and integrate them into the EFT-1 SM Pallet model for frequency response analysis and generating component environments.

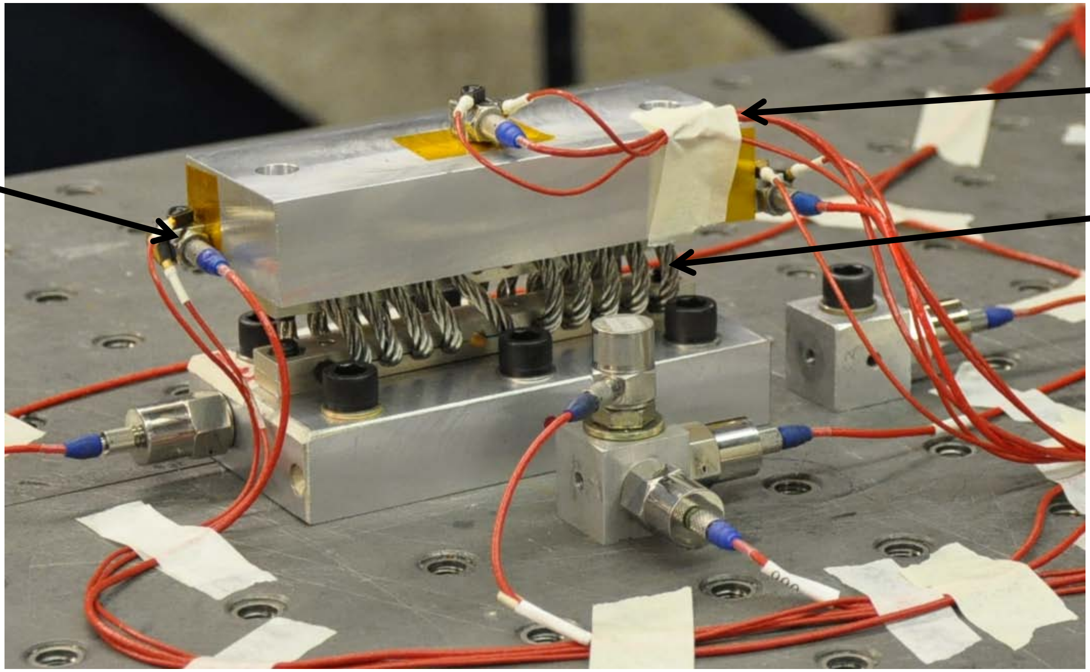


Small Pallet Configuration (March 2010)

EFT-1 Pallet Configuration

# Single M6 Isolator Test Configuration

- Original objective of March 2010 SM Avionics Pallet test was to determine feasibility and potential performance of design → not to model/correlate isolators in great detail
  - *Testing met initial intent*
  - *Correlation work requested well after test completed and torn down*
- Single M6-120-10 isolator test performed to better understand isolators
  - *Due to schedule and cost constraints isolators were not able to be tested in a configuration to load isolators to the extent they were/will be loaded in the SM Avionics Ring*
  - *Ideally isolator would be dynamically tested/loaded to flight like levels with forces and displacements explicitly measured*



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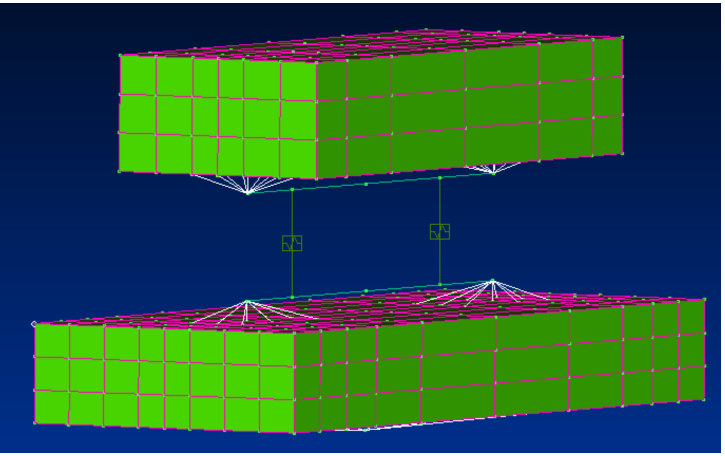
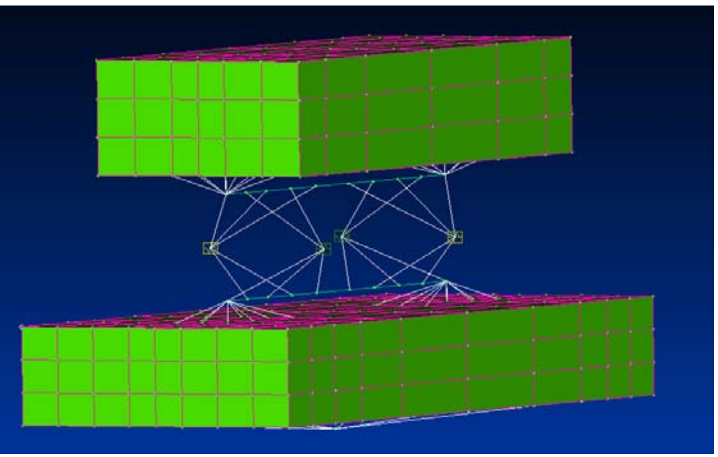
# Single M6 Isolator Test Results



Two CBUSH Isolator FEM

| MAC Matrix for Single M6 Isolator 2pt5g - 2CBUSH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | | | |
| | Mode # | | 1 | 2 | 4 | 3 | 6 | 5 |
| | | Freq (Hz) | 79.73 | 81.98 | 438.91 | 168.84 | 551.26 | 506.14 |
| Test Modes | 1 | 99.48 | 0.72 | 0.19 | | | | |
| | 2 | 157.50 | 0.20 | 0.62 | | | 0.17 | 0.15 |
| | 3 | 175.00 | | 0.18 | 0.72 | | | |
| | 4 | 407.25 | | | | 0.57 | 0.42 | 0.30 |
| | 5 | 445.00 | | | | 0.16 | 0.80 | 0.67 |
| | 6 | 458.13 | | | | | 0.60 | 0.98 |



Four CBUSH Isolator FEM

| MAC Matrix for Single M6 Isolator 2pt5g - 4CBUSH | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | | | |
| | Mode # | | 1 | 3 | 2 | 5 | 4 | 6 |
| | | Freq (Hz) | 100.72 | 125.73 | 125.08 | 311.99 | 277.70 | 377.14 |
| Test Modes | 1 | 99.48 | 0.80 | | | | | |
| | 2 | 157.50 | 0.27 | 0.72 | | | | |
| | 3 | 175.00 | | | 0.84 | | | |
| | 4 | 407.25 | | | | 0.84 | 0.23 | 0.30 |
| | 5 | 445.00 | | | | | 0.91 | 0.66 |
| | 6 | 458.13 | | | | | 0.50 | 0.96 |

Four CBUSH FEM Chosen and Used for Rest of Correlation Process

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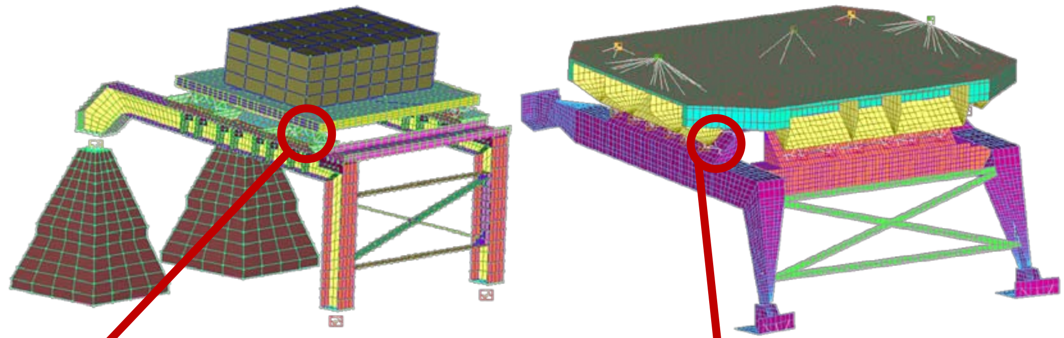
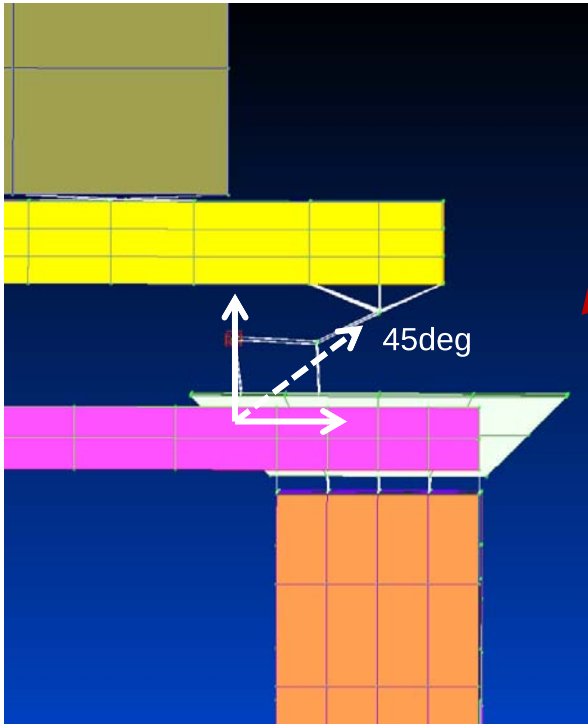
# Correlation

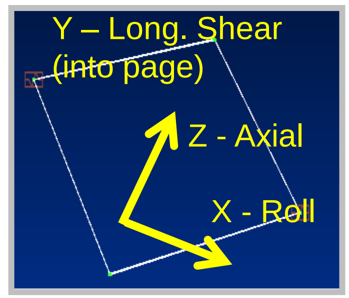
# Correlation

## *Isolator Orientation*

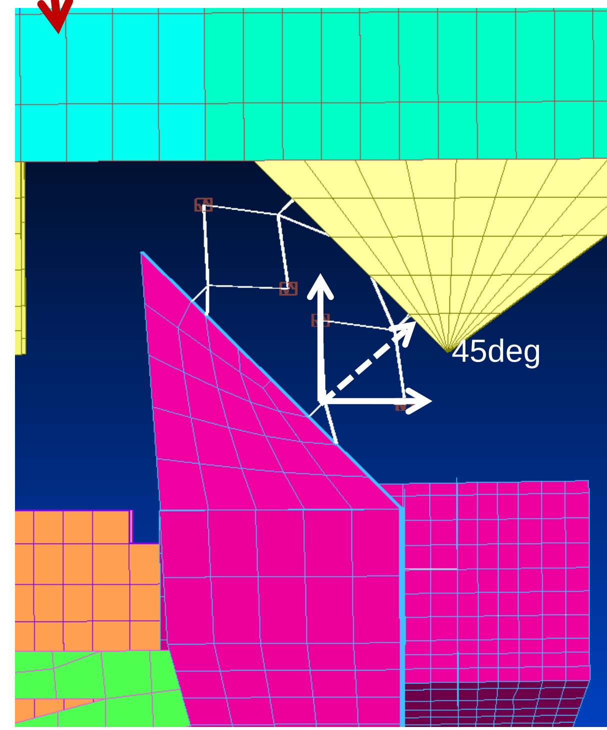





March 2010 Small Pallet




Isolator Local Coordinate System




EFT-1 Pallet

- EFT-1 Pallet isolators are oriented 45deg from the vertical
- Isolator local coordinate system used during correlation
- One configuration considered for correlation effort →
  - *Small Pallet w/ 70lb avionics mass simulator, isolated by 4 M6-120-10 wire ropes*
  - *This configuration most closely matched the EFT-1 Pallet design's isolator orientation*



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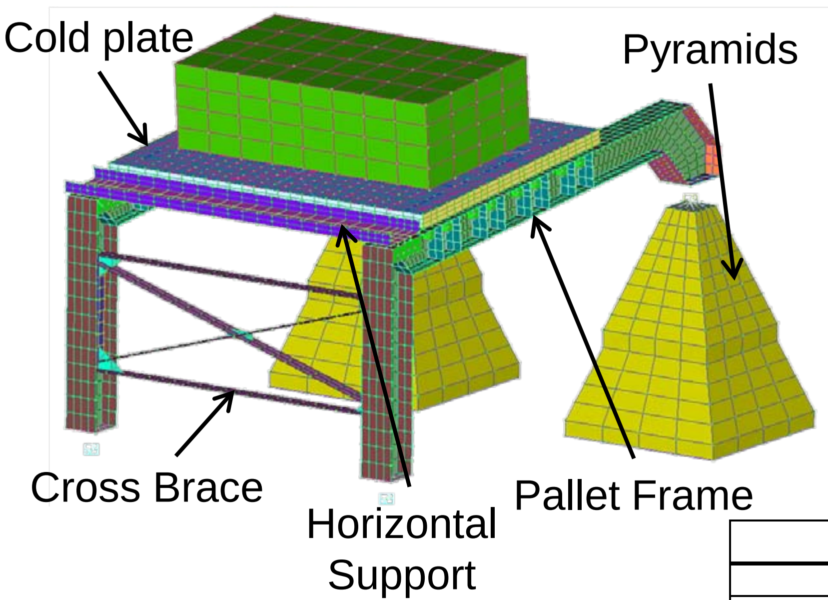
# Correlation: Hard Mounted Test Configuration

- Hard mounted configuration was correlated first to ensure proper boundary conditions and pallet structural properties were well correlated
- Young's Modulus, E, of pallet structure parts were allowed to vary +/-10%
- Thickness of cold plate ribs allowed to vary +/- 5% to account for radii
- Largest impact from changes in boundary conditions of pallet legs (rotational stiffness of CBUSH elements at pallet feet) and mass simulator to cold plate RBE connections

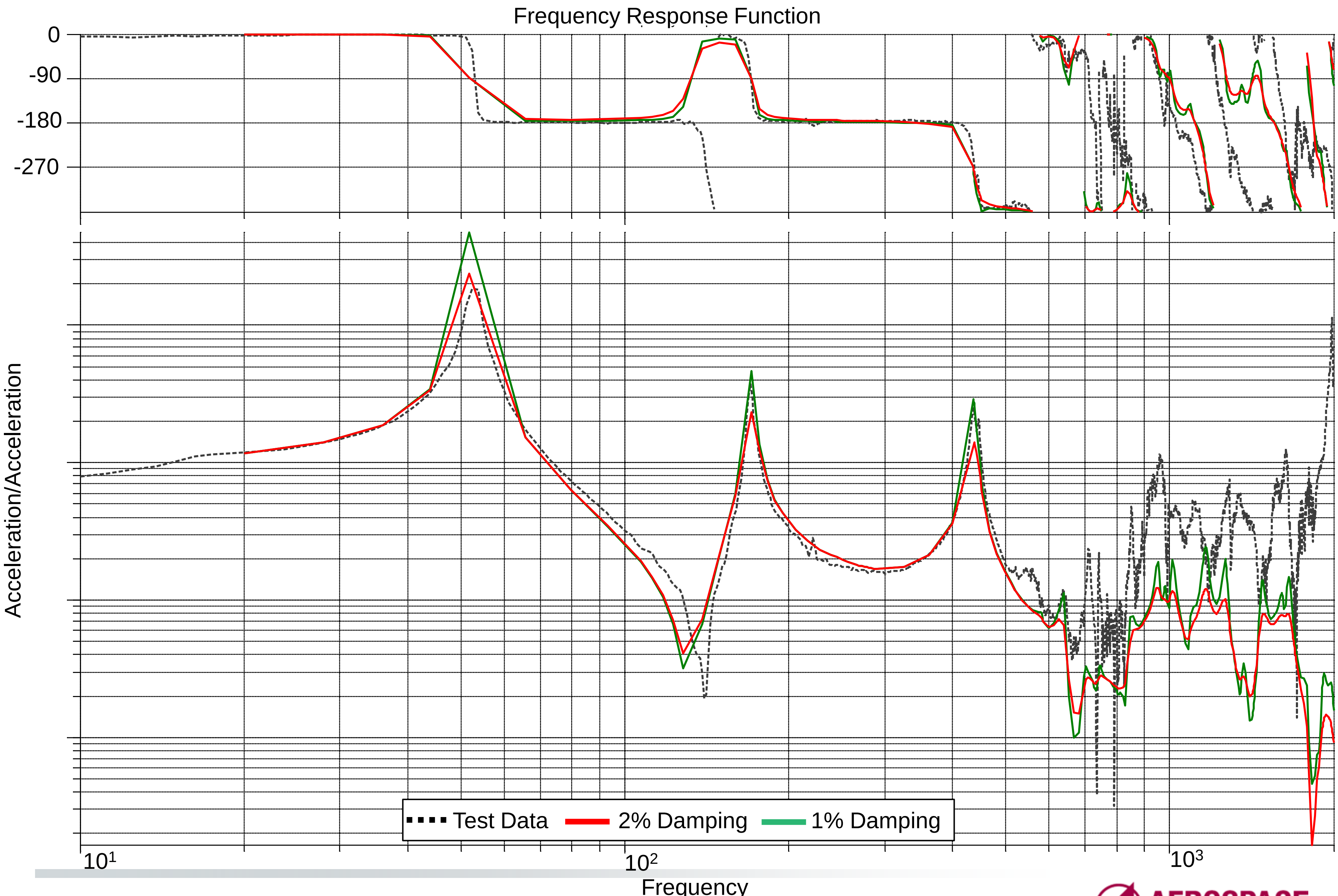



| | | | | Design Limits | | Set 1 | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 13 | MA213 | Pallet Frame, E | 9.90E+06 | 0.90 | 1.10 | 0.99 | 9.80E+06 |
| 14 | MA223 | Pallet Cross Brace, E | 9.90E+06 | 0.90 | 1.12 | 1.10 | 1.09E+07 |
| 15 | MA233 | Coldplate, E | 9.90E+06 | 0.85 | 1.12 | 1.10 | 1.09E+07 |
| 16 | MA263 | Horizontal Support, E | 9.90E+06 | 0.90 | 1.10 | 1.04 | 1.03E+07 |
| 17 | MA53 | Pyramids, E | 9.70E+06 | 0.90 | 1.10 | 0.98 | 9.51E+06 |
| 18 | PS324 | Coldplate, T | 0.125 | 0.95 | 1.07 | 1.05 | 0.131 |
| 19 | PS334 | Coldplate Outer Rib, T | 0.250 | 0.95 | 1.05 | 1.04 | 0.260 |
| 20 | PS344 | Coldplate Inner Rib, T | 0.125 | 0.95 | 1.07 | 1.05 | 0.131 |

XORTHO Matrix for Hard Mount Pallet

| | | | Analysis Modes | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Mode # | | 1 | 2 | 3 | 4 | 5 | 6 | Frequency |
| | | Freq (Hz) | 52.22 | 107.96 | 136.06 | 171.96 | 214.93 | 248.16 | % Diff. |
| Test Modes | 1 | 52.94 | 1.00 | | | | | | -1.37% |
| | 2 | 108.89 | | 0.99 | 0.10 | | | | -0.85% |
| | 3 | 136.38 | | | 0.97 | 0.15 | 0.19 | 0.15 | -0.23% |
| | 4 | 170.00 | | | | 0.99 | | | 1.16% |
| | 5 | 222.59 | | | | 0.15 | 0.86 | 0.58 | -3.44% |
| | 6 | 244.63 | 0.19 | | | 0.11 | 0.25 | 0.85 | 1.44% |

# Test vs. Analysis Mass Simulator FRF Comparison – X (Tangential) Input



# SM Small Isolated Pallet Correlation

- ATTUNE v2.1 was used for mode shape and frequency correlation in order to determine isolator stiffness properties
  - *Multiple optimization runs completed for each of the 10 test runs (All XORTHOs in Back-up)*
  - *X (Tangential) (3.65Grms, 7.35Grms, 14.7Grms, 21.9Grms)*
  - *Y (Radial) (3.65Grms, 7.35Grms, 14.7Grms)*
  - *Z (Axial) (5.2Grms, 10.4Grms, 20.8Grms)*
- Frequency response analysis comparisons were used to determine isolator damping properties
  - *Each test run was correlated (frequency/mode shape) which created 10 different FEMs with 10 different sets of isolator properties*
  - *For each of the 10 correlated models, four different damping values were applied during frequency response analyses and compared against the test data → This resulted in stiffness and damping as a function of isolator displacement*
  - *Stiffness/Damping properties showed an "asymptotic" behavior → asymptotic value used in EFT-1 Pallet*
- Isolator displacements recovered in EFT-1 frequency response analyses and compared back to correlated isolator displacement properties to validate isolators were performing/behaving consistently with the correlated results

# Correlation: SM Small Pallet Isolated – X (Tangential) Input

| XORTHO Matrix for Run83 X 21pt9g | | | | | | |
|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | |
| | Mode # | | **1** | **5** | **7** | Frequency |
| | | Freq (Hz) | 19.66 | 64.00 | 153.67 | Diff % |
| Test Modes | **1** | 19.63 | 0.99 | | | 0.1% |
| | **2** | 64.38 | | 0.99 | | -0.6% |
| | **3** | 168.13 | | | 0.96 | -8.6% |

| | | | | Design Limits | | Set 4 - X 21.9Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 1.34 | 348 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.00 | 260 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 2.16 | 2376 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 1.27 | 330 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.00 | 260 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 2.16 | 2376 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.10 | 1.09E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.02 | 1.02E+07 |

# Correlation: SM Small Pallet Isolated – Y (Radial) Input

| XORTHO Matrix for Run93 Y 14pt7g | | | | | | |
|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | |
| | Mode # | | **2** | **6** | **10** | Frequency |
| | | Freq (Hz) | 27.18 | 74.21 | 226.49 | Diff % |
| Test Modes | **1** | 26.88 | 1.00 | | | 1.1% |
| | **2** | 75.58 | | 0.94 | 0.12 | -1.8% |
| | **3** | 227.23 | | | 0.98 | -0.3% |

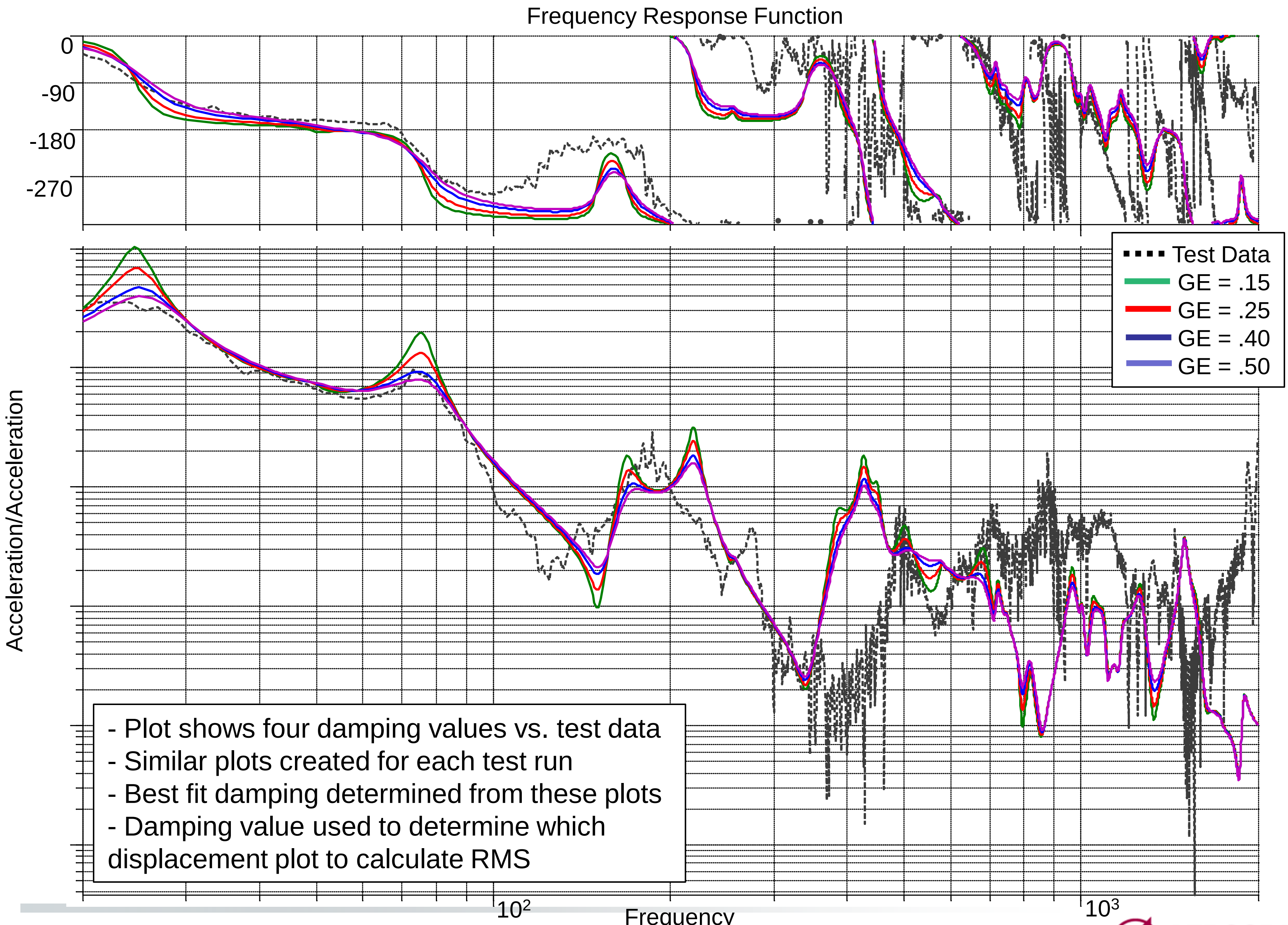
| | | | | Design Limits | | Set 3 - Y 14.7Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 1.85 | 481 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.98 | 515 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 2.52 | 2772 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 1.85 | 481 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.94 | 504 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 2.52 | 2772 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.09 | 1.08E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.03 | 1.03E+07 |

# Correlation: SM Small Pallet Isolated – Z (Axial) Input

| XORTHO Matrix for Run125 Z 20pt8g | | | | | |
|---|---|---|---|---|---|
| | | | Analysis Modes | | |
| | Mode # | | **3** | **10** | Frequency |
| | | Freq (Hz) | 31.47 | 223.54 | Diff % |
| Test Modes | **1** | 31.52 | 0.99 | | -0.2% |
| | **3** | 230.17 | | 0.98 | -2.9% |

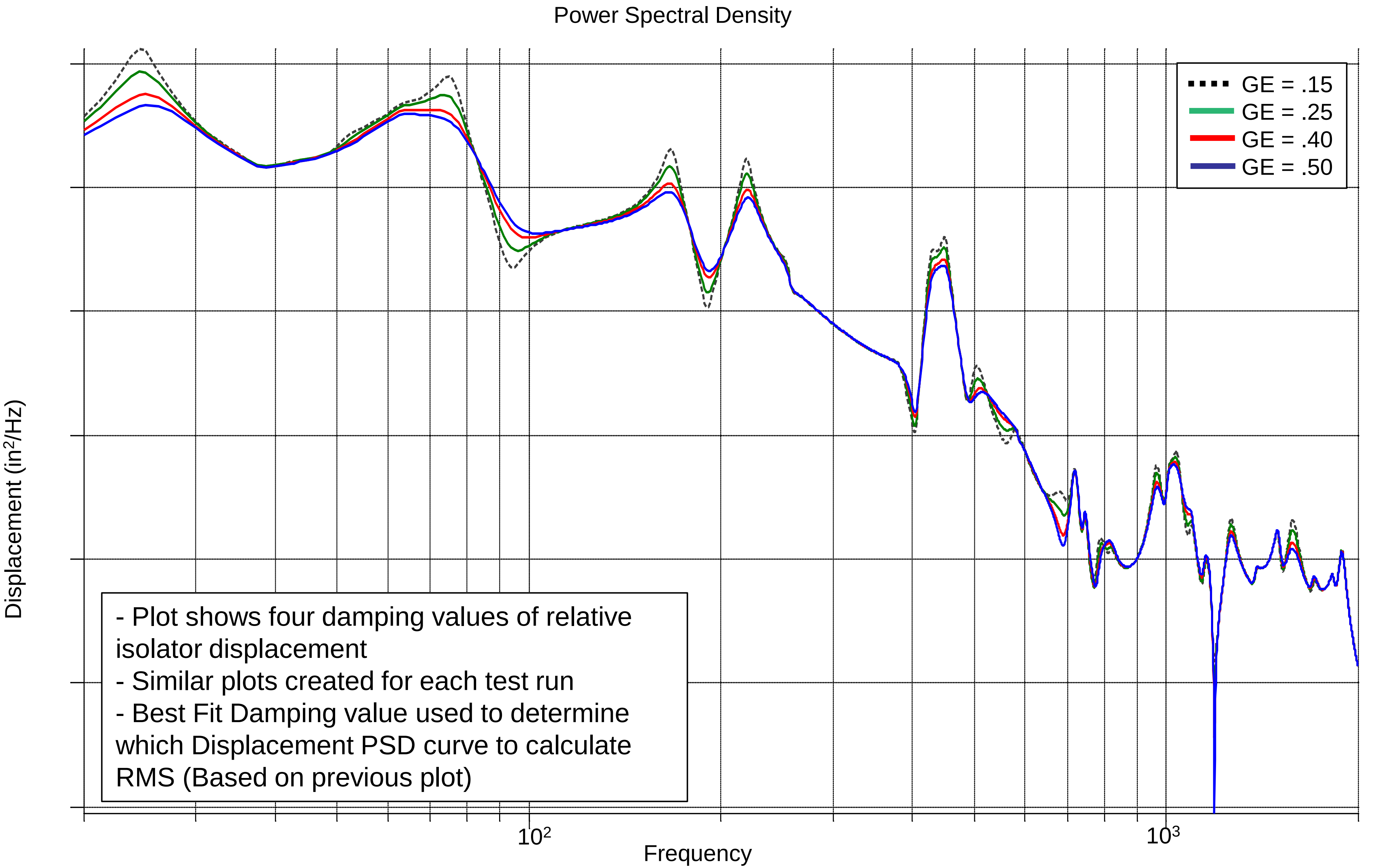
| | | | | Design Limits | | Set 4 - Z 20.8Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 1.26 | 328 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.04 | 270 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 1.26 | 1386 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 1.26 | 328 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.00 | 260 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 1.26 | 1386 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.04 | 1.03E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.01 | 1.01E+07 |

# Test vs. Analysis Damping Comparison – X (Tangential) Axis Mass Simulator



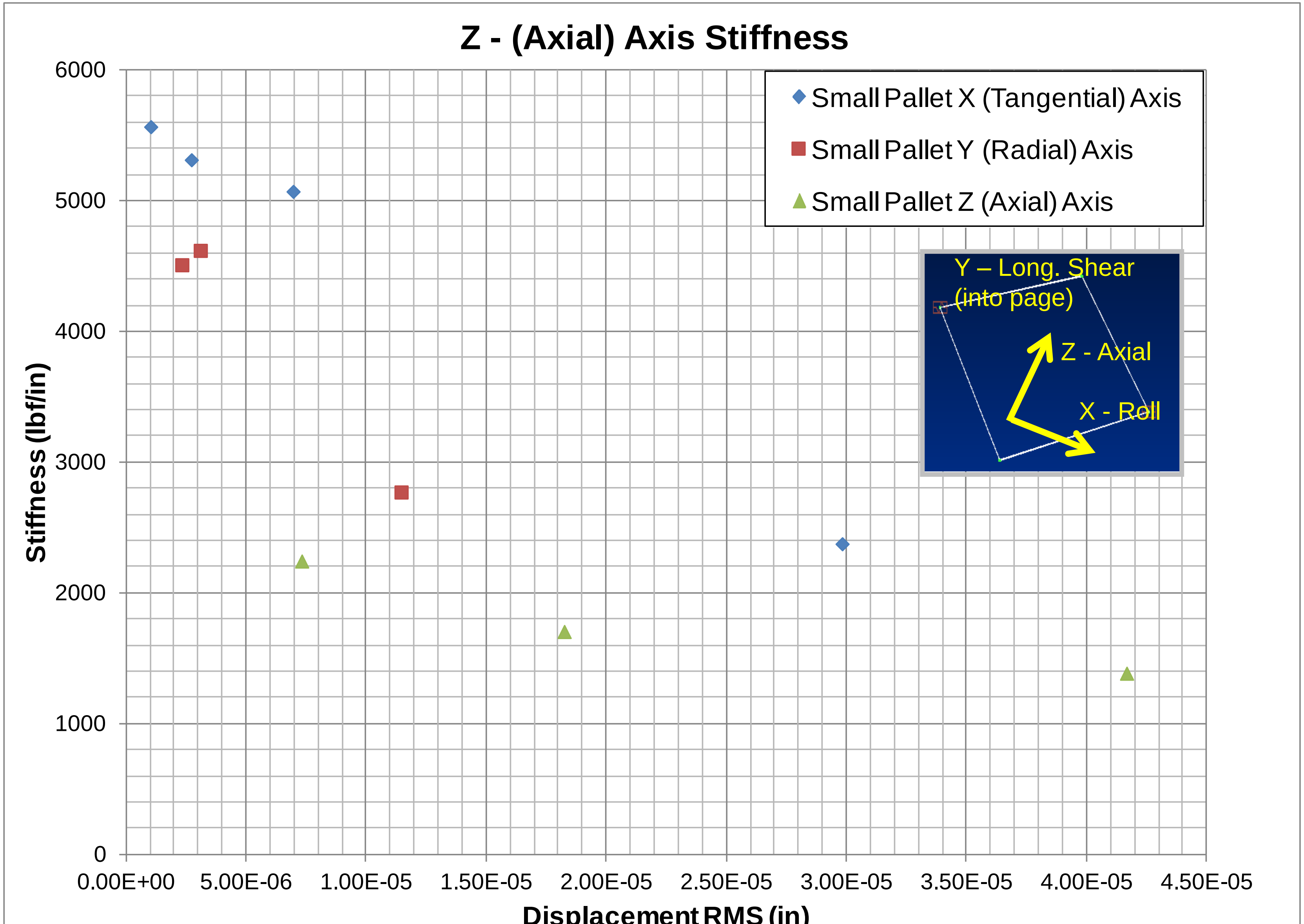

- Plot shows four damping values vs. test data
- Similar plots created for each test run
- Best fit damping determined from these plots
- Damping value used to determine which displacement plot to calculate RMS

# Isolator Displacement PSD Comparison – X (Tang.) Axis



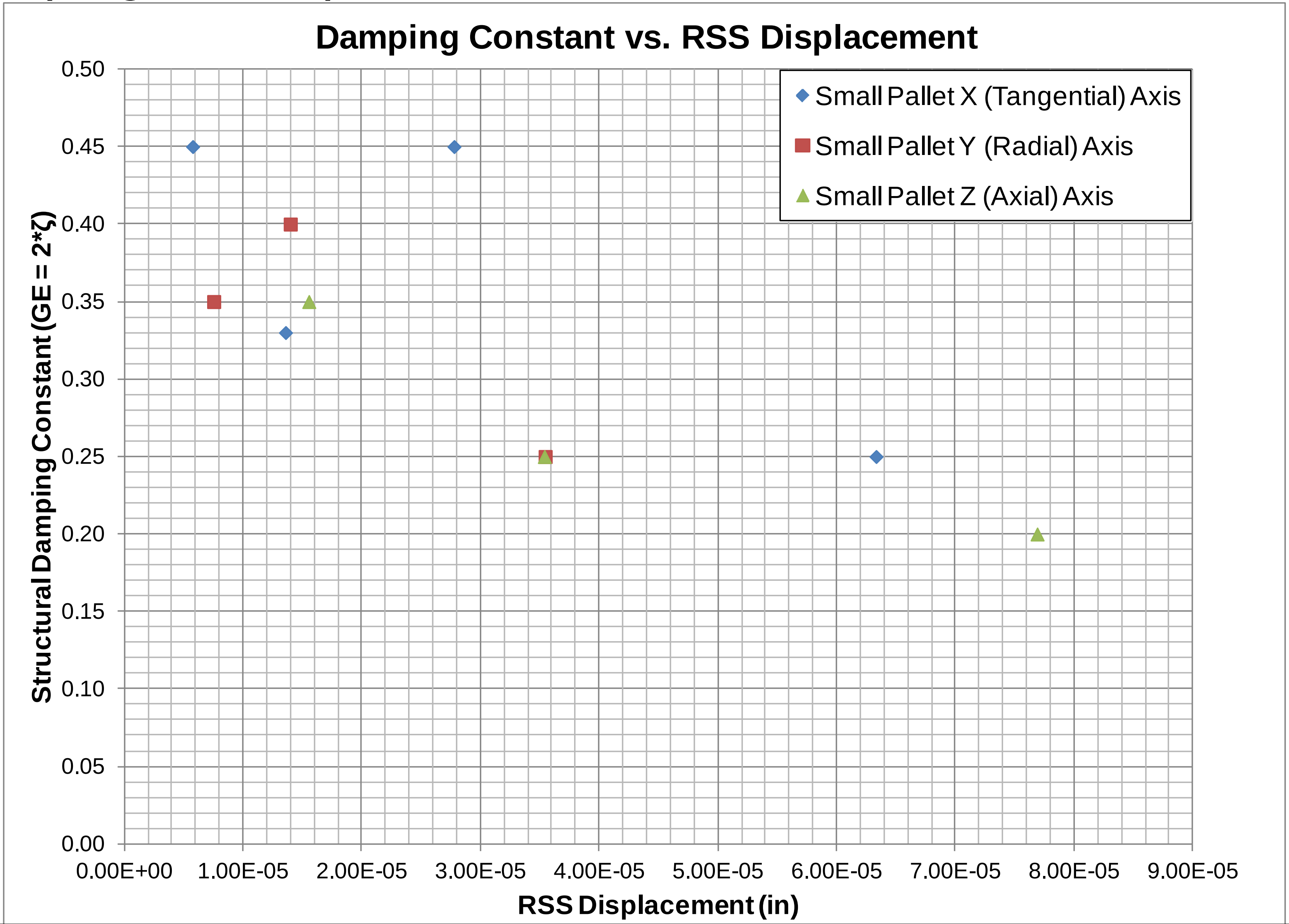

- Plot shows four damping values of relative isolator displacement
- Similar plots created for each test run
- Best Fit Damping value used to determine which Displacement PSD curve to calculate RMS (Based on previous plot)

# Stiffness vs. Displacement




Downward trend in stiffness as displacement increases → Approaches Manufacturer Spec

# Damping vs. Displacement




Downward trend in damping as displacement increases – not as apparent as stiffness

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# EFT-1 Configuration

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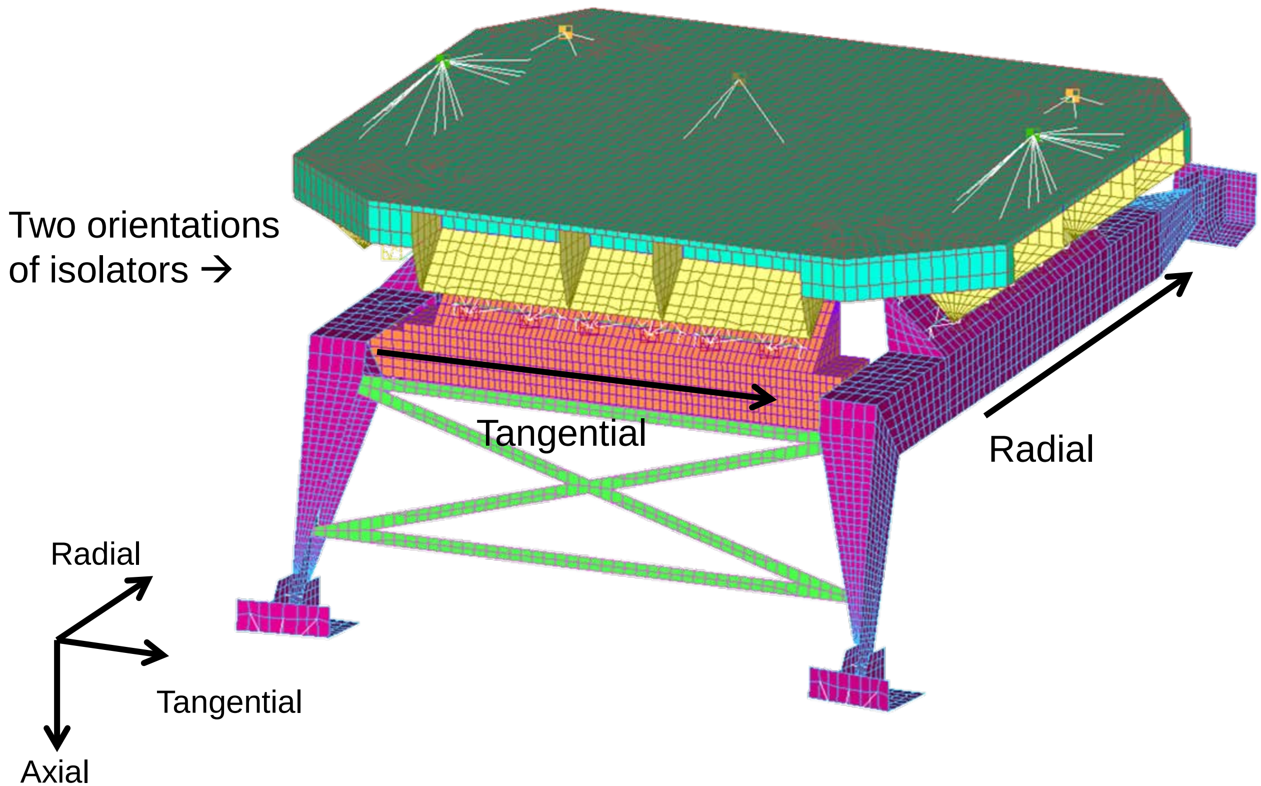
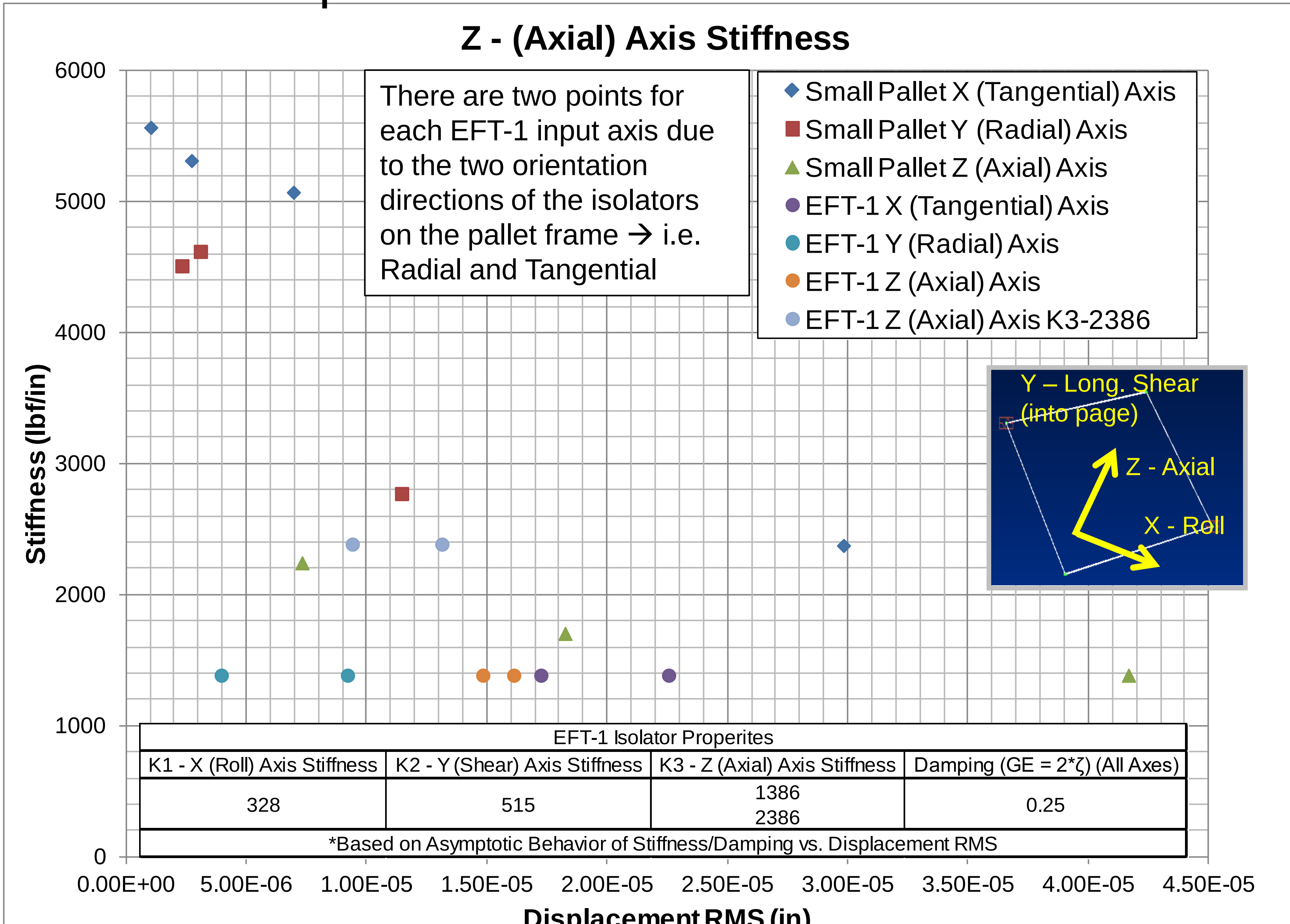
# EFT-1 Pallet Configuration




Mass: 185.52 lbs

| MODEL SUMMARY | |
|---|---|
| ENTRY NAME | NUMBER OF ENTRIES |
| ---------- | ----------------- |
| CBAR | 1028 |
| CBUSH | 96 |
| CHEXA | 7221 |
| CONM2 | 5 |
| CORD2C | 2 |
| CORD2R | 10 |
| CORD2S | 1 |
| CPENTA | 18 |
| CQUAD4 | 11016 |
| CTRIA3 | 188 |
| EIGRL | 1 |
| GRID | 23098 |
| MAT1 | 4 |
| MPC | 288 |
| MPCADD | 1 |
| PARAM | 4 |
| PBAR | 1 |
| PBARL | 1 |
| PBUSH | 4 |
| PSHELL | 5 |
| PSOLID | 1 |
| RBE2 | 198 |
| RBE3 | 192 |

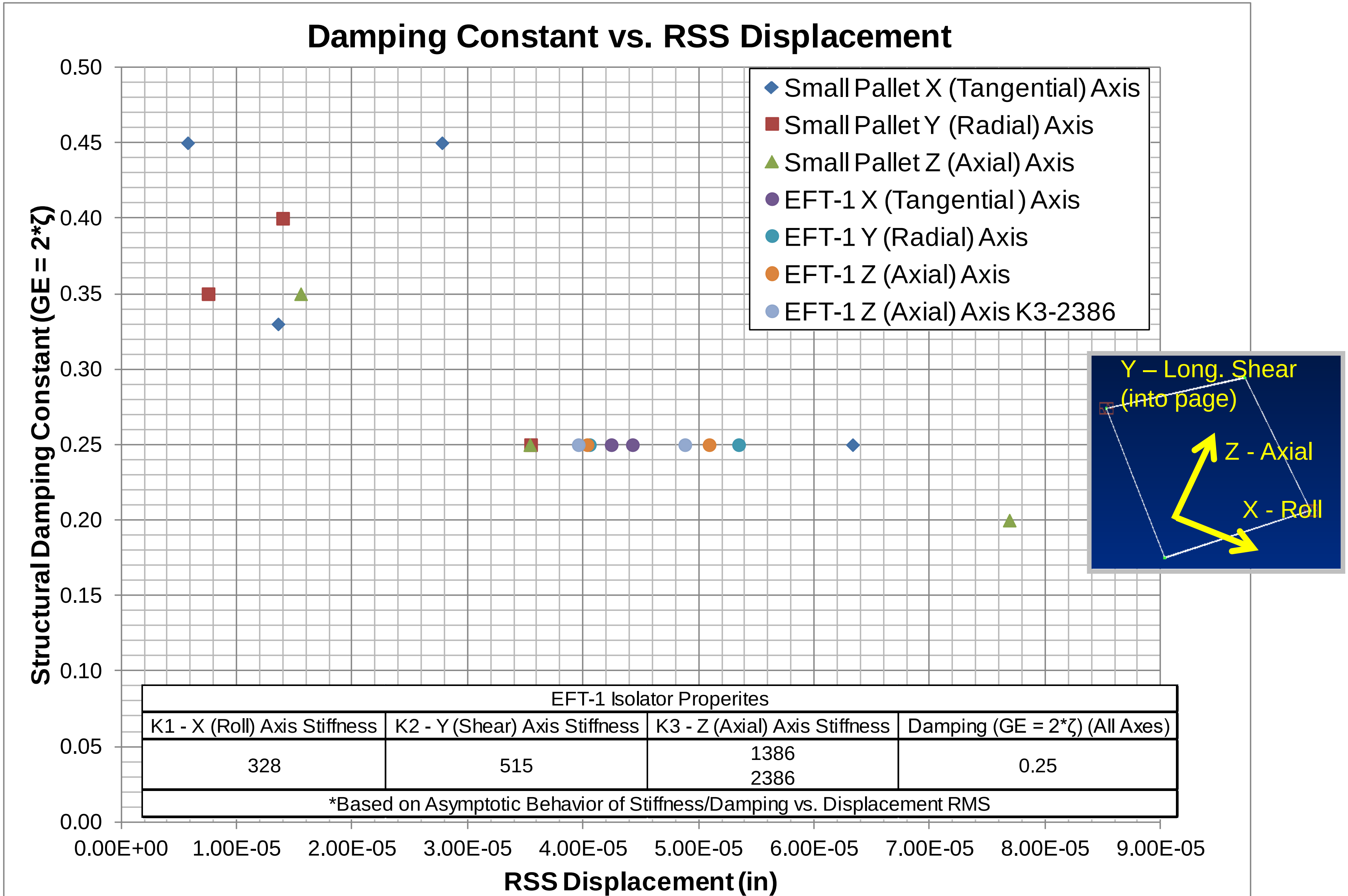
# Stiffness vs. Displacement w/ EFT-1 Results




| EFT-1 Isolator Properites | | | |
|---|---|---|---|
| K1 - X (Roll) Axis Stiffness | K2 - Y (Shear) Axis Stiffness | K3 - Z (Axial) Axis Stiffness | Damping (GE = 2*ζ) (All Axes) |
| 328 | 515 | 1386<br>2386 | 0.25 |
| *Based on Asymptotic Behavior of Stiffness/Damping vs. Displacement RMS | | | |

EFT-1 displacement results initially below correlation results → Axial Stiffness increased

# Damping vs. Displacement w/ EFT-1 Results




| EFT-1 Isolator Properites | | | |
|---|---|---|---|
| K1 - X (Roll) Axis Stiffness | K2 - Y (Shear) Axis Stiffness | K3 - Z (Axial) Axis Stiffness | Damping (GE = 2*ζ) (All Axes) |
| 328 | 515 | 1386<br>2386 | 0.25 |
| *Based on Asymptotic Behavior of Stiffness/Damping vs. Displacement RMS | | | |

EFT-1 displacements lie within the correlation results



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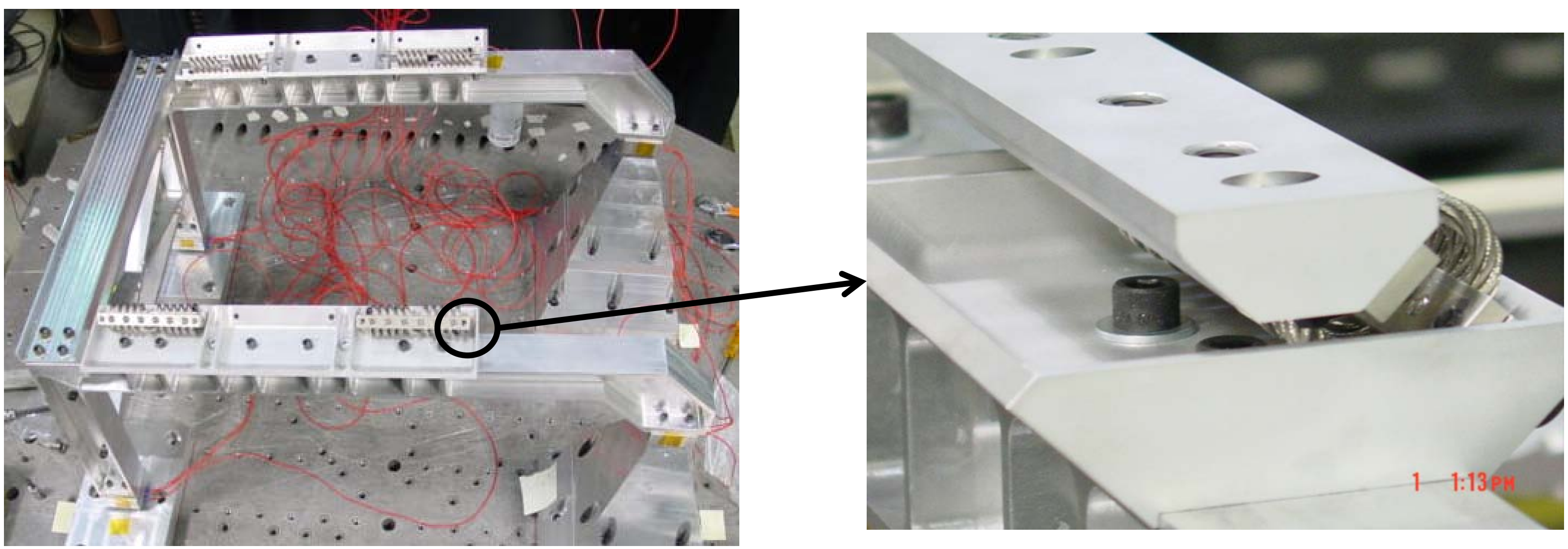
# Conclusion

# Conclusions

- March 2010 pallet development test proved feasibility of wire rope isolators
- Wire rope isolator properties developed as a function of isolator displacement
- Stepping block approach for correlation (hard mount pallet correlation, single isolator test, followed by isolated pallet correlation) was necessary to produce valid results
- Test data shows wire rope isolators soften as input level (relative displacement of isolator) increases
- Correlated analysis results illustrate same softening characteristics as test data
- Correlated isolator properties along with EFT-1 FEM will be used to develop more accurate/less conservative avionics component flight environments
  - *Caution must still be used (vary stiffness/damping to account for scatter and uncertainties) as no testing is planned for the EFT-1 isolated pallet design*



# Acknowledgements


- Jeff O’Brien – Lockheed Martin/Denver
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- Nancy Tengler – Lockheed Martin/Denver
- Drew Roussel – Lockheed Martin/Michoud
- Tom Goodnight – NASA GRC
- Lee Philley – NASA JSC

# Thank you

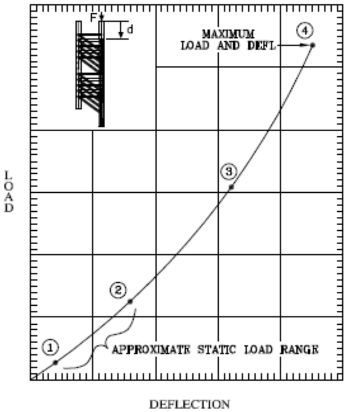
Spacecraft and Launch Vehicle Dynamic Environments Workshop

# BACK UP CHARTS

AEROSPACE

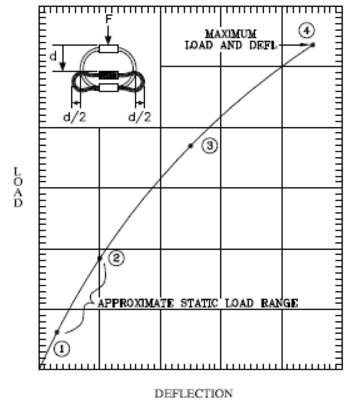
# M6-120-100 Manufacturer Spec

SHEAR



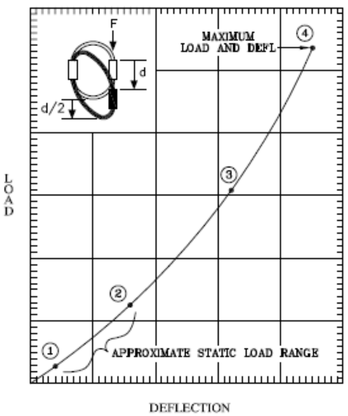

| PART NO. | 1 | | 2 | | 3 | | 4 | | $K_v$ (VIBR) (lbs/in) | $K_s$ (SHOCK) (lbs/in) |
|---|---|---|---|---|---|---|---|---|---|---|
| | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | | |
| M6–120–10 | 52 | .05 | 123 | .10 | 230 | .18 | 625 | .35 | 1040 | 1280 |
| M6–130–10 | 40 | .05 | 93 | .10 | 190 | .22 | 490 | .45 | 800 | 870 |
| M6–140–10 | 31 | .05 | 72 | .10 | 175 | .28 | 465 | .55 | 620 | 640 |
| M6–150–10 | 24 | .05 | 53 | .10 | 145 | .35 | 390 | .70 | 480 | 500 |
| M6–160–10 | 17 | .05 | 40 | .10 | 140 | .40 | 370 | .80 | 340 | 360 |
| M6–170–10 | 14 | .05 | 33 | .10 | 120 | .45 | 335 | .90 | 280 | 300 |

COMPRESSION



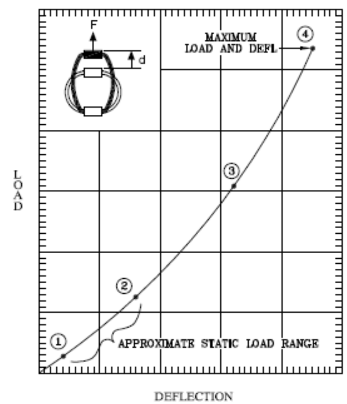

| PART NO. | 1 | | 2 | | 3 | | 4 | | $K_v$ (VIBR) (lbs/in) | $K_s$ (SHOCK) (lbs/in) |
|---|---|---|---|---|---|---|---|---|---|---|
| | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | | |
| M6–120–10 | 210 | .05 | 370 | .10 | 580 | .18 | 750 | .35 | 4200 | 3200 |
| M6–130–10 | 160 | .05 | 280 | .10 | 470 | .22 | 610 | .45 | 3200 | 2150 |
| M6–140–10 | 125 | .05 | 215 | .10 | 440 | .28 | 580 | .55 | 2500 | 1575 |
| M6–150–10 | 95 | .05 | 160 | .10 | 360 | .35 | 490 | .70 | 1900 | 1025 |
| M6–160–10 | 70 | .05 | 120 | .10 | 350 | .40 | 460 | .80 | 1400 | 875 |
| M6–170–10 | 55 | .05 | 100 | .10 | 300 | .45 | 420 | .90 | 1100 | 675 |

ROLL




| PART NO. | 1 | | 2 | | 3 | | 4 | | $K_v$ (VIBR) (lbs/in) | $K_s$ (SHOCK) (lbs/in) |
|---|---|---|---|---|---|---|---|---|---|---|
| | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | | |
| M6–120–10 | 52 | .05 | 123 | .10 | 230 | .18 | 625 | .35 | 1040 | 1280 |
| M6–130–10 | 40 | .05 | 93 | .10 | 190 | .22 | 490 | .45 | 800 | 870 |
| M6–140–10 | 31 | .05 | 72 | .10 | 175 | .28 | 465 | .55 | 620 | 640 |
| M6–150–10 | 24 | .05 | 53 | .10 | 145 | .35 | 390 | .70 | 480 | 500 |
| M6–160–10 | 17 | .05 | 40 | .10 | 140 | .40 | 370 | .80 | 340 | 360 |
| M6–170–10 | 14 | .05 | 33 | .10 | 120 | .45 | 335 | .90 | 280 | 300 |

TENSION




| PART NO. | 1 | | 2 | | 3 | | 4 | | $K_v$ (VIBR) (lbs/in) | $K_s$ (SHOCK) (lbs/in) |
|---|---|---|---|---|---|---|---|---|---|---|
| | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | LOAD (lbs) | DEFL (in) | | |
| M6–120–10 | 230 | .05 | 520 | .10 | 950 | .15 | 1740 | .20 | 4600 | 6330 |
| M6–130–10 | 180 | .05 | 390 | .10 | 700 | .15 | 1400 | .25 | 3600 | 4670 |
| M6–140–10 | 140 | .05 | 300 | .10 | 530 | .15 | 1320 | .30 | 2800 | 3530 |
| M6–150–10 | 105 | .05 | 225 | .10 | 440 | .18 | 1080 | .35 | 2100 | 2420 |
| M6–160–10 | 75 | .05 | 170 | .10 | 420 | .20 | 1050 | .40 | 1500 | 2100 |
| M6–170–10 | 60 | .05 | 140 | .10 | 360 | .23 | 900 | .45 | 1200 | 1570 |

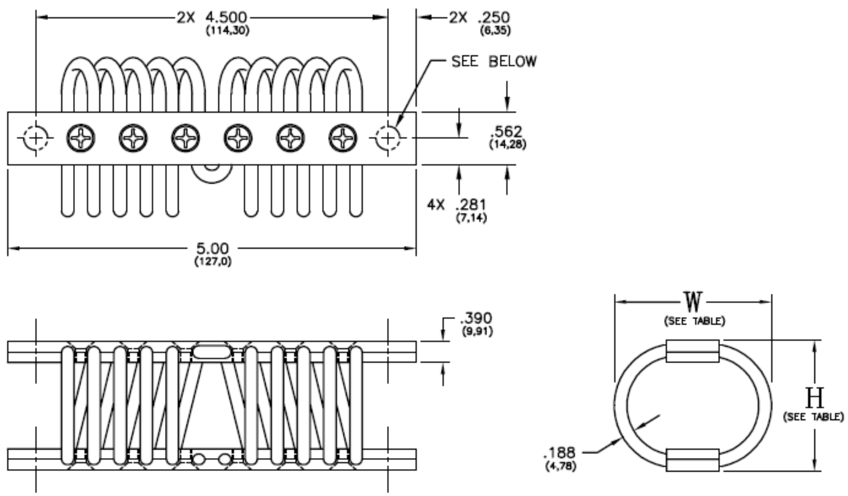
ULTIMATE BREAKING STRENGTH –3k lbs

-Local coordinate systems used lined up with the shear, roll and compression stiffness values provided by the manufacturer
- Tension and Compression values averaged
-DATA from www.isolator.com (Isolation Dynamics Corp.)

# M6-120-10 Design Data

DESIGN DATA • **M6** SERIES • 3/16" DIAMETER CABLE

SHOCK & VIBRATION ISOLATORS




**FEATURES:**

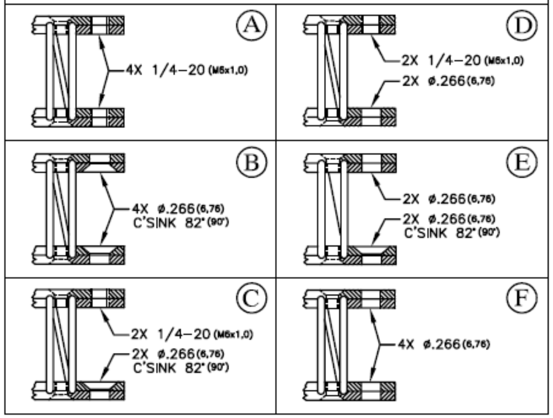
- RUGGED ALL METAL CONSTRUCTION
- UNEQUALLED TEMP. RANGE: −200°F TO 500°F
- THREE AXIS CAPABILITY
- MAINTENANCE FREE
- FAIL SAFE DESIGN
- HIGH DAMPING: C/Cc ≃.20
- EXCEPTIONAL RELIABILITY AND LONG LIFE

**MATERIALS/FINISHES:**

- CABLE: 300 SERIES SS PER MIL−W−83420 OR RR−W−410
- SCREWS: 300 SERIES SS PER MS51959−28
- INSERTS: 300 SERIES SS (ALUM BARS ONLY)
- RETAINER BARS: SEE BELOW

| PART NUMBER | DIMENSIONS, in. H ±.03 | DIMENSIONS, in. W (REF) | ISOLATOR WEIGHT (SEE NOTE 3) |
|---|---|---|---|
| M6 − 120 − 10 − [ ] | 1.20 (30,5) | 1.40 (35,6) | .42lbs (.19kg) |
| M6 − 130 − 10 − [ ] | 1.30 (33,0) | 1.50 (38,1) | .44lbs (.20kg) |
| M6 − 140 − 10 − [ ] | 1.40 (35,6) | 1.60 (40,6) | .46lbs (.21kg) |
| M6 − 150 − 10 − [ ] | 1.50 (38,1) | 1.70 (43,2) | .47lbs (.21kg) |
| M6 − 160 − 10 − [ ] | 1.60 (40,6) | 1.80 (45,7) | .49lbs (.22kg) |
| M6 − 170 − 10 − [ ] | 1.70 (43,2) | 1.90 (48,2) | .51lbs (.23kg) |

MOUNTING HOLE OPTIONS




-DATA from www.isolator.com (Isolation Dynamics Corp.)



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# SM Avionics Pallet Test Levels

- Unit under test was exposed to three distinct ‘g’ levels in each axis
- The FRF data acquired during testing showed increased distortion (high damping and softening characteristics) as input level was increased → wire rope isolators are known to behave non-linearly

| Small Pallet | | | | | | |
|---|---|---|---|---|---|---|
| | Tangential (X Axis) | | Radial (Yaxis) | | Axial (Z Axis) | |
| Set | Grms Level | Test Run | Grms Level | Test Run | Grms Level | Test Run |
| 1 | 3.65 | Run83 18dB Down | 3.65 | Run91 6dB Down | 5.2 | Run125 12 dB Down |
| 2 | 7.35 | Run83 12dB Down | 7.35 | Run91 0 dB Down | 10.4 | Run125 6 dB Down |
| 3 | 14.6 | Run83 6dB Down | 14.7 | Run93 0 dB Down | N/A | N/A |
| 4 | 21.9 | Run84 3dB Down | N/A | N/A | 20.8 | Run125 0 dB Down |

# SM Pallet Hard Mounted

*Modal Effective Mass Table*

| SM Pallet Hard Mounted | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MODE | FREQ | T1 Tangential | T2 Radial | T3 Axial | R1 | R2 | R3 | Mode Description |
| NO. | Hz | FRAC | FRAC | FRAC | FRAC | FRAC | FRAC | |
| 1 | **52.24** | 0.47 | 0.00 | 0.00 | 0.00 | 0.69 | 0.10 | |
| 2 | **108.03** | 0.00 | 0.12 | 0.31 | 0.00 | 0.00 | 0.00 | |
| 3 | **136.31** | 0.00 | 0.33 | 0.06 | 0.31 | 0.00 | 0.00 | |
| 4 | 172.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | |
| **5** | **215.44** | 0.00 | 0.03 | 0.05 | 0.01 | 0.00 | 0.00 | |
| 6 | 248.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.02 | |
| 7 | 264.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 8 | 290.26 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 9 | 292.65 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 10 | 298.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 11 | 440.62 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 12 | 440.83 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 13 | 454.81 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 14 | 514.68 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 15 | 545.58 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 16 | 605.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 17 | 617.16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 18 | 626.55 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | |
| 19 | 681.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 20 | 703.54 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| | | | | | | | | |
| SUM MEF | | 0.49 | 0.49 | 0.44 | 0.34 | 0.74 | 0.15 | |



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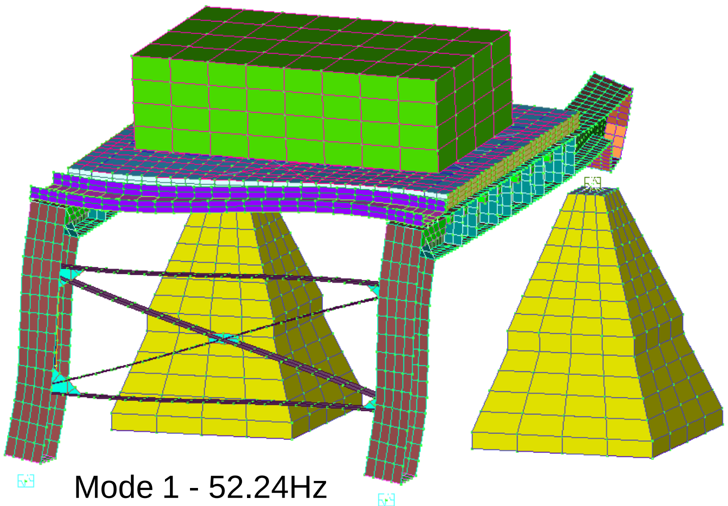
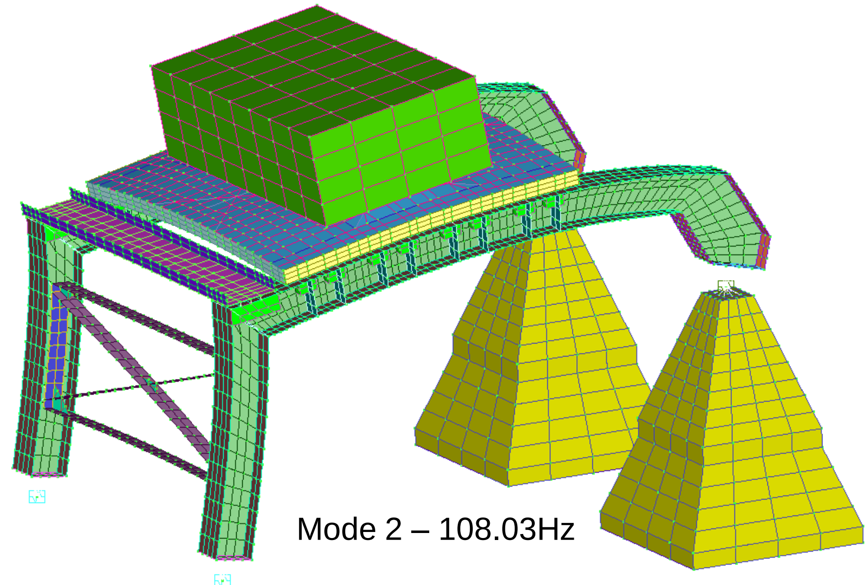
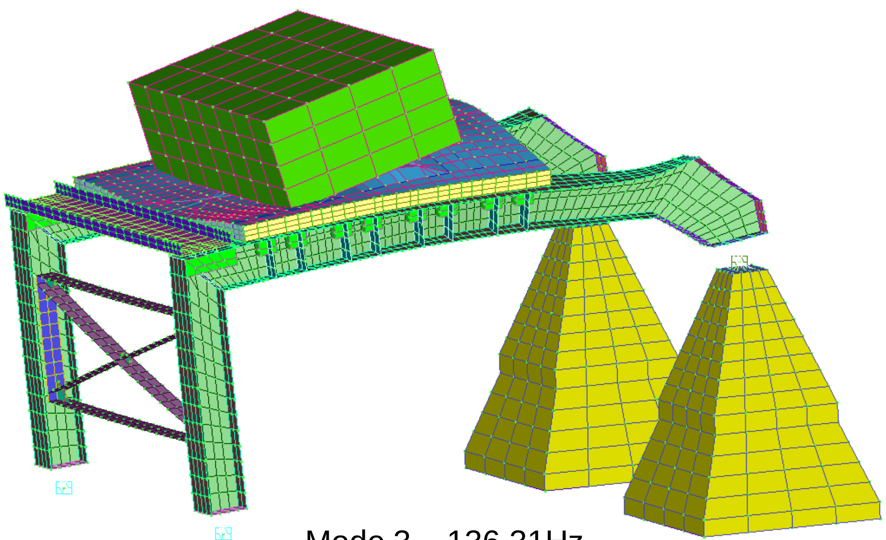
# Hard Mounted Mode Shapes



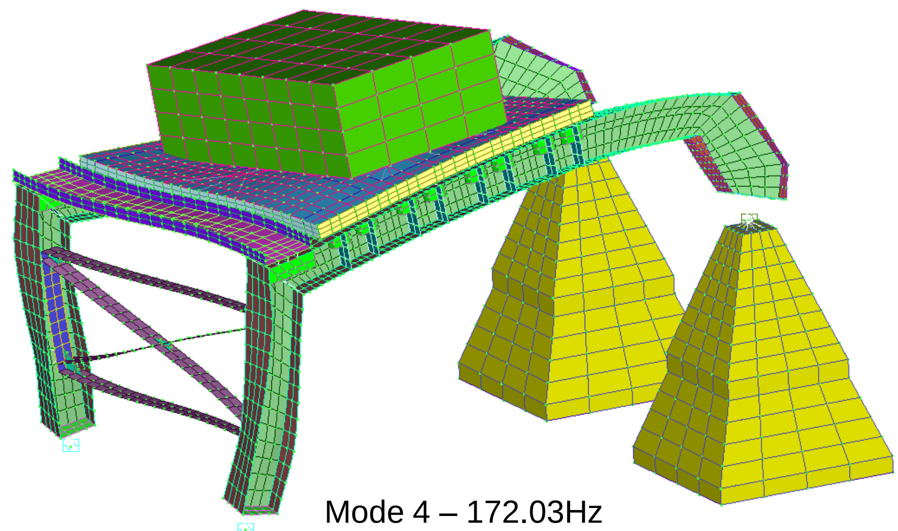
Mode 1 - 52.24Hz



Mode 2 – 108.03Hz



Mode 3 – 136.31Hz



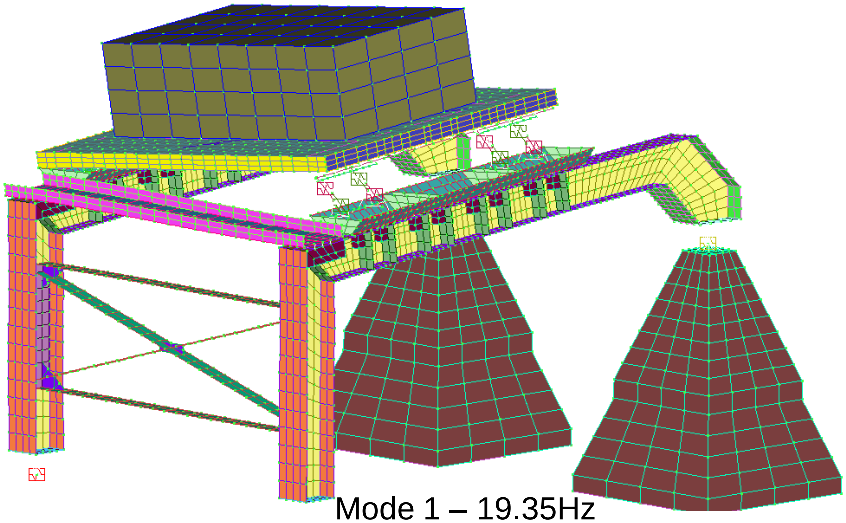
Mode 4 – 172.03Hz

# SM Pallet Isolated

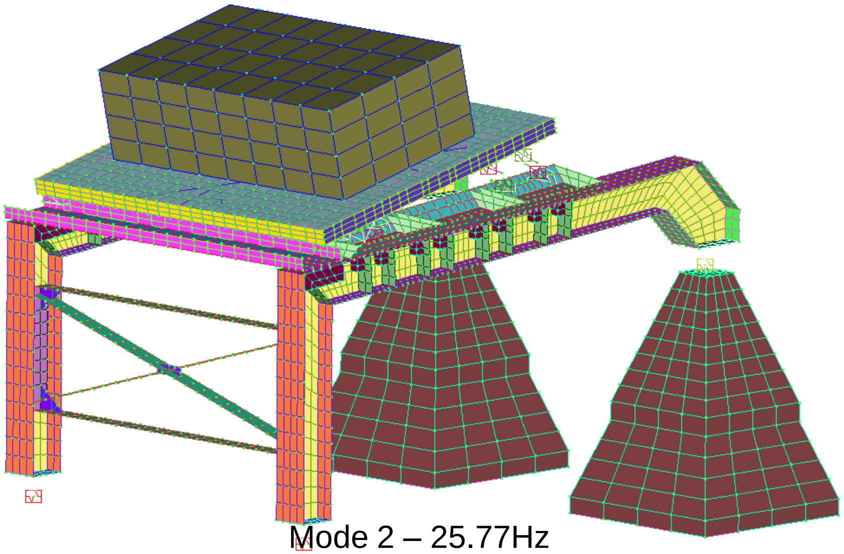
*Modal Effective Mass Table – Using Asymptotic Stiffness Values from Displacement vs. Stiffness Curves*

| Small Pallet - Asymptotic Stiffness | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MODE | FREQ | T1 Tangential | T2 Radial | T3 Axial | R1 | R2 | R3 | Mode Description |
| NO. | Hz | FRAC | FRAC | FRAC | FRAC | FRAC | FRAC | |
| 1 | **19.35** | 0.38 | 0.00 | 0.00 | 0.00 | 0.71 | 0.08 | Tang. Isolation Mode |
| 2 | **25.77** | 0.00 | 0.37 | 0.00 | 0.29 | 0.00 | 0.00 | Radial Isolation Mode |
| 3 | **31.62** | 0.00 | 0.00 | 0.40 | 0.04 | 0.00 | 0.00 | Axial Isolation Mode |
| 4 | **49.32** | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | Torsion Mode |
| 5 | 57.66 | 0.06 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | |
| 6 | 61.78 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 7 | **144.92** | 0.04 | 0.00 | 0.00 | 0.00 | 0.05 | 0.01 | Pallet Frame |
| 8 | 154.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 9 | 205.32 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | |
| 10 | 225.37 | 0.00 | 0.07 | 0.01 | 0.01 | 0.00 | 0.00 | |
| 11 | 254.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 12 | 261.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 13 | 275.77 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 14 | 277.99 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 15 | 302.92 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | |
| 16 | 315.35 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 17 | 320.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 18 | 402.62 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 19 | 406.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 20 | 431.61 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| | | | | | | | | |
| SUM MEF | | 0.51 | 0.48 | 0.43 | 0.35 | 0.77 | 0.15 | |

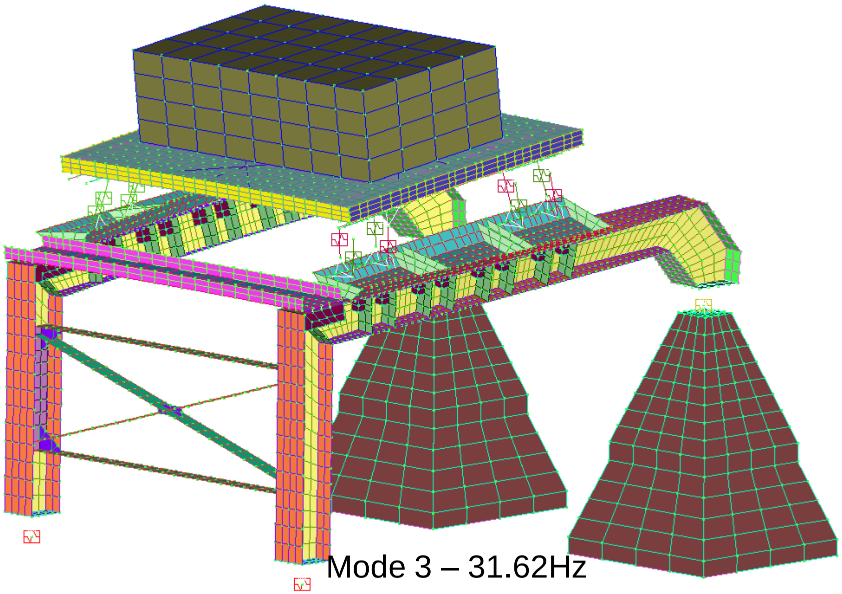
# SM Pallet Isolated Mode Shapes (1)



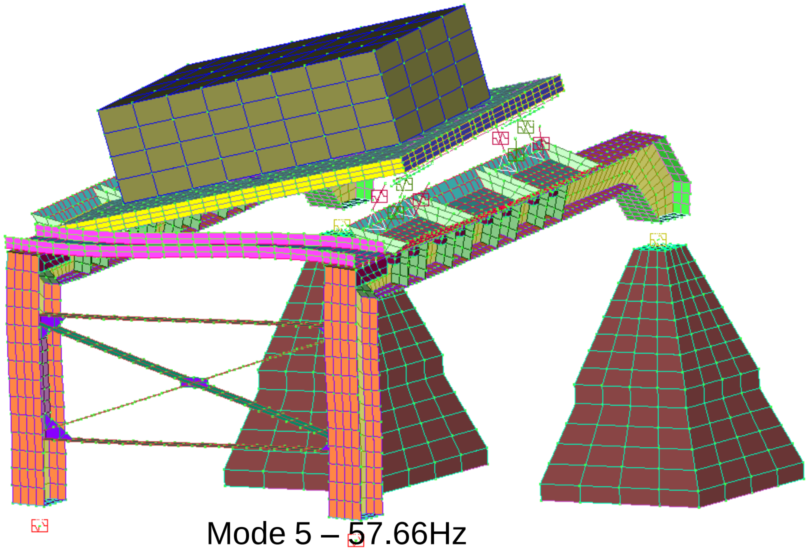
Mode 1 – 19.35Hz



Mode 2 – 25.77Hz

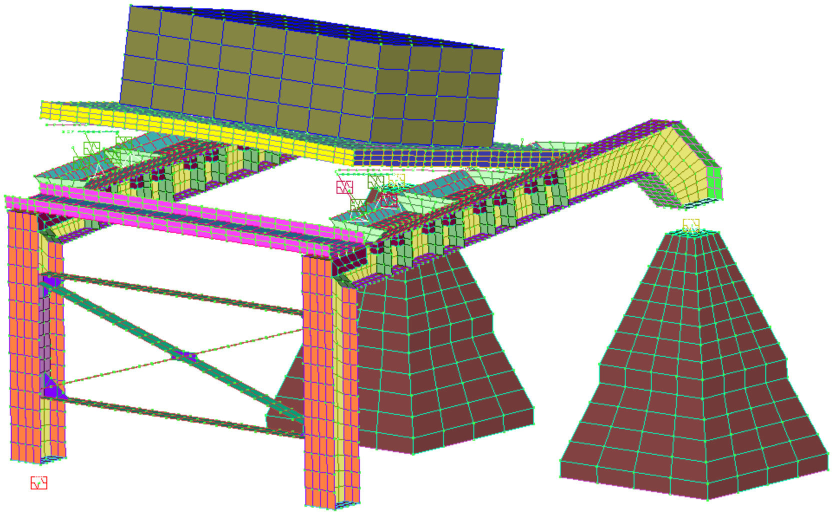


Mode 3 – 31.62Hz

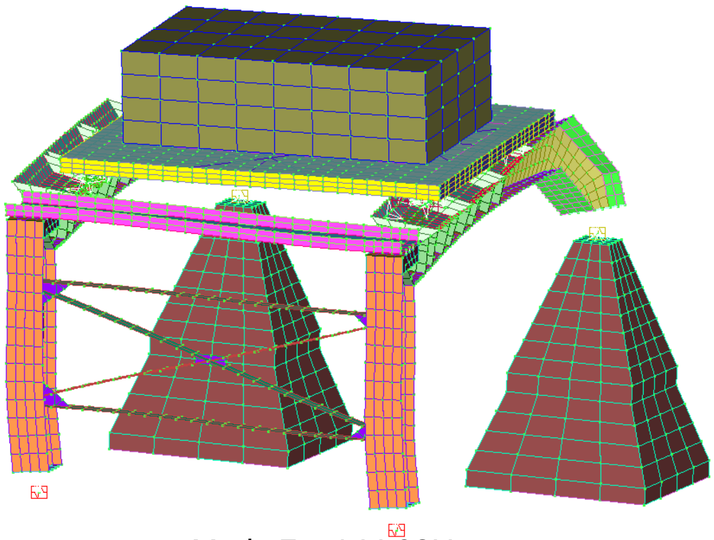


Mode 5 – 57.66Hz

# SM Pallet Isolated Mode Shapes (2)



Mode 6 – 61.78Hz



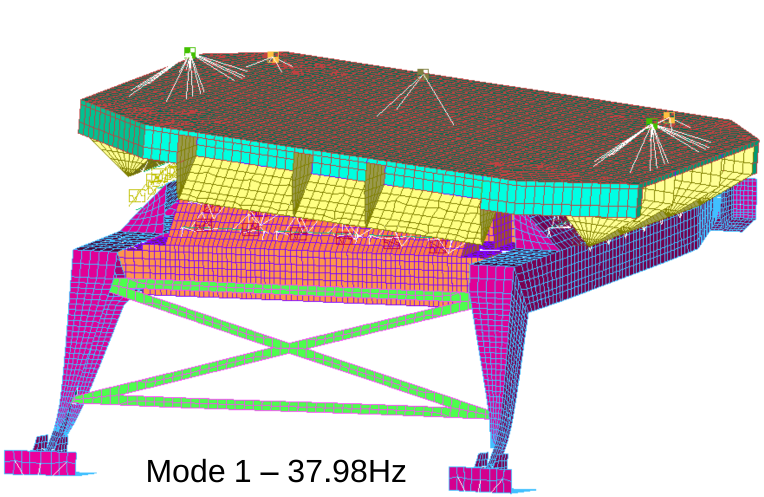
Mode 7 – 144.92Hz

# EFT-1 Pallet

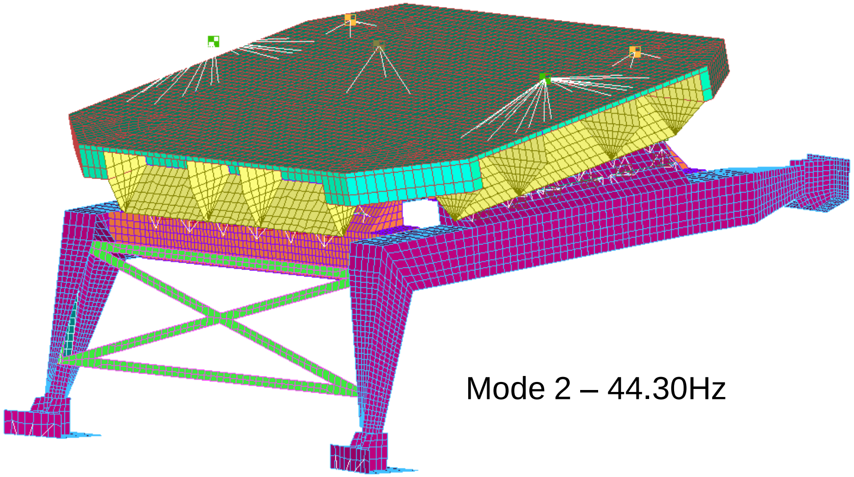
## *Modal Effective Mass Table*

| OFT1 Pallet - Correlated Results | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MODE | FREQ | T1 Tangential | T2 Radial | T3 Axial | R1 | R2 | R3 | Mode Description |
| NO. | Hz | FRAC | FRAC | FRAC | FRAC | FRAC | FRAC | |
| 1 | **37.98** | 0.00 | 0.72 | 0.06 | 0.76 | 0.06 | 0.71 | |
| 2 | **44.30** | 0.00 | 0.05 | 0.59 | 0.00 | 0.57 | 0.05 | |
| 3 | **59.70** | 0.83 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | |
| 4 | 69.13 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | |
| 5 | **75.02** | 0.00 | 0.13 | 0.02 | 0.15 | 0.02 | 0.14 | |
| 6 | **104.89** | 0.00 | 0.01 | 0.14 | 0.00 | 0.14 | 0.01 | |
| 7 | 135.60 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | |
| 8 | 172.72 | 0.00 | 0.04 | 0.00 | 0.04 | 0.00 | 0.05 | |
| 9 | 200.18 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 10 | 208.93 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 11 | 217.85 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 12 | 257.78 | 0.00 | 0.01 | 0.00 | 0.02 | 0.00 | 0.01 | |
| 13 | 270.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 14 | 292.60 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 15 | **295.24** | 0.07 | 0.00 | 0.02 | 0.00 | 0.01 | 0.00 | |
| 16 | 372.43 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 17 | 384.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 18 | 393.98 | 0.00 | 0.00 | 0.05 | 0.00 | 0.05 | 0.00 | |
| 19 | 408.40 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| 20 | 415.73 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | |
| | | | | | | | | |
| SUM MEF | | 0.92 | 0.98 | 0.88 | 0.99 | 0.87 | 0.98 | |

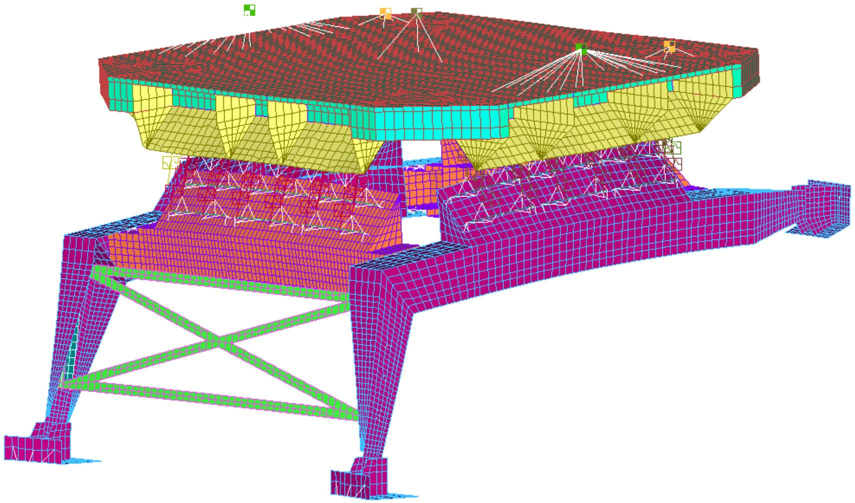
# EFT-1 Pallet Mode Shapes(1)



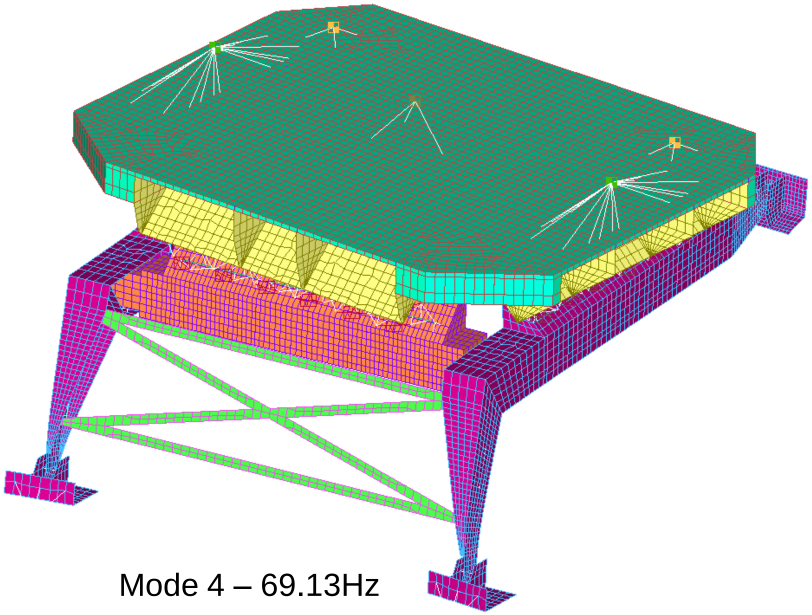
Mode 1 – 37.98Hz



Mode 2 – 44.30Hz



Mode 3 – 59.70Hz



Mode 4 – 69.13Hz



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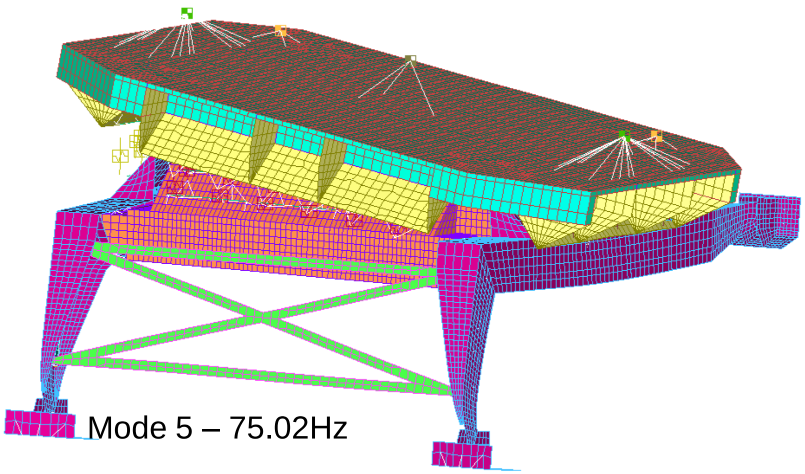
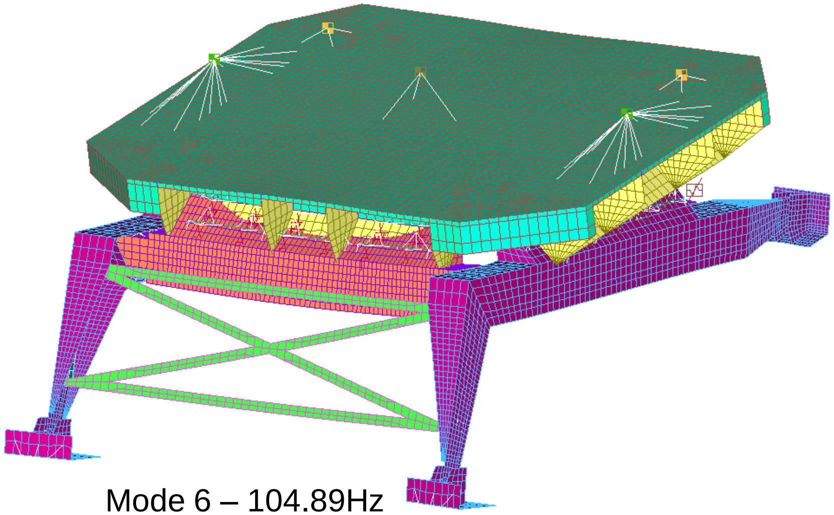
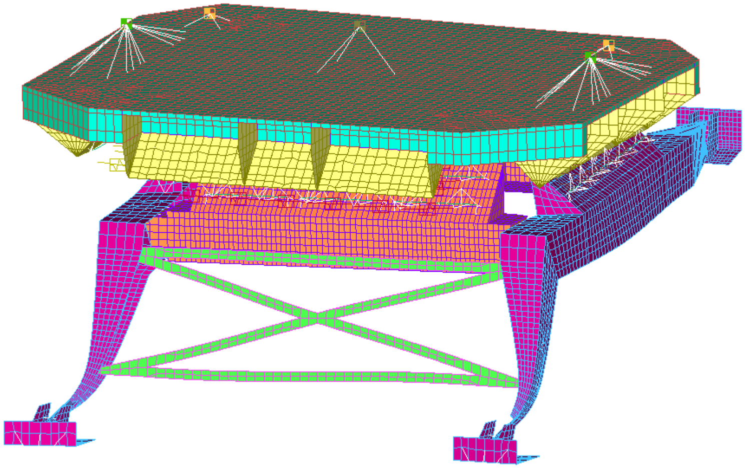
# EFT-1 Pallet Mode Shapes(2)



Mode 5 – 75.02Hz



Mode 6 – 104.89Hz



Mode 8 – 172.72Hz



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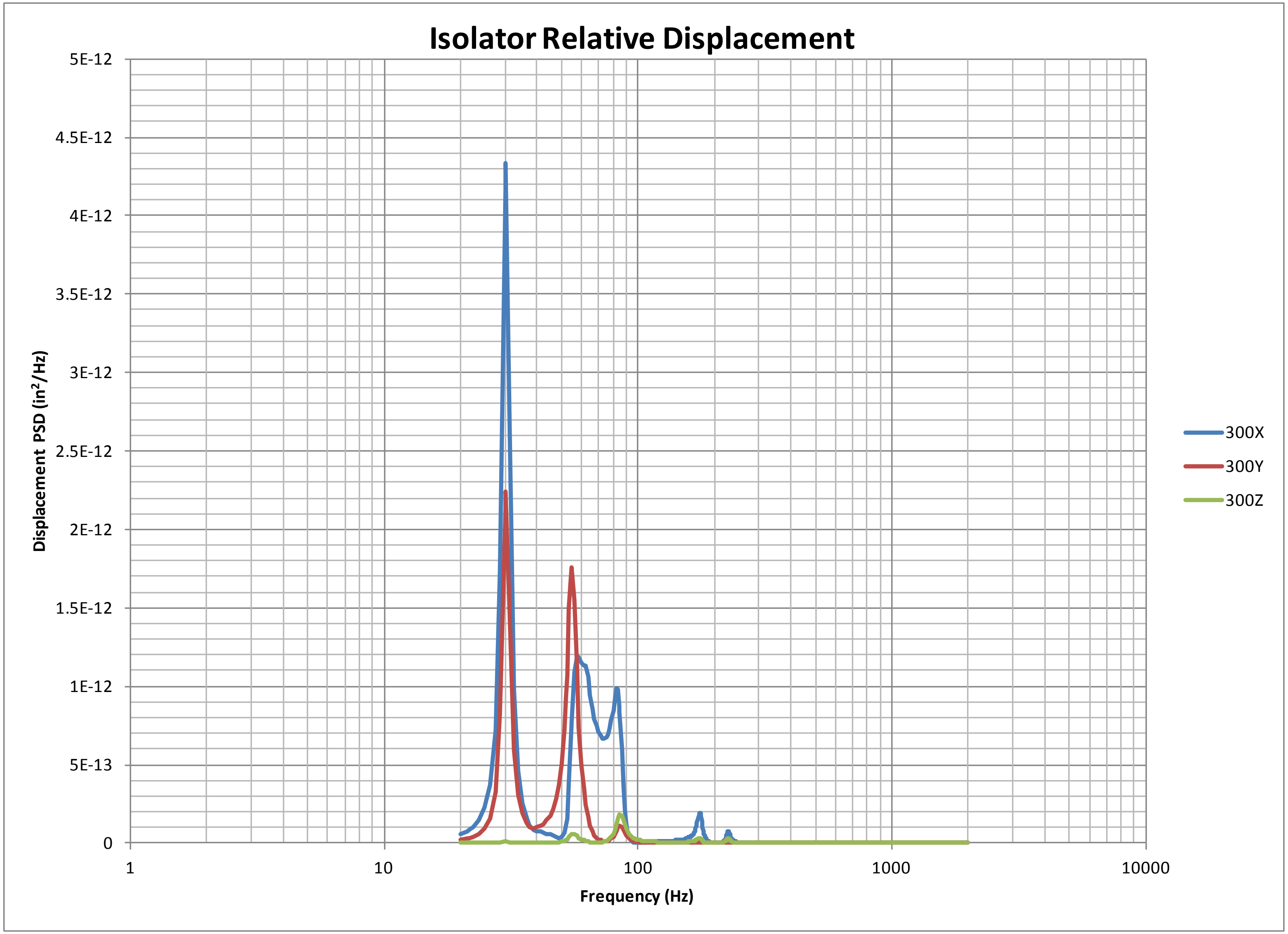
# Correlation (6)

*Isolator Displacement*

- MPC relationship created to determine relative displacement of the isolator CBUSH elements → this node was recovered in the analysis runs
- FRF plots of the Analysis FEM (with 4 different Damping Constants) overlaid with the test data → first mode was used to fit the best damping constant value
- Using the "best fit damping value" the Displacement RMS was calculated from the relative displacement node in the MPC relationship in each response axis → The displacement RMS was calculated from 0-100Hz (See Plots on Next Page)
- In the cases where an in-between damping value was needed the displacement RMS values from two different runs (i.e. two different damping values) were averaged
- The stiffness values found during the ATTUNE FEM correlation process were plotted vs. the displacement RMS values calculated above
- Damping values determined as "best fit" were plotted vs. RSS of the displacement RMS values ($SQRT(dispRMSX^2 + dispRMSY^2 + dispRMSZ^2)$)

# Isolator Relative Displacement - X (Tangential) Input



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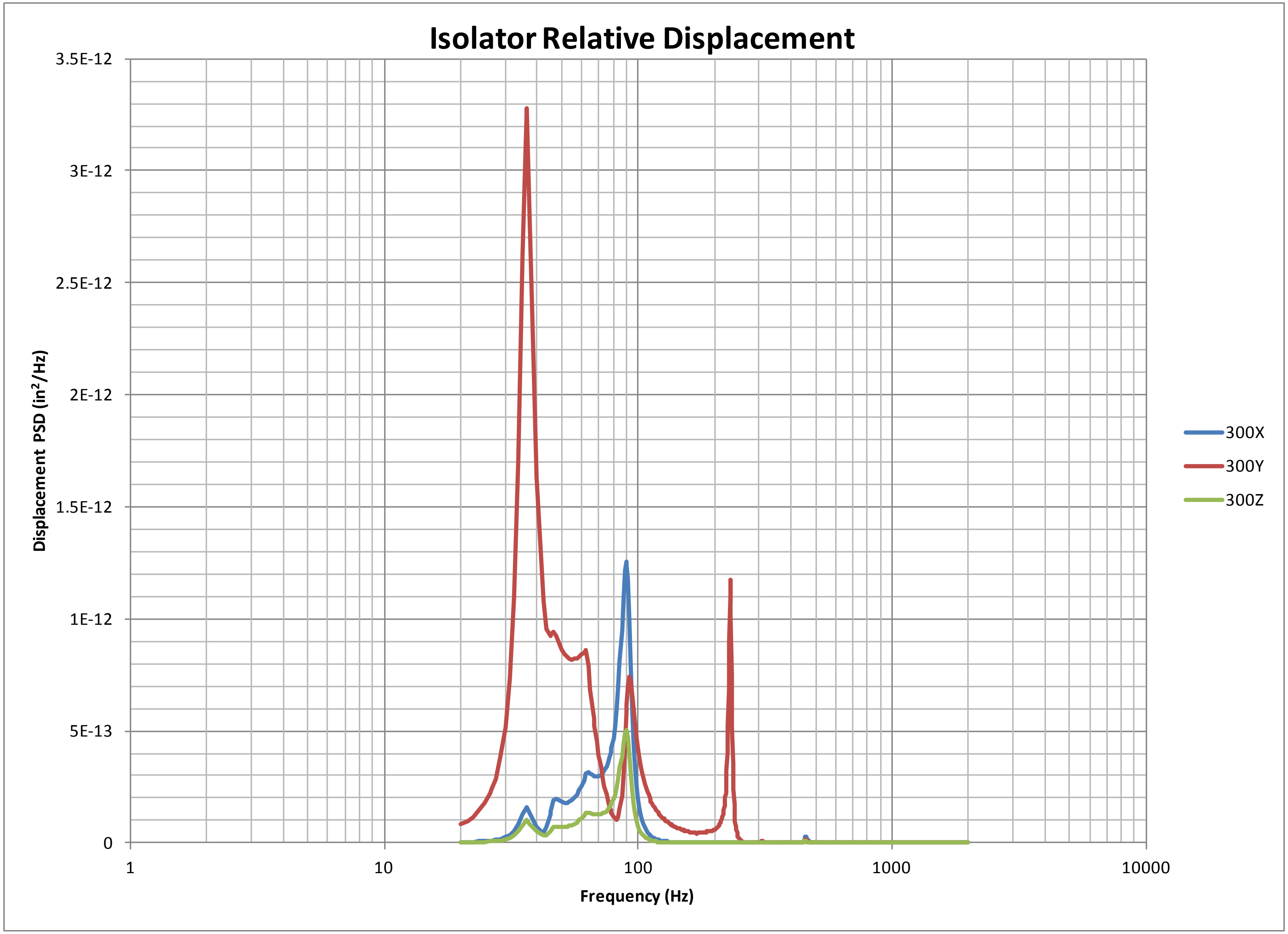
# Isolator Relative Displacement - Y (Radial) Input



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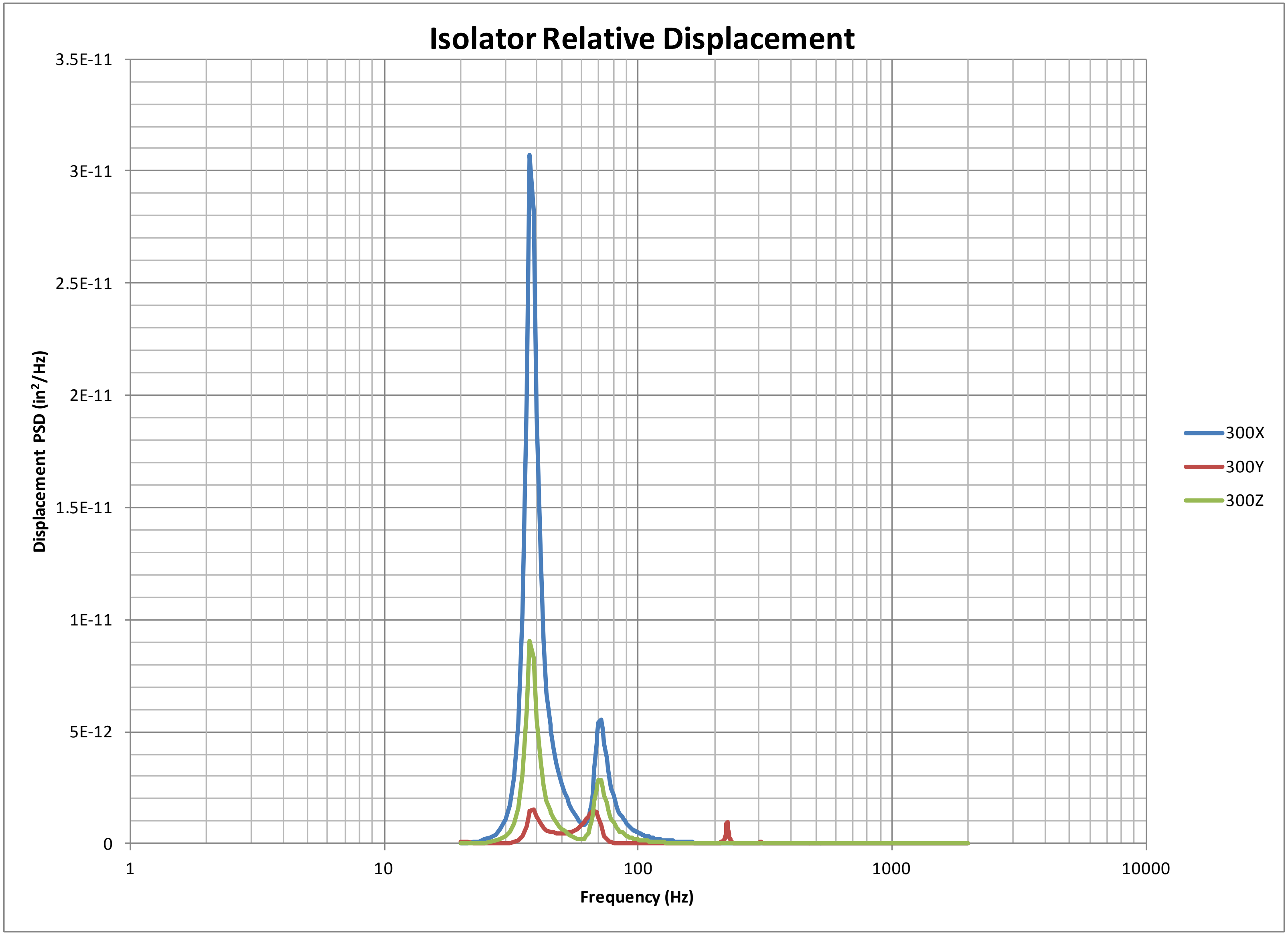
# Isolator Relative Displacement - Z (Axial) Input



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# Small Pallet Set 1 – X (Tangential) 3.65 Grms Results

| XORTHO Matrix for Run83 X 3pt65g | | | | | | |
|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | |
| | Mode # | | **2** | **5** | **7** | Frequency |
| | | Freq (Hz) | 30.17 | 84.67 | 176.07 | Diff % |
| Test Modes | **1** | 30.15 | 0.99 | | | 0.1% |
| | **2** | 84.65 | | 0.99 | | 0.0% |
| | **3** | 194.88 | | 0.12 | 0.96 | -9.7% |

| | | | | Design Limits | | Set 1 - X 3.65Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 5.84 | 1518 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.08 | 281 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 5.06 | 5566 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 5.84 | 1518 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.08 | 281 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 5.03 | 5533 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.10 | 1.09E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.07 | 1.07E+07 |

# Small Pallet Set 2 – X (Tangential) 7.35 Grms Results

| XORTHO Matrix for Run83 X 7pt35g | | | | | | |
|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | |
| | Mode # | | **2** | **5** | **7** | Frequency |
| | | Freq (Hz) | 29.22 | 82.40 | 173.84 | Diff % |
| Test Modes | **1** | 28.92 | 0.99 | | | 1.0% |
| | **2** | 84.00 | | 0.99 | | -1.9% |
| | **3** | 186.89 | | 0.13 | 0.96 | -7.0% |

| | | | | Design Limits | | Set 2 - X 7.35Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 4.95 | 1287 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.08 | 281 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 4.83 | 5313 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 4.95 | 1287 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.08 | 281 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 4.89 | 5379 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.10 | 1.09E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.07 | 1.07E+07 |

# Small Pallet Set 3 – X (Tangential) 14.7 Grms Results

| XORTHO Matrix for Run83 X 14pt7g | | | | | | |
|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | |
| | Mode # | | **2** | **5** | **7** | Frequency |
| | | Freq (Hz) | 24.48 | 75.50 | 167.51 | Diff % |
| Test Modes | **1** | 23.71 | 1.00 | | | 3.3% |
| | **2** | 75.00 | | 0.99 | | 0.7% |
| | **3** | 185.97 | | | 0.96 | -9.9% |

| | | | | Design Limits | | Set 3 - X 14.7Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 2.45 | 637 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.04 | 270 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 4.61 | 5071 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 2.49 | 647 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.00 | 260 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 4.57 | 5027 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.10 | 1.09E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.05 | 1.05E+07 |

# Small Pallet Set 1 – Y (Radial) 3.65 Grms Results

| XORTHO Matrix for Run91 Y 3pt65g | | | | | | |
|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | |
| | Mode # | | **2** | **6** | **10** | Frequency |
| | | Freq (Hz) | 36.30 | 90.29 | 231.32 | Diff % |
| Test Modes | **1** | 35.58 | 1.00 | | | 2.0% |
| | **2** | 94.26 | | 0.95 | 0.13 | -4.2% |
| | **3** | 236.25 | | | 0.98 | -2.1% |

| | | | | Design Limits | | Set 1 - Y 3.65Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 3.22 | 837 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 3.80 | 988 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 4.10 | 4510 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 3.22 | 837 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 3.84 | 998 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 4.14 | 4554 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.10 | 1.09E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.04 | 1.04E+07 |

# Small Pallet Set 2 – Y (Radial) 7.35 Grms Results

| XORTHO Matrix for Run91 Y 7pt35g | | | | | | |
|---|---|---|---|---|---|---|
| | | | Analysis Modes | | | |
| | Mode # | | **2** | **6** | **10** | Frequency |
| | | Freq (Hz) | 31.21 | 88.17 | 228.95 | Diff % |
| Test Modes | **1** | 30.00 | 1.00 | | | 4.0% |
| | **2** | 93.13 | 0.15 | 0.93 | 0.12 | -5.3% |
| | **3** | 236.41 | | | 0.98 | -3.2% |

| | | | | Design Limits | | Set 2 - Y 7.35Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 3.25 | 845 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 2.55 | 663 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 4.20 | 4620 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 3.25 | 845 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 2.55 | 663 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 4.20 | 4620 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.10 | 1.09E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.04 | 1.04E+07 |



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# Small Pallet Set 1 – Z (Axial) 5.2 Grms Results

| XORTHO Matrix for Run125 Z 5pt2g | | | | | |
|---|---|---|---|---|---|
| | | | Analysis Modes | | |
| | Mode # | | **3** | **10** | Frequency |
| | | Freq (Hz) | 37.53 | 224.55 | Diff % |
| Test Modes | **1** | 38.13 | 0.99 | | -1.5% |
| | **2** | 236.25 | | 0.98 | -5.0% |

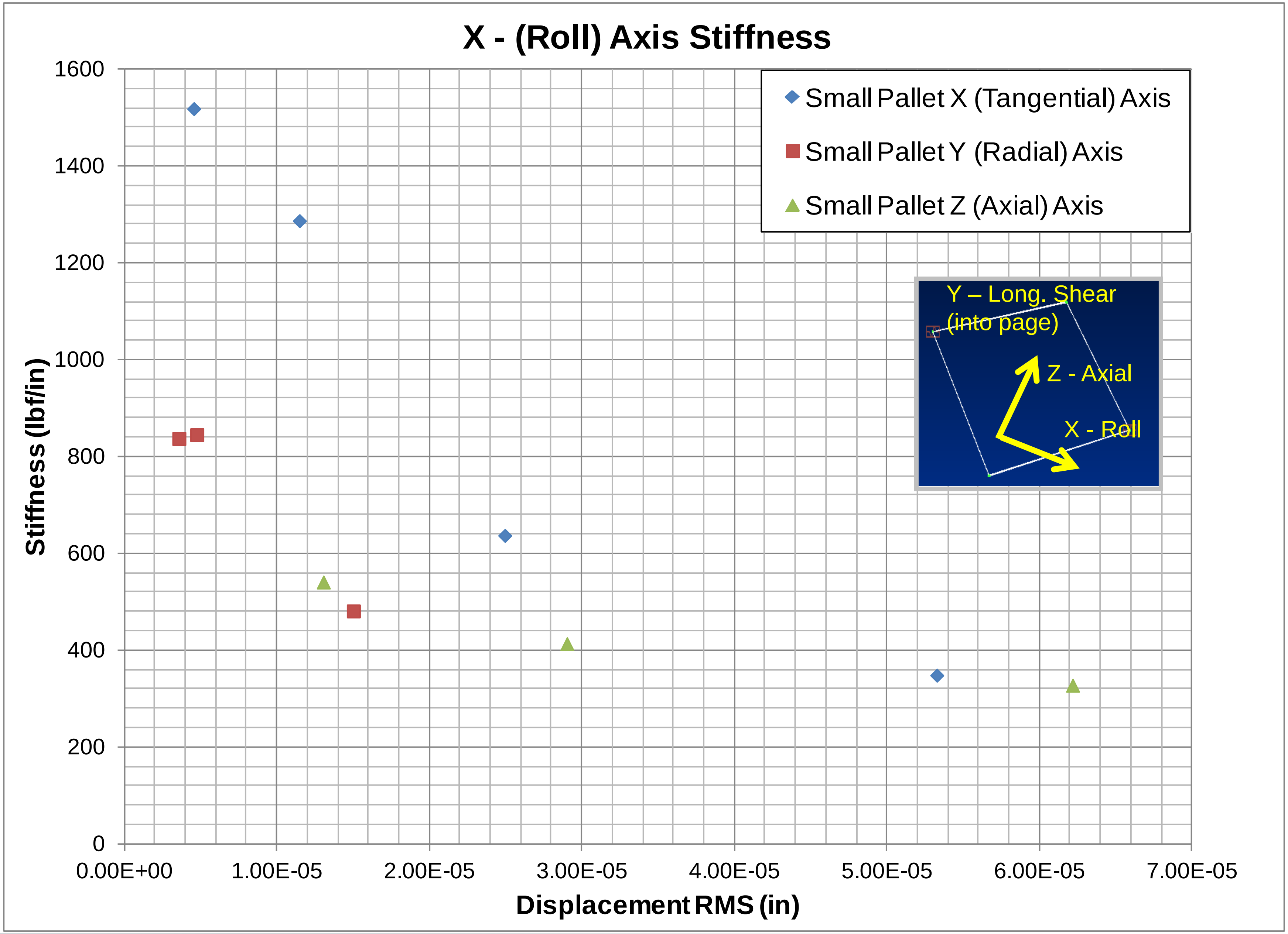
| | | | | Design Limits | | Set 1 - Z 5.2Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 2.08 | 541 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.00 | 260 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 2.04 | 2244 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 2.08 | 541 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.00 | 260 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 2.04 | 2244 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.10 | 1.09E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.03 | 1.03E+07 |

# Small Pallet Set 2 – Z (Axial) 10.4 Grms Results

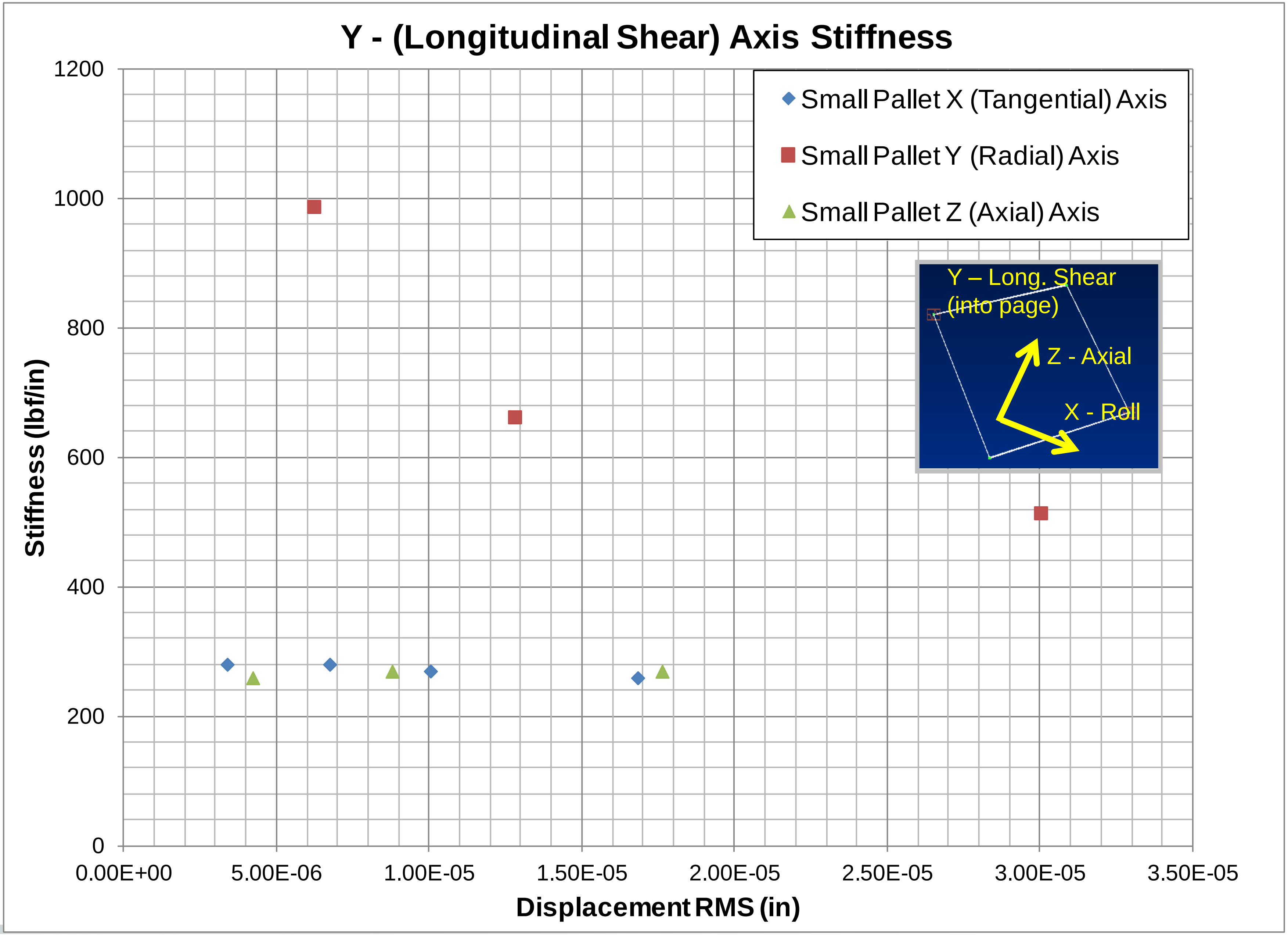
| XORTHO Matrix for Run125 Z 10pt4g | | | | | |
|---|---|---|---|---|---|
| | | | Analysis Modes | | |
| | Mode # | | **3** | **10** | Frequency |
| | | Freq (Hz) | 34.11 | 224.06 | Diff % |
| Test Modes | **1** | 34.38 | 0.99 | | -0.8% |
| | **2** | 233.71 | | 0.98 | -4.1% |

| | | | | Design Limits | | Set 2 - Z 10.4Grms | |
|---|---|---|---|---|---|---|---|
| | Design Variables | Description | Initial Value | Lower Bound | Upper Bound | Attune Factor | Value |
| 1 | PB164 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 1.59 | 413 |
| 2 | PB165 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.04 | 270 |
| 3 | PB166 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 1.55 | 1705 |
| 4 | PB184 | Isolator CBUSH, K1 | 260 | 0.1 | 10.0 | 1.59 | 413 |
| 5 | PB185 | Isolator CBUSH, K2 | 260 | 0.1 | 10.0 | 1.04 | 270 |
| 6 | PB186 | Isolator CBUSH, K3 | 1100 | 0.1 | 10.0 | 1.55 | 1705 |
| 7 | MA243 | Isolator trays, E | 9.90E+06 | 0.90 | 1.10 | 1.10 | 1.09E+07 |
| 8 | MA253 | Isolator Retainer Bars, E | 1.00E+07 | 0.90 | 1.10 | 1.02 | 1.02E+07 |

# Stiffness vs. Displacement RMS (X – Roll Axis) Results



Stiffness vs. Displacement RMS (Y – Long. Shear Axis) Results



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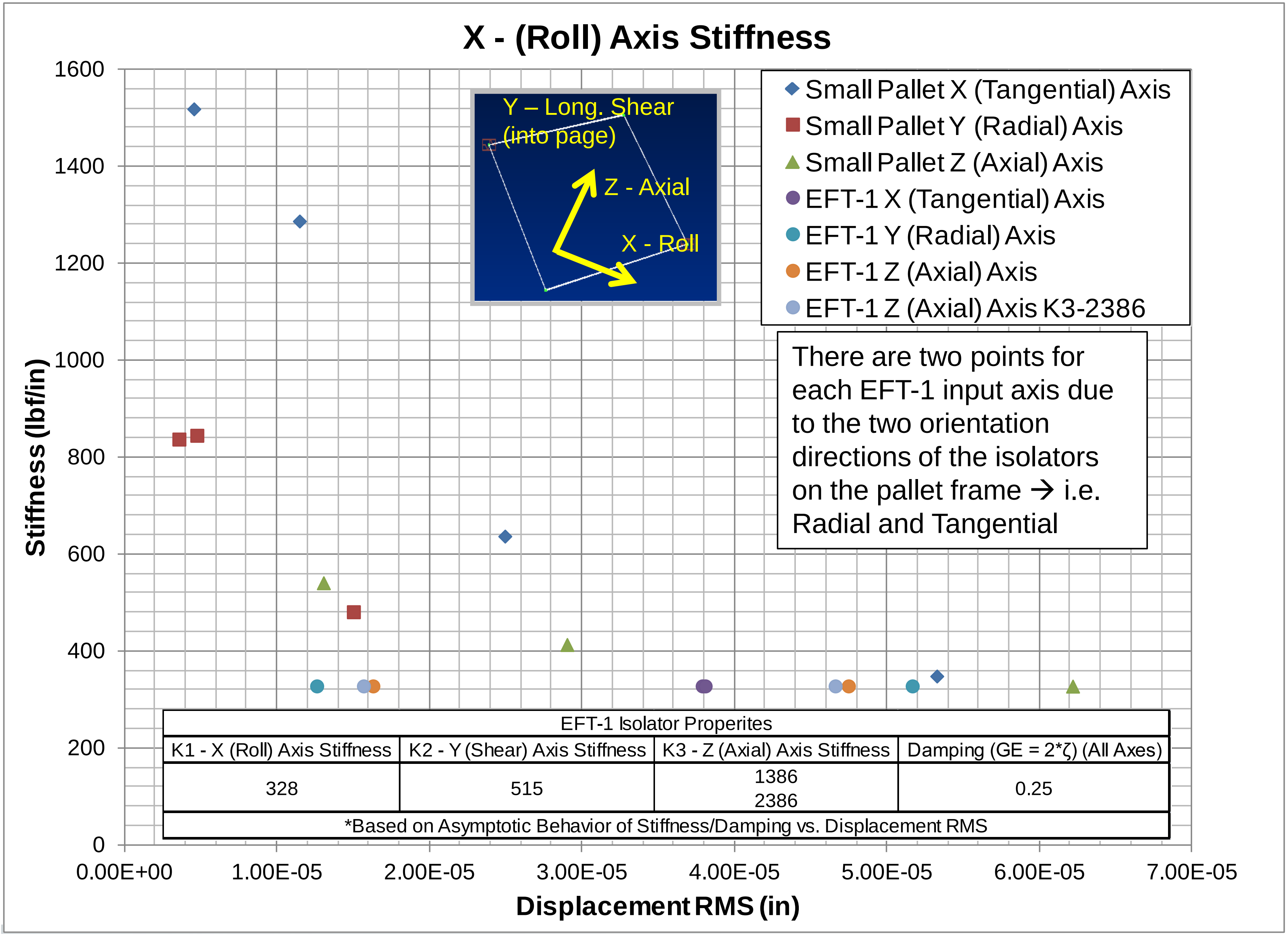
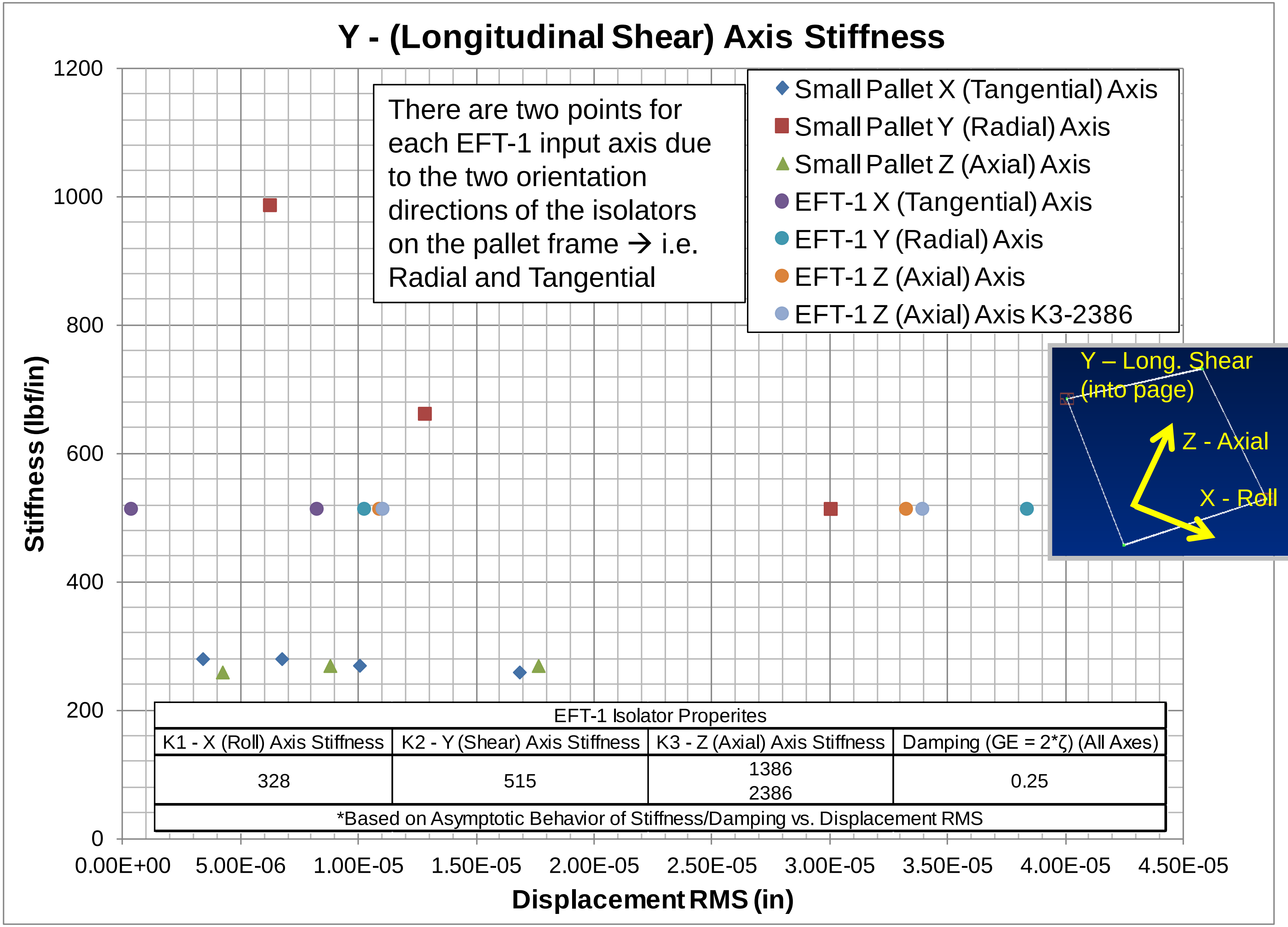
Stiffness vs. Displacement RMS (X – Roll Axis) Results




| EFT-1 Isolator Properites | | | |
|---|---|---|---|
| K1 - X (Roll) Axis Stiffness | K2 - Y (Shear) Axis Stiffness | K3 - Z (Axial) Axis Stiffness | Damping (GE = 2*ζ) (All Axes) |
| 328 | 515 | 1386<br>2386 | 0.25 |
| *Based on Asymptotic Behavior of Stiffness/Damping vs. Displacement RMS | | | |

# Stiffness vs. Displacement RMS (Y – Long. Shear Axis) Results




| EFT-1 Isolator Properites | | | |
|---|---|---|---|
| K1 - X (Roll) Axis Stiffness | K2 - Y (Shear) Axis Stiffness | K3 - Z (Axial) Axis Stiffness | Damping (GE = 2*ζ) (All Axes) |
| 328 | 515 | 1386<br>2386 | 0.25 |
| *Based on Asymptotic Behavior of Stiffness/Damping vs. Displacement RMS | | | |



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