Welcome

Estimating Static Equivalent Load Factors from Interface Force Response Results using a Finite Element Analysis Approach in the Frequency Domain

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Overview

Problem:

- It is difficult to produce vector sums of interface forces in random response analyses because of the need to track positive and negative signs.
  - *Power Spectral Density (PSD) values are (positive) squared results.*
- The traditional approach rigidizes interfaces using a Rigid Body Element (RBE).
  - *Rigidizing the interface is desired for shaker tests.*
  - *Rigidizing the interface is not desired for system analyses of flight like assemblies.*

Goal:

- To compare two methods of creating a Center of Gravity (CG) load factor using interface forces in the frequency domain.
  - *The traditional base drive approach is to excite from one grid ID and recover the forces from a single element.*
  - *The generalized method is to recover the interface forces at multiple interface locations using relative displacements.*

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Agenda

- Map Shaker Test Response Measurements To FEM
- Finite Element Model (FEM) Assumptions/Approach to Shaker Simulation
- FEM Simulation (Traditional Approach)
- FEM Simulation (Generalized Approach)
- Generalized Approach Verification (for Shaker Test Case Simulation)
- Forward Work - Evaluate and Report system response using Generalized Approach
- Conclusions

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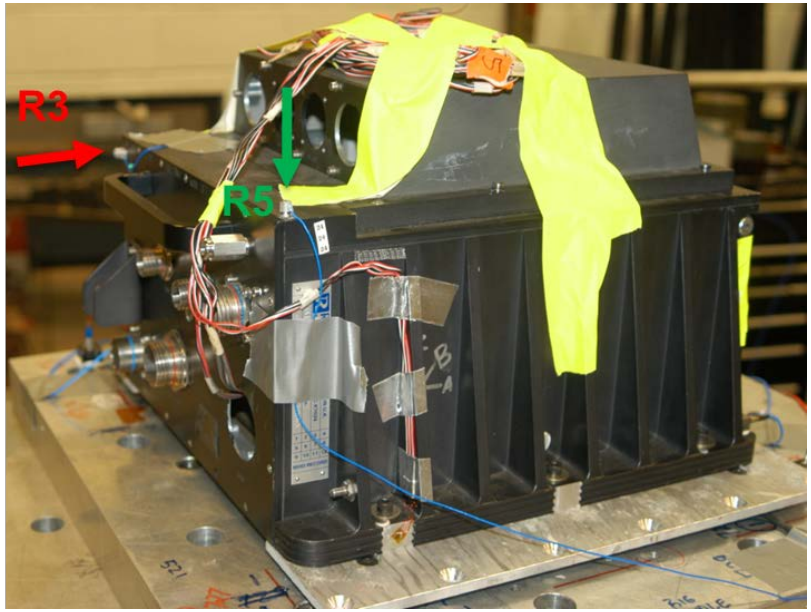
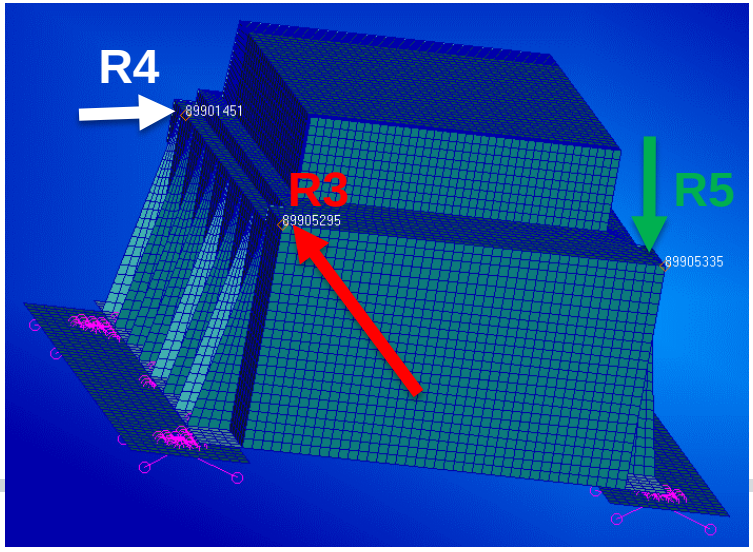
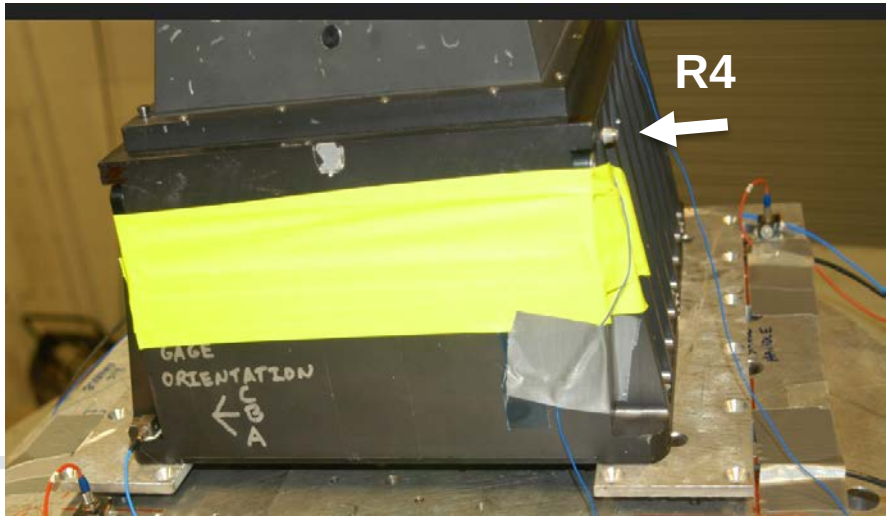
Map Shaker Test Response Measurements To FEM

- A flight like avionics box was excited to random vibration inputs.
- Vibration responses were measured by three uni-axial accelerometers.
  - *One for each drive direction*
  - *R5 is featured in excitation cases normal to the box*
- An FEM was created to compare results to the test.







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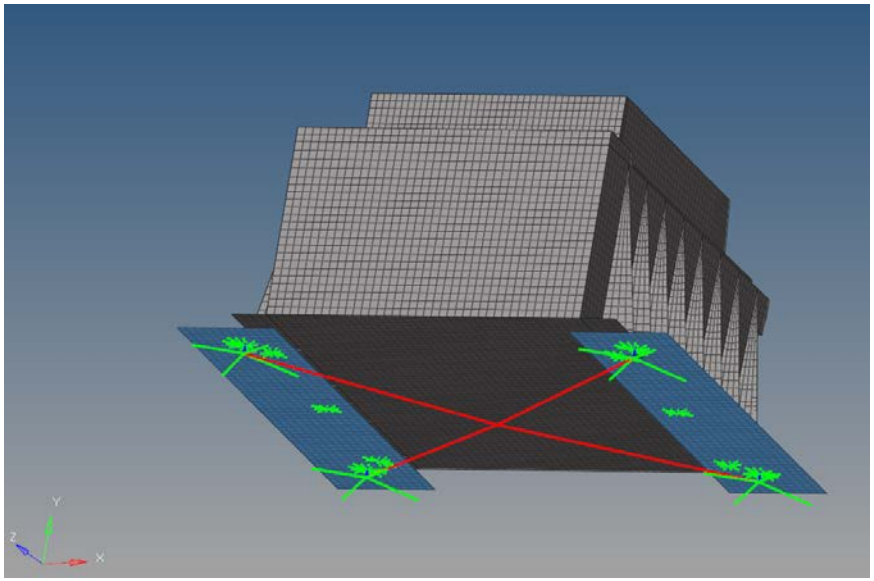
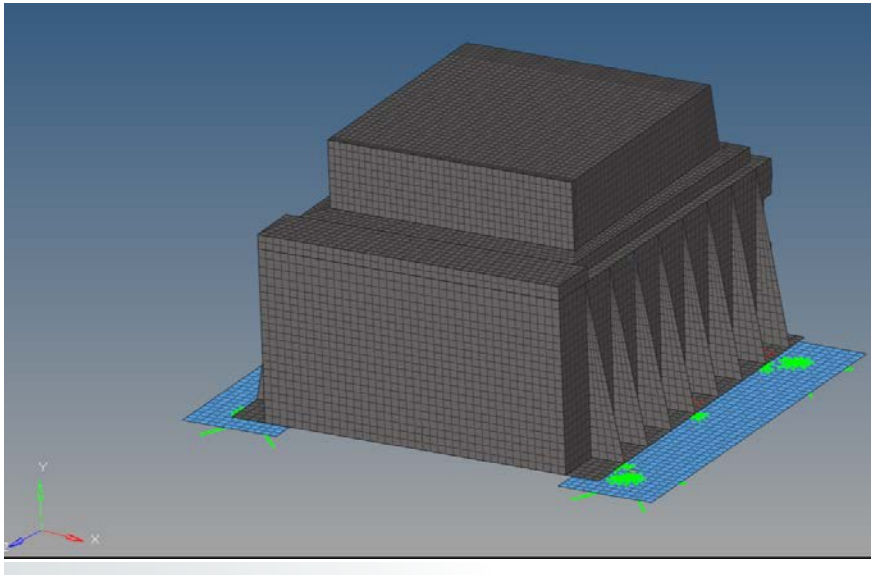
FEM Assumptions/Approach Shaker Simulation

- Weight: 52.4 lbs
- Q = 9.1 (5.5 % Critical Damping)
  - *Adjust damping to reasonably simulate the development testing results.*
- Use an FEM with reasonable Multiple Degree of Freedom (MDOF) detail.
- Set up a tuned base drive response study of the Avionics Box.
- Recover interface reactions as forces.
  - *Force Spectral Density, Root Mean Squared (RMS) Force.*
  - *Use broadband reaction forces to develop equivalent static load factors (20-2000 Hz).*
  - *F = ma = Weight (lb) * Load Factor (g)*
  - *Random Vibration Loads at NASA/MSFC are calculated using 3-sigma standard deviation.*
- Applying the static load factor to FEM produces the same net interface force as the dynamic solution.





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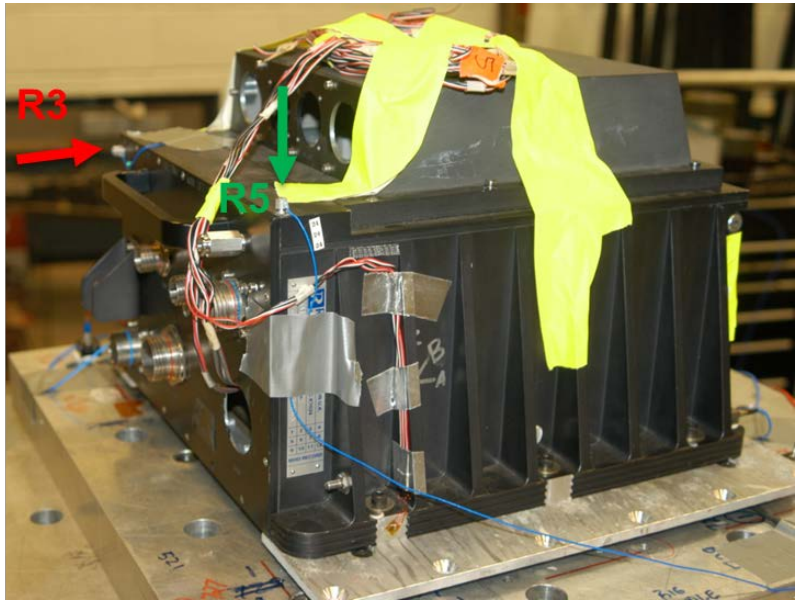
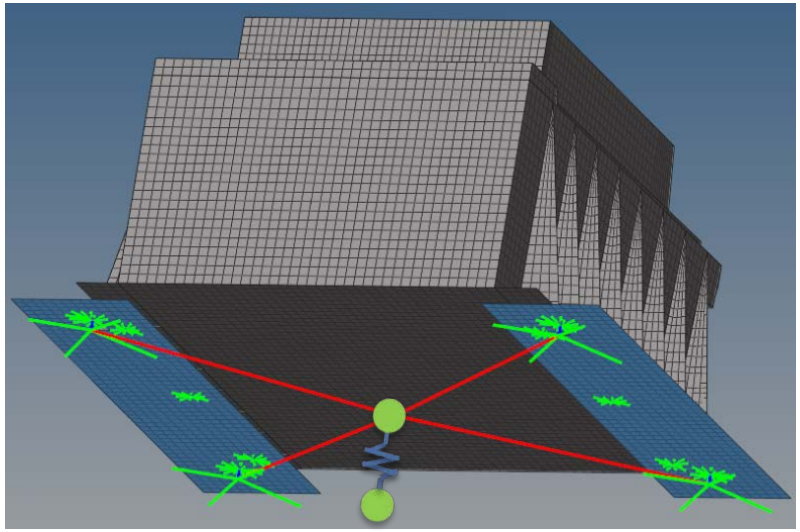
FEM Simulation (Traditional Approach)

- Use of massive, high impedance fixtures and enforcing piston like translational motion in the test lab makes simulation easier.
- The traditional approach:
  - *Excitation forces can be applied using an RBE2 which rigidizes the interface bolt locations in 6 DOF is an appropriate assumption for the base drive shaker test.*
  - *In this approach we can recover the total interface forces from a single spring element and redundant node at the central independent grid location for the RBE2.*
  - *Use FEM with reasonable MDOF detail*.
- The traditional approach rigidizes interfaces and this would not be desired in a system analysis of a flight like assembly.





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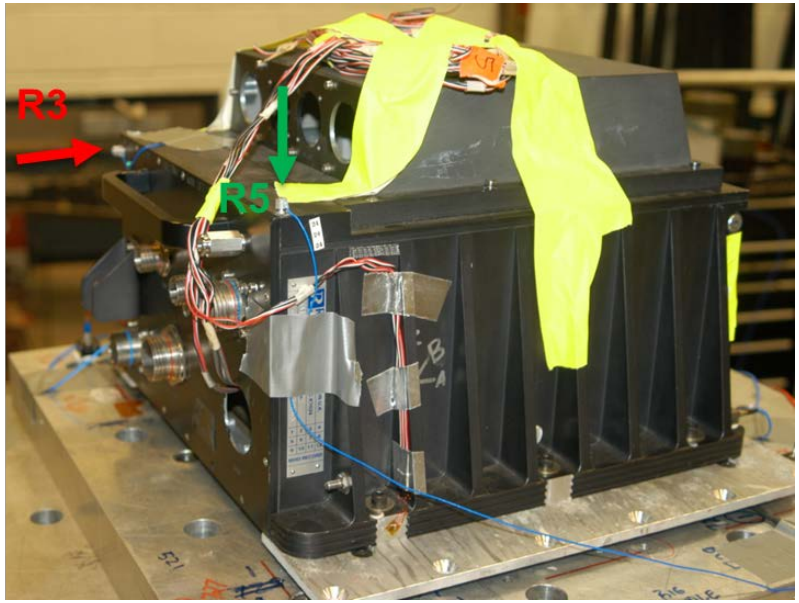
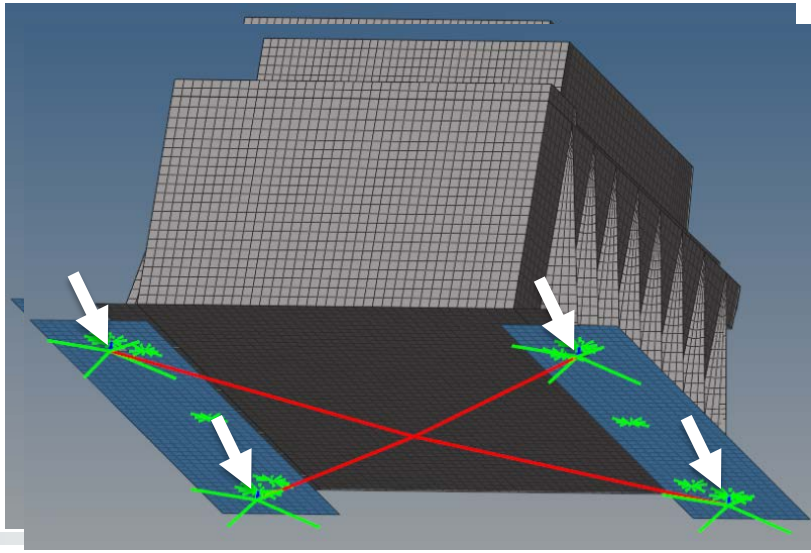
FEM Simulation (Generalized Approach)

- Instead of recovering the forces from the centrally located spring, relative displacements were recovered at each of four interface locations.
- The relative displacements were used to calculate interface forces at each of the four interface locations.
- Afterward the vector sum of the interface forces was determined for each mode shape.
- In the end, the RMS interface forces were determined in a similar way to the traditional approach from the broadband response of the net interface forces.
- White arrows denote relative deflection recovery locations used in MPC equations. The displacement difference between coincident nodes is calculated at 4 interface locations.





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FEM Simulation (Generalized Approach)

Working with SPOINTS and MPCs to store Relative Displacements and calculate Net Interface Forces

```
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678
MPCADD  10      300001  300002  300003  300004  300005
$***1***$***2***$***3***$***4***$***5***$***6***$***7***$***8***$***9***$**10***
SPOINT  200001      200002    200003    200004    200005
$***1***$***2***$***3***$***4***$***5***$***6***$***7***$***8***$***9***$**10***
```

```
MPC     300001  200001  1       -1.0    900024812       1.0
                900003132       -1.0
MPC     300002  200002  1       -1.0    900024802       1.0
                900003162       -1.0
MPC     300003  200003  1       -1.0    900017732       1.0
                900003152       -1.0
MPC     300004  200004  1       -1.0    900017762       1.0
                900003142       -1.0
$
MPC     300005  200005  1       -1.     200001  1       1.E8
                200002  1       1.E8    200003  1       1.E8
                200004  1       1.E8
```

Equations 1 through 4 store relative deflections:

- Calculated for each interface spring
- Determined in the drive direction
- Corresponding SPOINT Scalar storage location

The 5th Equation Provides:

- The vector Sum of the Forces in the drive direction

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FEM Simulation (Generalized Approach)

Working with SPOINTS and MPCs to store Relative Displacements and calculate Net Interface Forces

Equations 1 through 4 store relative deflections:

- Calculated for each interface spring
- Determined in the drive direction
- Corresponding SPOINT Scalar storage location

$$S_{200001} = -[U^2_{90002481} - U^2_{90000313}] \quad (300001)$$
$$S_{200002} = -[U^2_{90002481} - U^2_{90000313}] \quad (300002)$$
$$S_{200003} = -[U^2_{90002481} - U^2_{90000313}] \quad (300003)$$
$$S_{200004} = -[U^2_{90002481} - U^2_{90000313}] \quad (300004)$$

The 5th Equation Provides:

- The vector Sum of the Forces in the drive direction

$$\left[U^{direction}_{node\ id}\right]$$

$$U = Displacement$$

$$S_{20005} = -[(1.0x10^8)S_{200001} + (1.0x10^8)S_{200002} +$$

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FEM Simulation (Generalized Approach)

Working with SPOINTS and SPCs to store Relative Displacements and calculate Sum of the Interface Forces

- NASTRAN Provides the Modal SPOINT Stored Result of MPC Equations

EIGENVALUE = 4.817140E+06
CYCLES = 3.493130E+02 REAL EIGENVECTOR NO. 1

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
200001	S	5.1290850E-03	-5.4028140E-03	-5.0572730E-03	5.5583820E-03	2.2738030E+04	
89898387	G	2.6419700E-02	-3.0772690E+00	2.4324770E-01	4.7854010E-01	-1.2574830E-02	-1.1625890E-01
89898413	G	2.8900490E-02	2.7703850E+00	2.4504700E-01	4.9861470E-01	1.6007990E-02	-1.0554770E-01
89901451	G	2.9918510E+00	-8.1665870E-02	2.1155750E+00	1.0726280E-02	4.4485650E-01	-2.0338290E-02
89905295	G	3.2222130E+00	-5.3658200E-02	-3.2379330E+00	-1.0075900E-02	4.4238290E-01	-8.8893540E-03
89905335	G	3.2294870E+00	-4.8981750E-02	-3.1454500E+00	2.2788360E-02	4.4267460E-01	8.0113650E-03

Notice 5 S Values are given for each mode corresponding to the number of SPOINTS we specified (not the DOF direction)

- But the user must relate these to the ascending SPOINT ID

Frequency [Hz]	Mode	SPOINT 200001 [in]/unit	SPOINT 200002 [in]/unit	SPOINT 200003 [in]/unit	SPOINT 200004 [in]/unit	SPOINT 200005 **[lb]/unit**
349.3	1	0.0051	-0.0054	-0.0051	0.0056	**22738.0**
406.8	2	0.0054	0.0049	0.0051	0.0059	**2133910.0**
443.9	3	0.0069	0.0063	-0.0065	-0.0070	**-30279.4**
456.9	4	-0.0040	-0.0035	-0.0027	-0.0034	**-1368776.0**
892.9	5	0.0005	-0.0002	-0.0002	0.0006	**72975.3**

The 5th Equation Provided the Sum of the forces in the drive direction of the Sol 111 for each mode.

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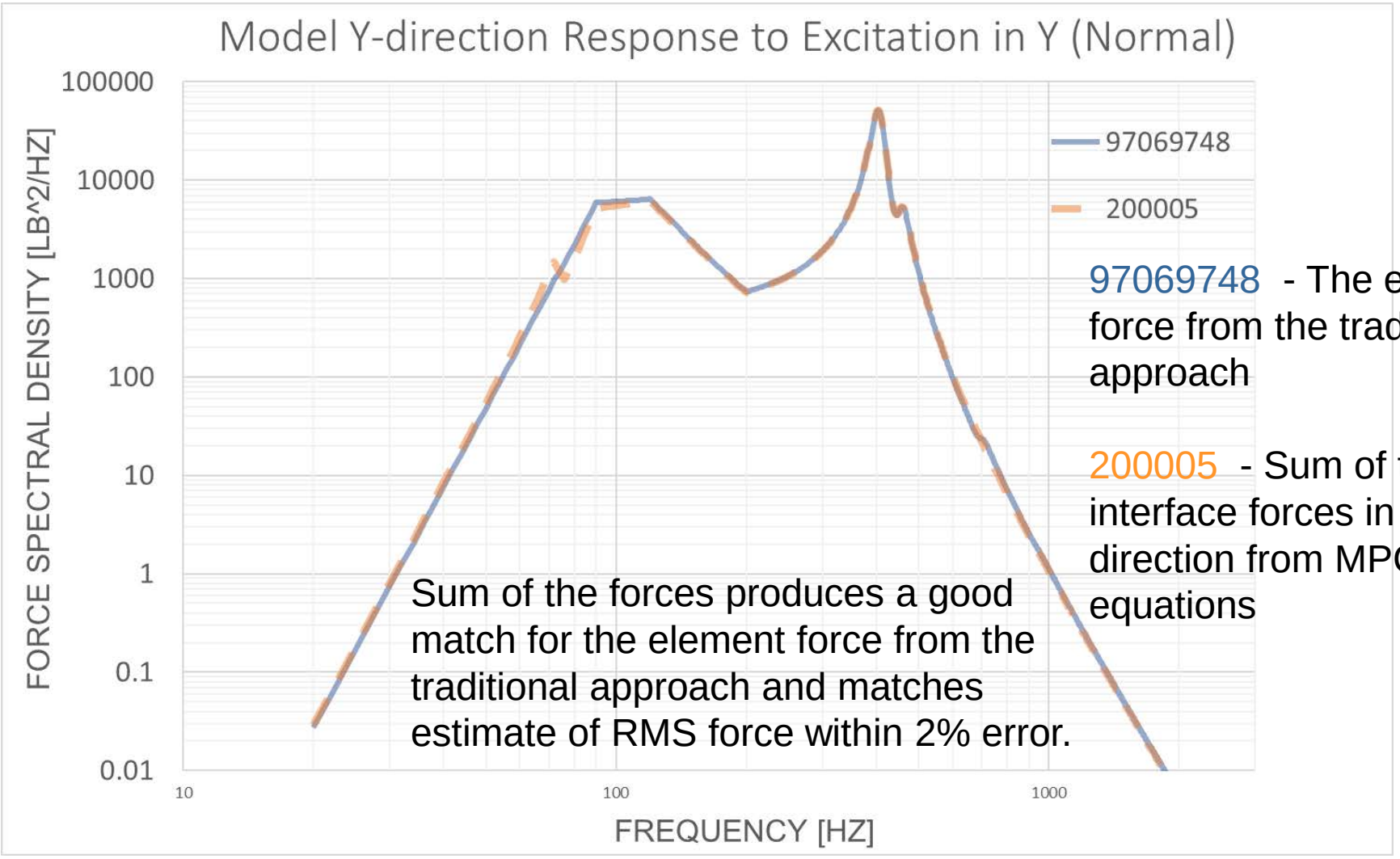
Generalized Approach Verification (for Shaker Test Case Simulation)

Comparing Two Analysis Approaches to determine the total interface force:



97069748 - The element force from the traditional approach

200005 - Sum of the interface forces in Normal direction from MPC equations

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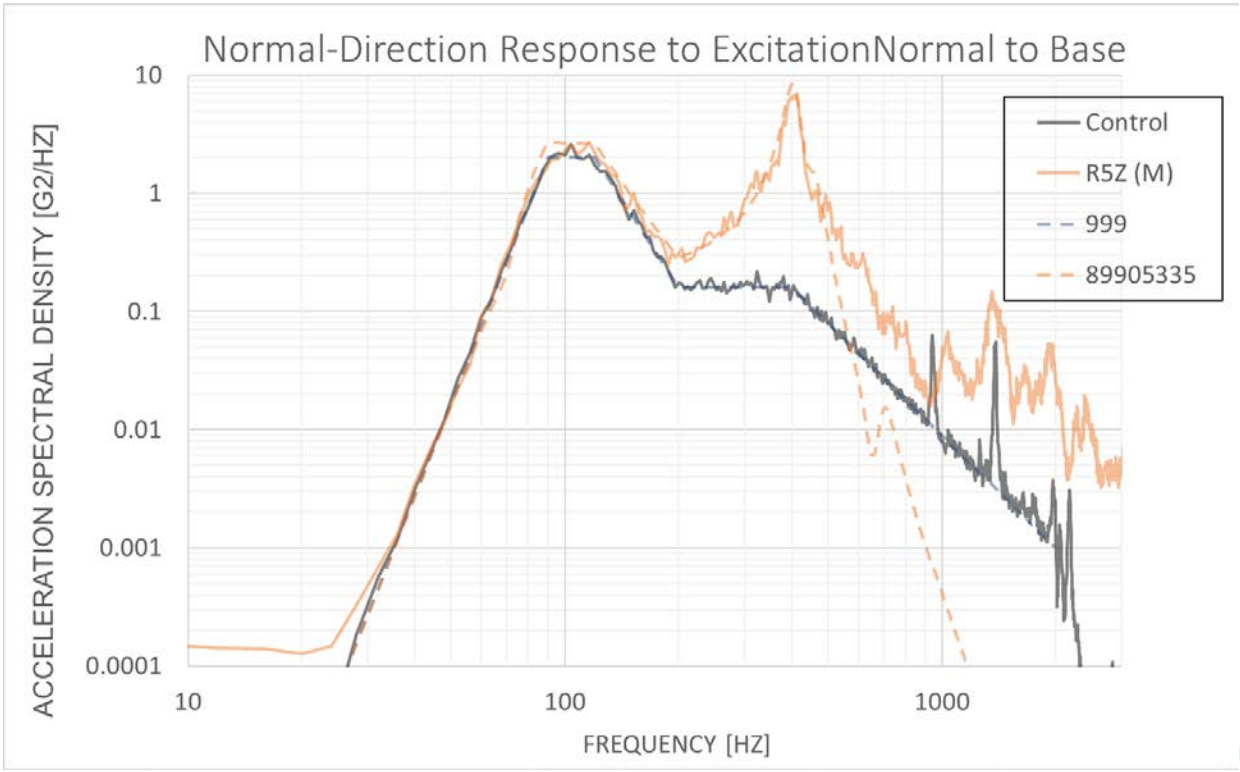
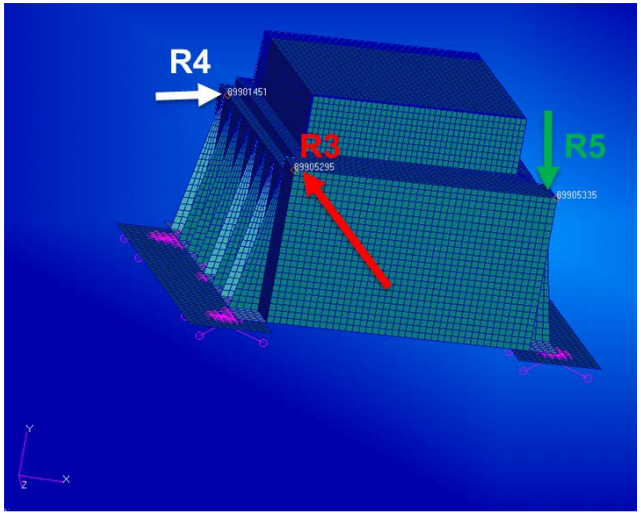
Base Drive Response Verification

Comparing Acceleration PSD from Test to analysis Simulation

- Solid lines are processed test measurements.
- Dashed lines are NASTRAN solution 111 FEM results for nodes at response accelerometer locations.





- Grid ID 999 corresponds to the drive location in the FEM.
- Grid ID 89905335 corresponds to the R5 uniaxial response measurement location as represented by the FEM.

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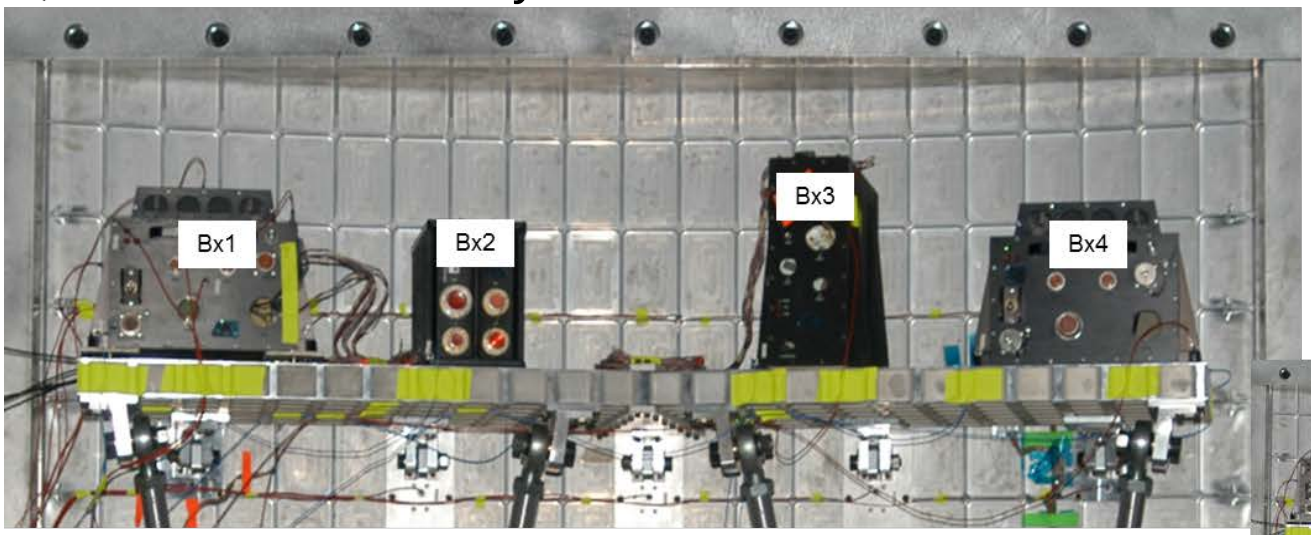
Forward Work - Evaluate and Report System Response Using Generalized Approach

System Test

a)



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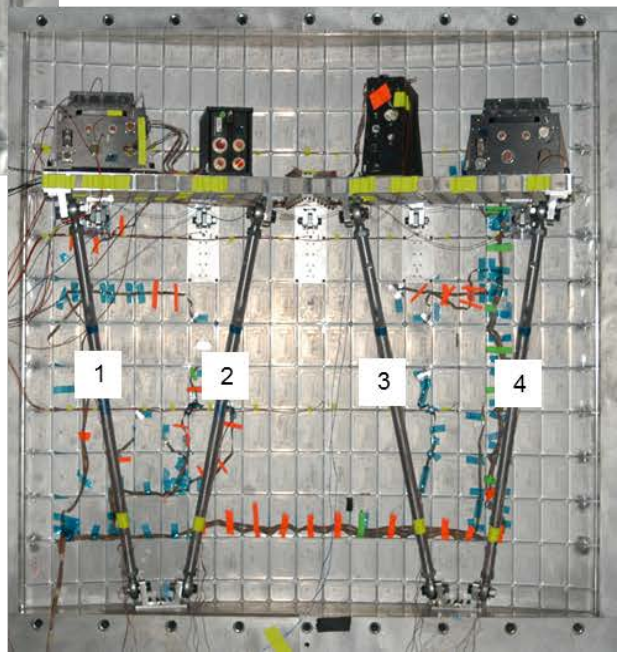

- During Test 1 a set of 4 Tri-Axial Force Transducers were Located at the Base of Box 1.
  - *Figure a) Presents the Box Designations.*
  - *Figure b) Presents the Strut Numbering.*

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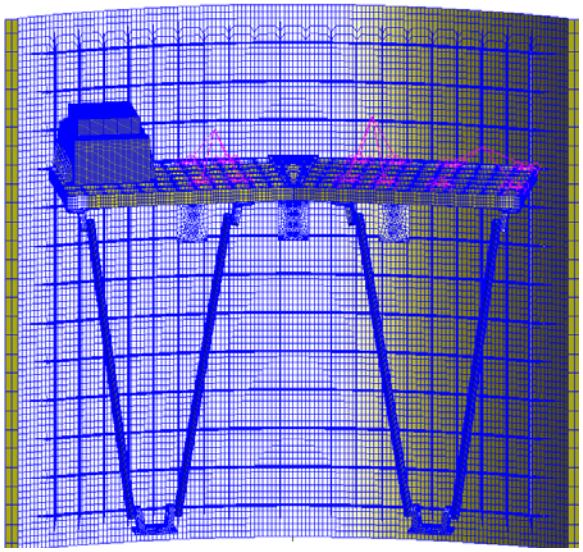
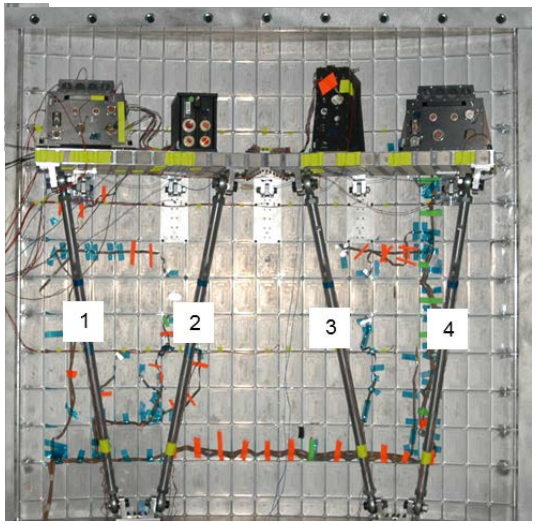
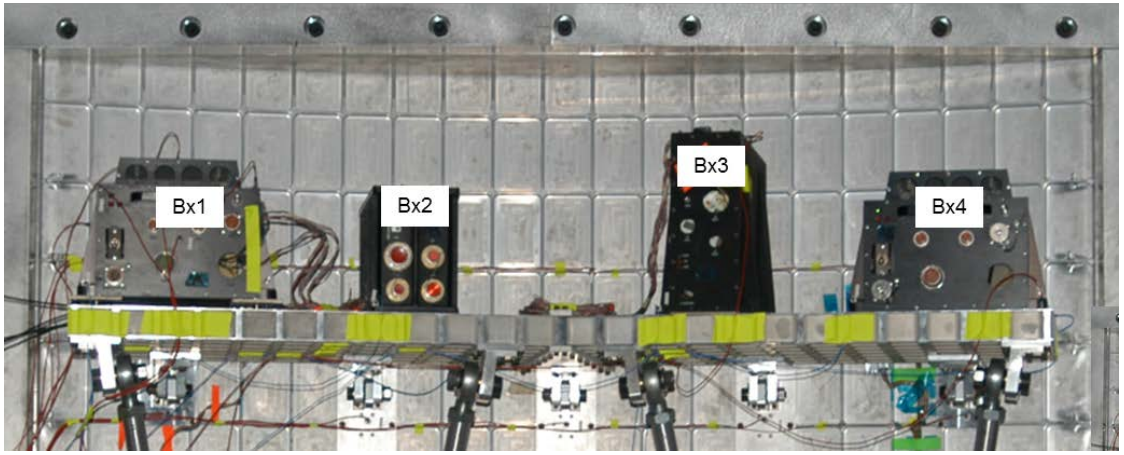
Forward Work - Evaluate and Report Using Generalized Approach

Intro: System Test Configuration and FEM Simulation

- The Generalized Approach can be implemented within a system model response solution. Response provides interface forces and/or moments in 3 orthogonal axes.
- Provides an estimate of “Net CG Acceleration” suitable for development of 3 sigma load factor.
- Does not require the interface to be stiff or have high impedance.
- Reporting on a system level response solution is to be the subject of future work.







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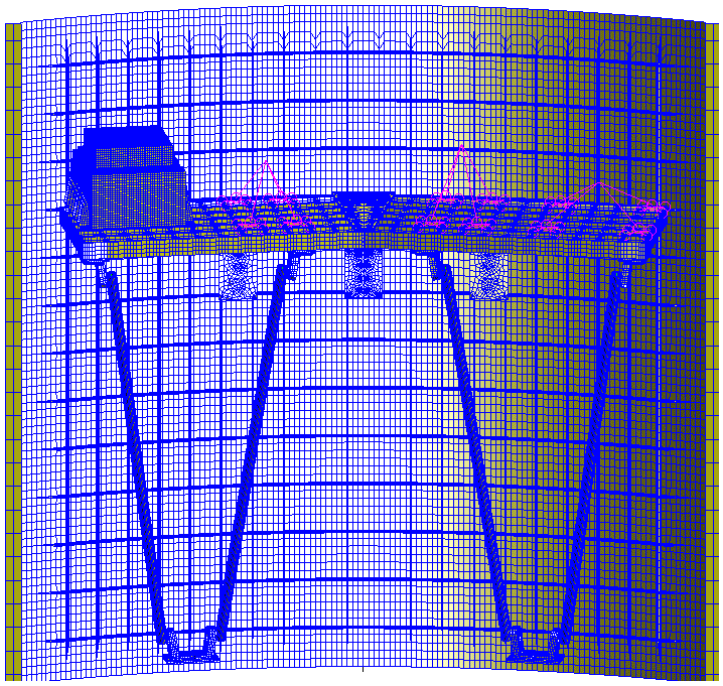
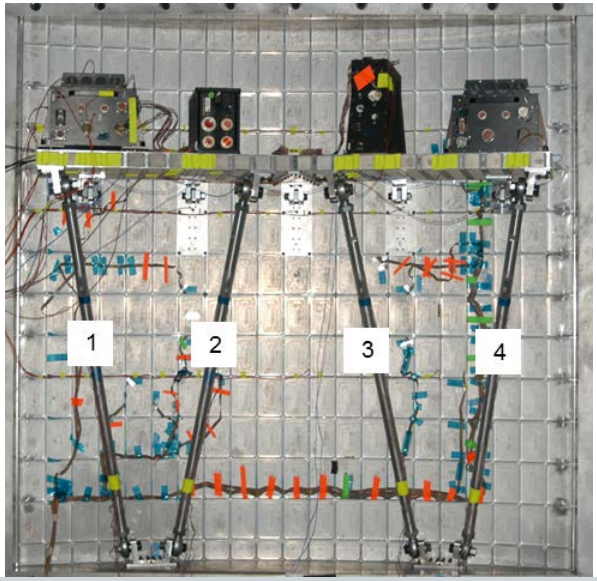
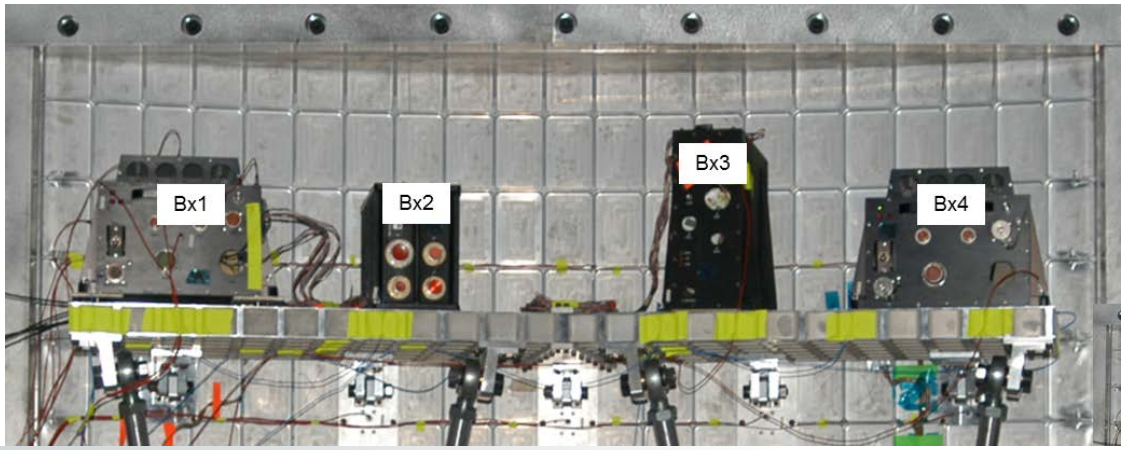
Forward Work - Evaluate and Report Using Generalized Approach

Intro: System Test Configuration and FEM Simulation

- Use of an RBE2 to rigidize the interface underneath the box is not desired for the flight-like system FEM simulation.
- Therefore the Traditional approach to recover net interface forces is not viable.
- The Generalized approach is recommended.







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Conclusions

- We illustrated the recovery of net interface forces for a traditional single direction base shake simulation.
- The Generalized approach for the recovery of net interface forces was also demonstrated and compared very favorably with the Traditional result.
  - *The Generalized approach has promise for removing conservatism from Equivalent Static Load Factors.*
  - *The Generalized recovery can be derived from system FEM response analyses without over-stiffening the component to backup structure interface.*
  - *The Generalized recovery can be implemented without over-rigidizing the flight–like interface backup structure of the system response FEM.*
- Future work will validate this for system response recoveries from measured test response (Part 2).

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Backup Slides

Equations for Generalized Approach with System FEM

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Generalized Approach For the System FEM Response

Working with SPOINTS and SPCs to store Relative Displacements and calculate Sum of the Interface Forces

```
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678
$***1***$***2***$***3***$***4***$***5***$***6***$***7***$***8***$***9***$**10***
SPOINT   200001  200002  200003  200004  200005 200201  200202  200203
         200204  200205 200301  200302  200303 200304  200305
$***1***$***2***$***3***$***4***$***5***$***6***$***7***$***8***$***9***$**10***
MPC     300001  200001  1       -1.0    900024812       1.0
                900003132       -1.0
MPC     300002  200002  1       -1.0    900024802       1.0
                900003162       -1.0
MPC     300003  200003  1       -1.0    900017732       1.0
                900003152       -1.0
MPC     300004  200004  1       -1.0    900017762       1.0
                900003142       -1.0
$
MPC     300005  200005  1       -1.     200001  1       1.E8
                200002  1        1.E8   200003  1       1.E8
                200004  1        1.E8
$ in the example
$    there is a range of IDs for scalar points  200001-1001233
$    there is a range of IDs for GridPoints at CBUSH RBE Dep 3001101-100110
$    there is a range of IDs for GridPoints at CBUSH 3001201-1001210
```

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$***1***$***2***$***3***$***4***$***5***$***6***$***7***$***8***$***9***$**10***
SPOINT   200001  200002  200003  200004  200005 200201  200202  200203
         200204  200205 200301  200302  200303 200304  200305
$***1***$***2***$***3***$***4***$***5***$***6***$***7***$***8***$***9***$**10***
MPC     300001  200201  1       -1.0    900024811       1.0
                900003131       -1.0
MPC     300002  200202  1       -1.0    900024801       1.0
                900003161       -1.0
MPC     300003  200203  1       -1.0    900017731       1.0
                900003151       -1.0
MPC     300004  200204  1       -1.0    900017761       1.0
                900003141       -1.0
$
MPC     300005  200205  1       -1.     200201  1       1.E8
                200202  1        1.E8   200203  1       1.E8
                200204  1        1.E8
$ in the example
$    there is a range of IDs for scalar points  200001-1001233
$    there is a range of IDs for GridPoints at CBUSH RBE Dep 3001101-100110
$    there is a range of IDs for GridPoints at CBUSH 3001201-1001210
```

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```
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678
$***1***$***2***$***3***$***4***$***5***$***6***$***7***$***8***$***9***$**10***
SPOINT   200001  200002  200003  200004  200005 200201  200202  200203
         200204  200205 200301  200302  200303 200304  200305
$***1***$***2***$***3***$***4***$***5***$***6***$***7***$***8***$***9***$**10***
MPC     300001  200301  1       -1.0    900024813       1.0
                900003133       -1.0
MPC     300002  200302  1       -1.0    900024803       1.0
                900003163       -1.0
MPC     300003  200303  1       -1.0    900017733       1.0
                900003153       -1.0
MPC     300004  200304  1       -1.0    900017763       1.0
                900003143       -1.0
$
MPC     300005  200305  1       -1.     200301  1       1.E8
                200302  1        1.E8   200303  1       1.E8
                200304  1        1.E8
$ in the example
$    there is a range of IDs for scalar points  200001-1001233
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Estimating Static Equivalent Load Factors from Interface Force Response Results using a Finite Element Analysis approach in the Frequency Domain.

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