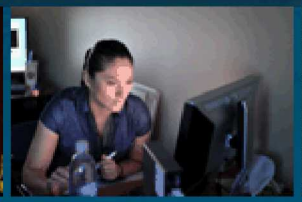
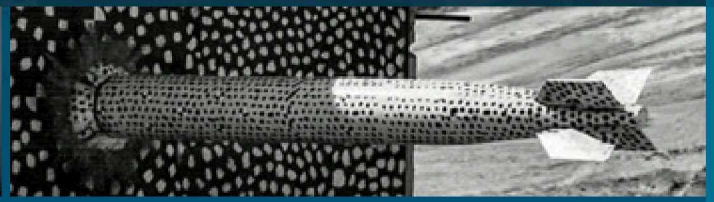
SAND2019-9672C

As-Measured Surface Properties for Modal Predictability





PRESENTED BY

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Presented at:
ASME IDETC August 2019 – Anaheim, CA

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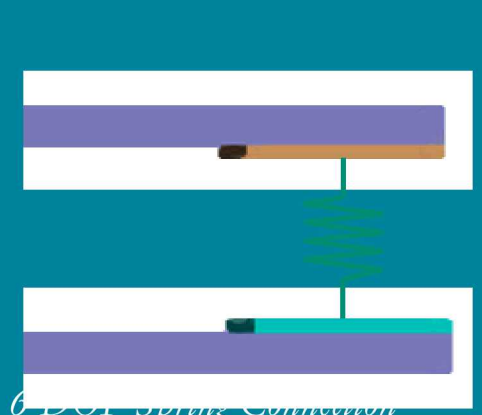
Agenda

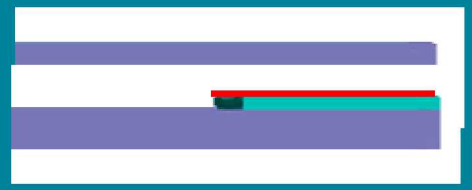
- Current modeling techniques and hypothesis
- Surface measurement technology
- As-Built methodology
- Results with parameter perturbation
- Statistical surface analysis
- Conclusions and future work

Hypothesis

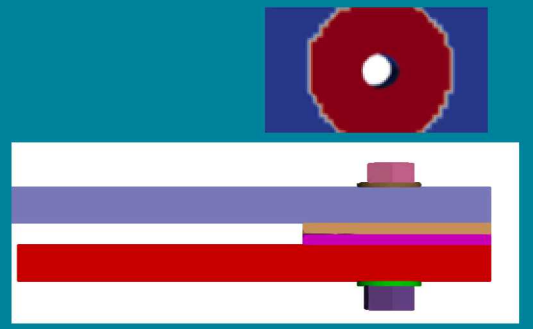
Current Modeling Techniques for Modal Analysis of Structures with Interfaces



6 DOF Spring Connection



Fully Tied Interface

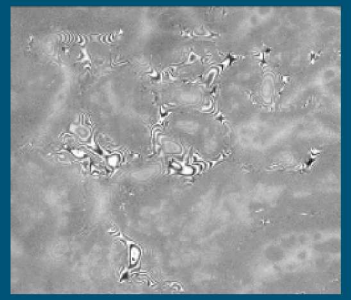


Tied Interface Based on Preload Nominally Flat

- Hypothesis:
  - By taking detailed surface measurements and tying the true contact distribution at the interface, we will improve modal predictability.

Taking detailed surface measurements via Scanning White Light Interferometry (SWLI)

Zygo NexView NX2

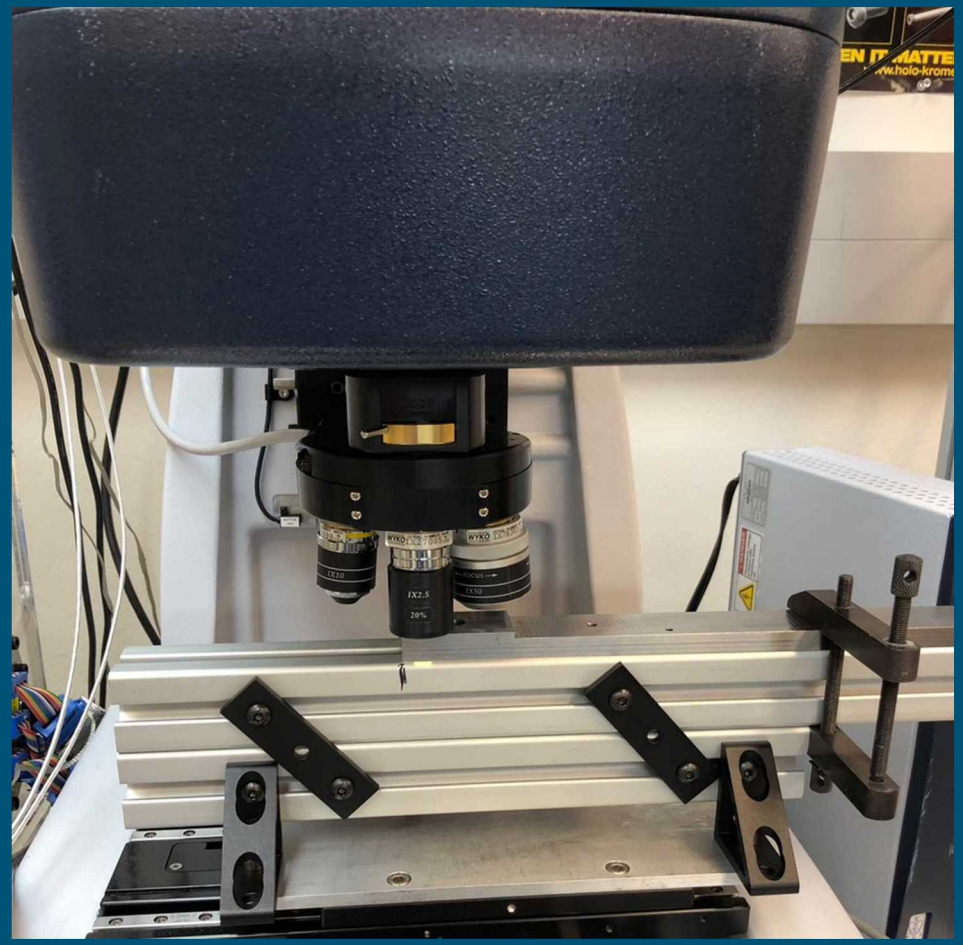


Fringe viewed by camera

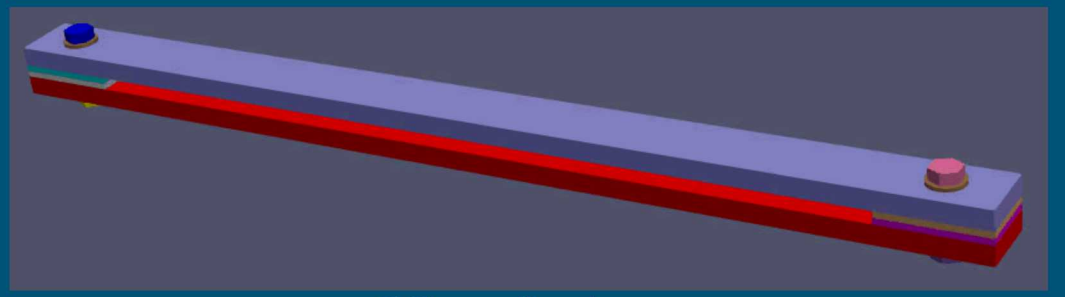
Final height map

- SWLI is used for the surface measurements in this presentation
  - SWLI utilizes interference fringes created by interfering light waves.
  - Vertical Shift Interferometry was used in this study.
    - ~10 nm vertical resolution
    - ~1 µm lateral resolution

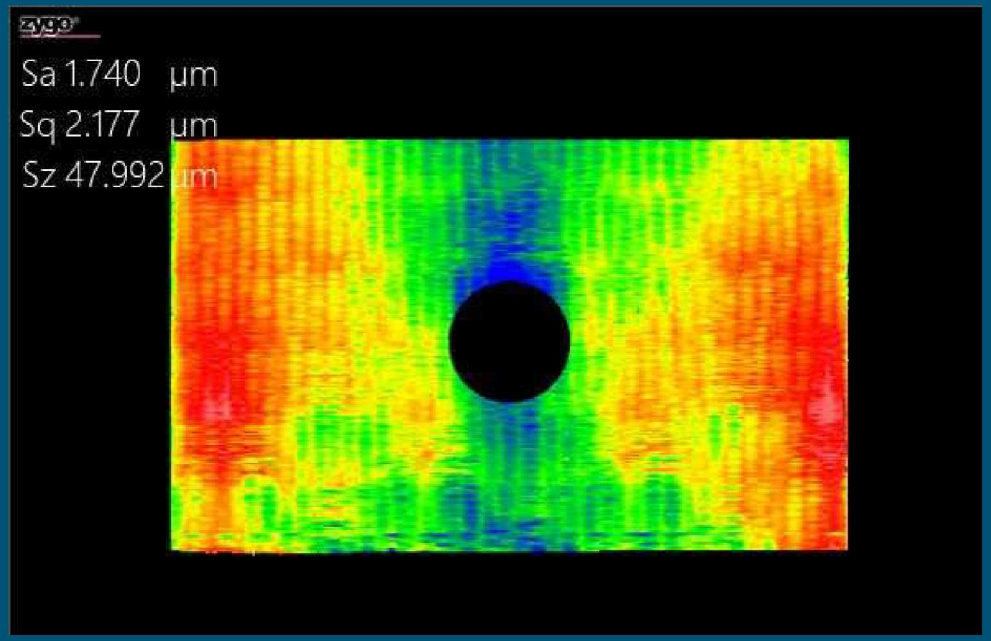
SWLI measurement applied to the C-Beam



C-Beam Experimental Setup

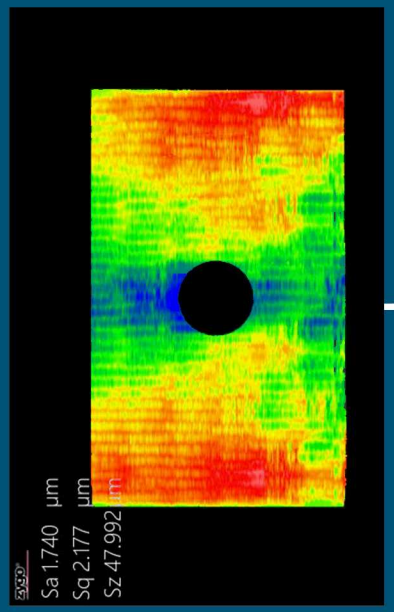


C-Beam Specimen

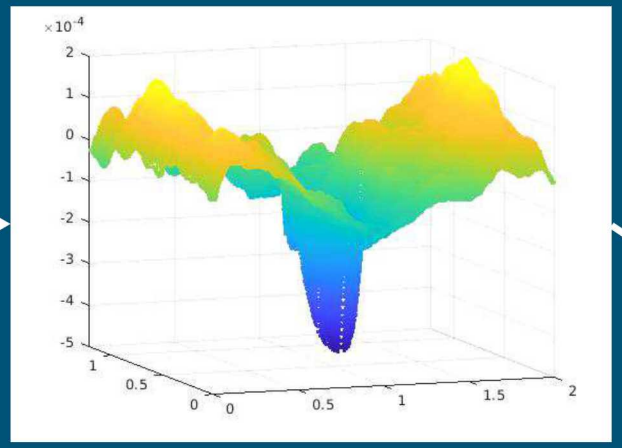


Typical Surface Measurement of C-Beam Interface

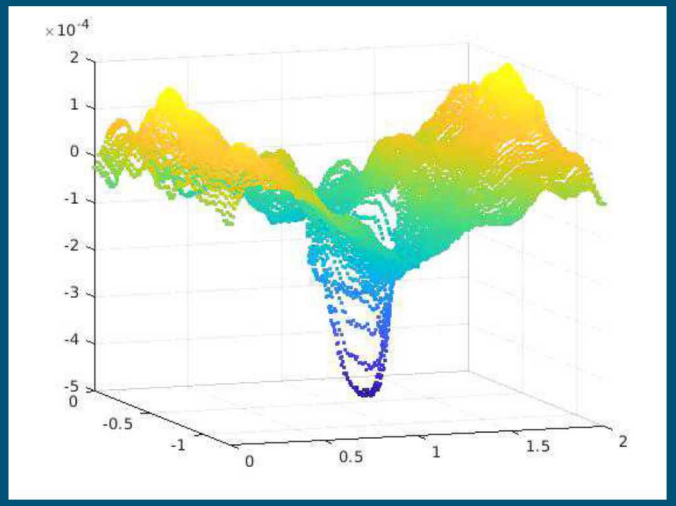
As-Built methodology



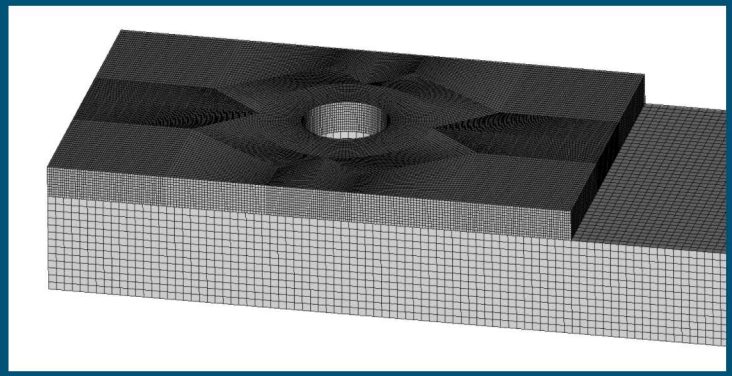
Raw Data from SWLI



Decimated Data



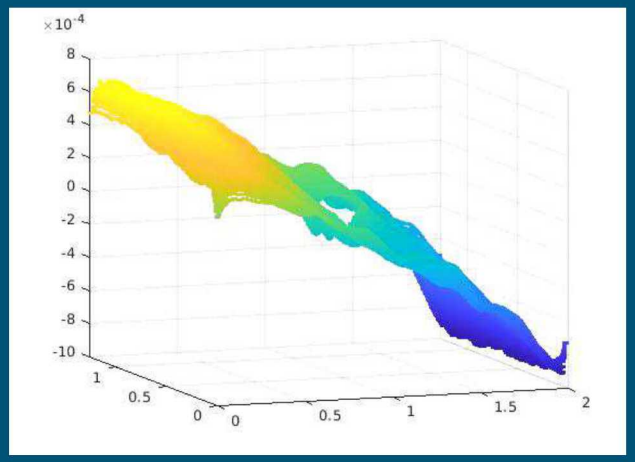
Perturbed FE Surface Mesh

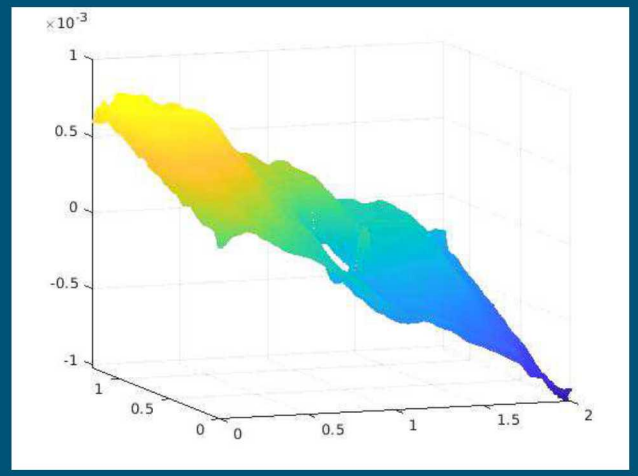


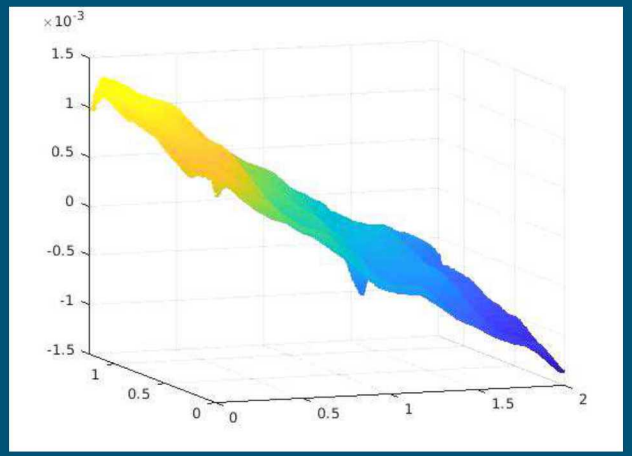
FE Mesh of Surface

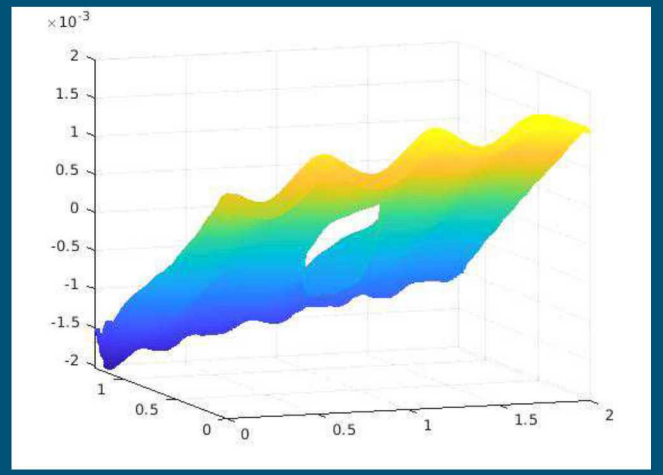
- Raw data is decimated to a manageable size (optional)
- Surface is ‘smoothed’ to remove singularities
- FE Mesh is perturbed to match smoothed SWLI data
- The interfaces are assembled using a nonlinear analysis
- Tied constraints are created where contact was made
- Linear modal analysis is conducted

Perturbed mesh surfaces of C-Beam assembly B12A to B12B



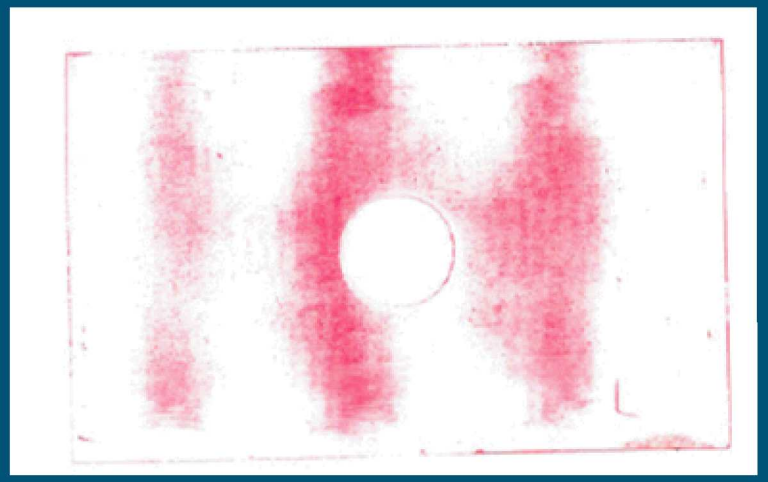




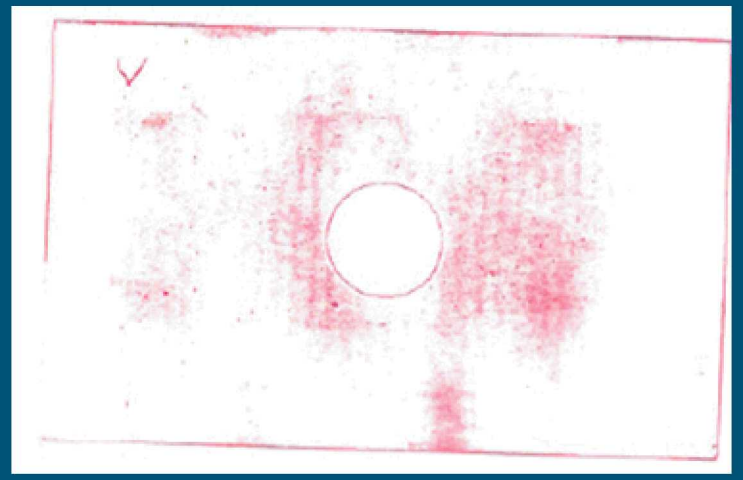


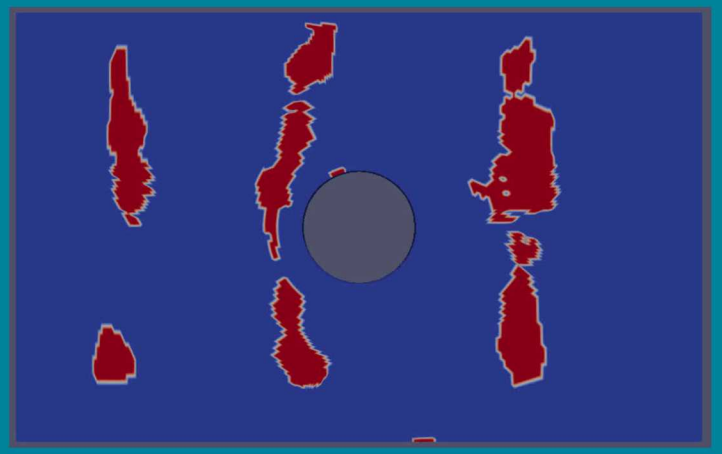
Perturbed mesh preload state matches contact from pressure films

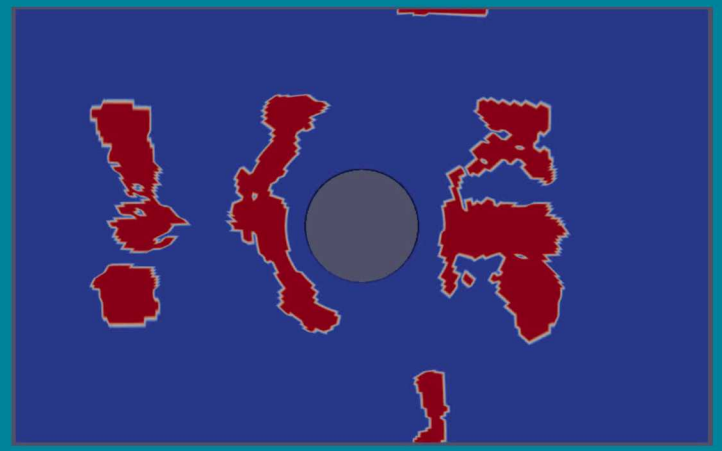
B12A R to B12B L



B12A L to B12B R



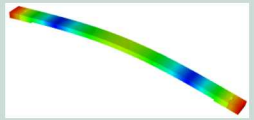
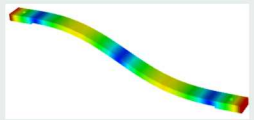
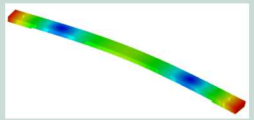
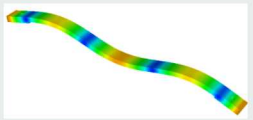
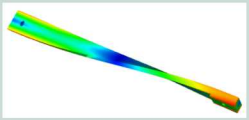




These contact regions will be turned into tied multi-point constraints in a linear modal analysis.

Beam properties are tuned with single beam mode matching

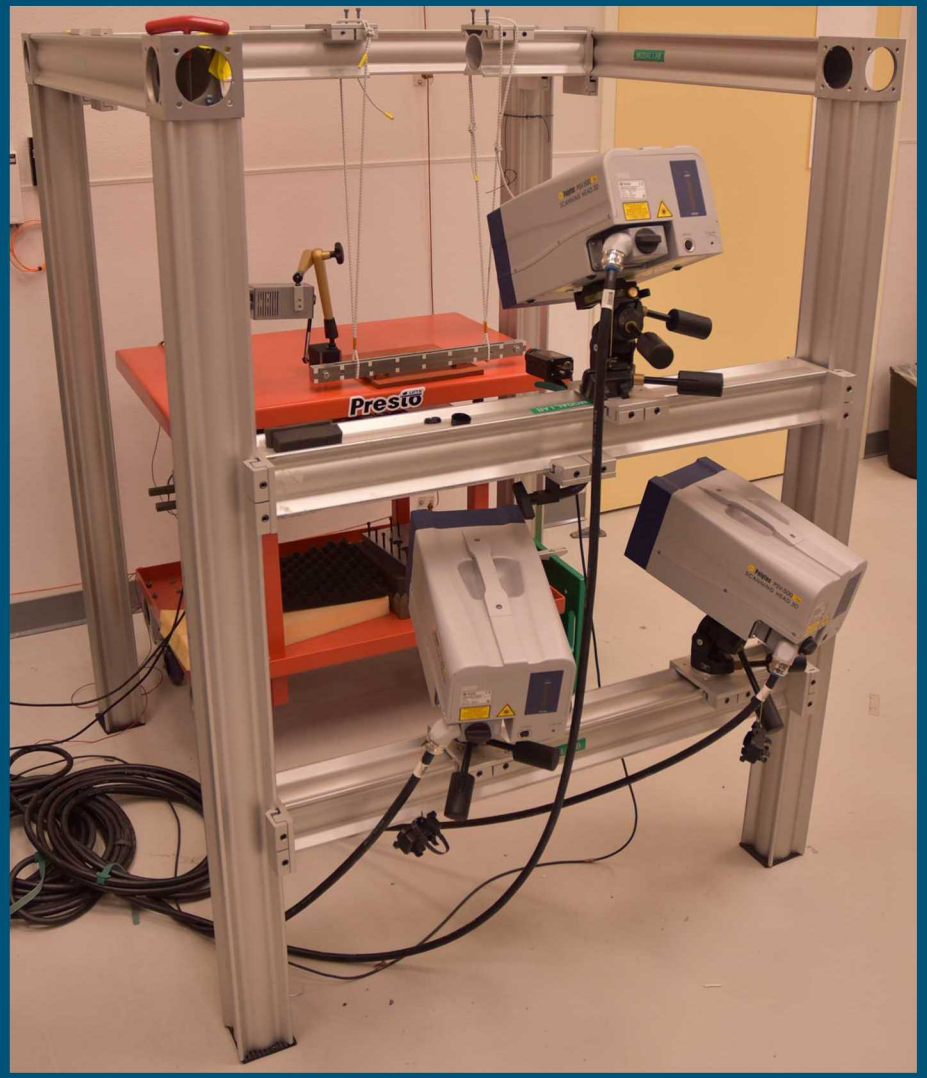
Error in Mode Matching

Mode	B12A	B12B	Shape
1	185.1 Hz (0.60 %)	187.7 Hz (0.04 %)	
2	520.5 Hz (0.47 %)	525.7 Hz (0.31 %)	
3	609.4 Hz (-0.72 %)	611.4 Hz (-0.21 %)	
4	1034 Hz (0.30 %)	1044 Hz (0.23 %)	
5	1527 Hz (0.26 %)	1543 Hz (0.11 %)	

Properties Derived from Mode Matching

Property	B12A	B12B
E, ksi	29,700	30,400
v, [-]	0.285	0.285
ρ, lb-s^2/in^4	$7.26 \cdot 10^{-4}$	$7.31 \cdot 10^{-4}$

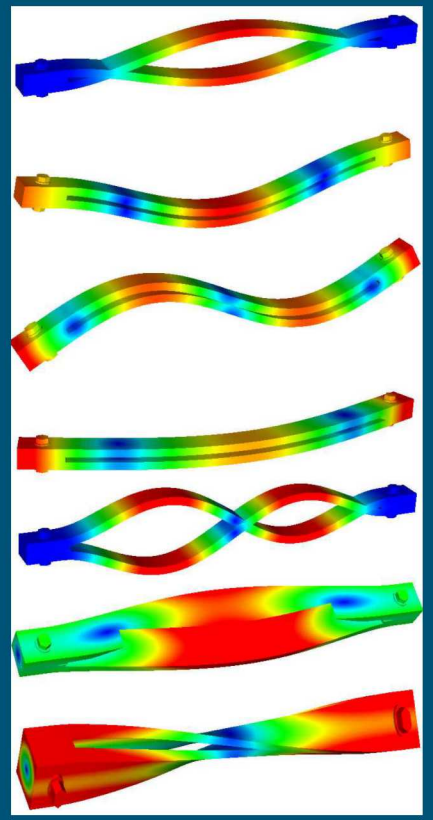
Experimental Modal Evaluation



Modal Measurements

- Non-contact measurements were requested to preserve interface pad integrity
  - Used Polytec 3D Scanning Laser Doppler Vibrometer (LDV)
- Free-free boundary condition
  - Beams were suspended by bungee cords
- Hammer impact excitation
  - Targeted a peak impulse force of ~0.5 lb
  - 10 averages per measurement set for FRF estimates
- Measurement locations
  - 36 nodes total: 9 stations spaced at 2.5” intervals along the front and back spans of the beam, two nodes per station (top and bottom).
    - 108 DOF measured
  - Retroreflective tape squares placed at measurement nodes

Perturbed surface mesh outperforms the FE Stuck mesh method



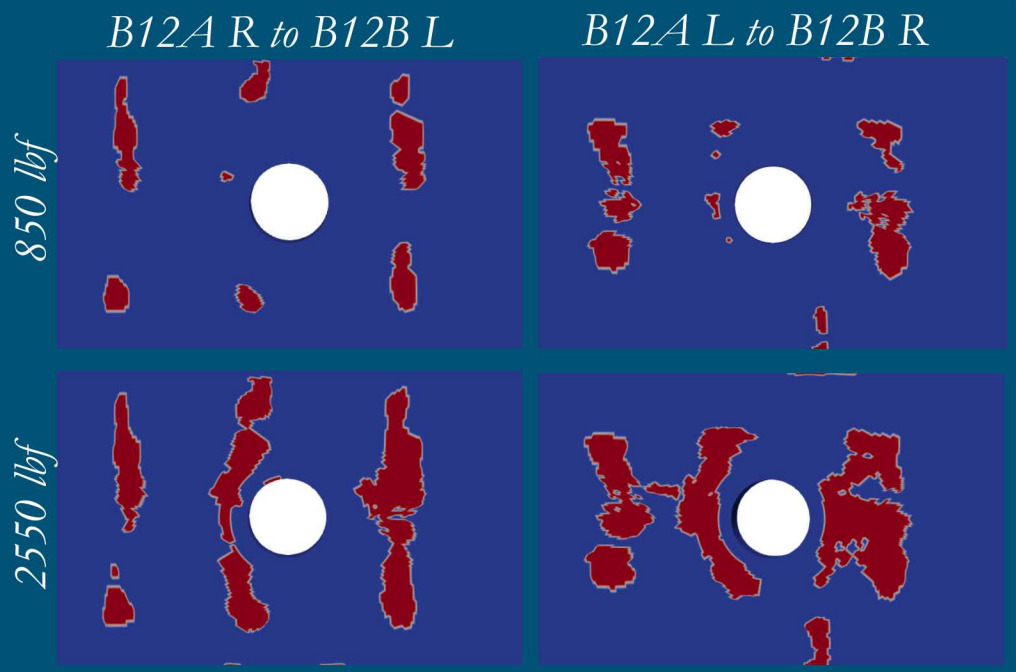
C-Beam Mode Shapes

Comparison of Methods

	% Error	
Test (Hz)	FE Stuck	FE Perturbed
285.9	2.66	-1.61
352.3	0.94	-0.65
505.6	0.40	0.28
597.6	-0.47	-0.57
778.5	3.56	-1.12
935.5	4.64	-1.98
1174.6	0.75	0.03

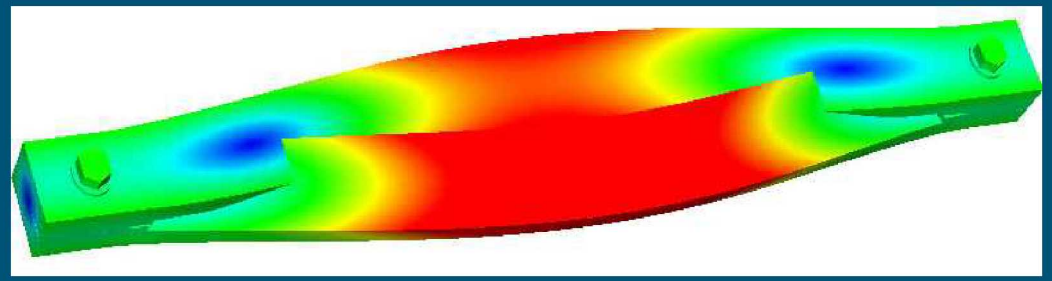
Preload Effect

- Nominal preload was measured at 1760 lbf.
- Preload was varied by ±50%
- Biggest difference in frequency was evident in Mode 6
- Effect was small for this structure



Preload Percent Difference

	Measured	Nom Model	R1	R2	R3	R4
1	285.9	281.3	-0.39	-0.11	0.07	0.14
2	352.3	350	-0.23	-0.09	0.06	0.11
3	505.6	507	-0.02	0.00	-0.02	0.02
4	597.6	594.2	0.00	0.00	0.00	0.00
5	778.5	769.8	-0.38	-0.12	0.09	0.17
6	935.5	917	-0.98	-0.29	0.21	0.38
7	1174.6	1175	-0.02	0.02	0.02	0.08
8	1339.8	1338.1	-0.20	-0.06	0.04	0.07



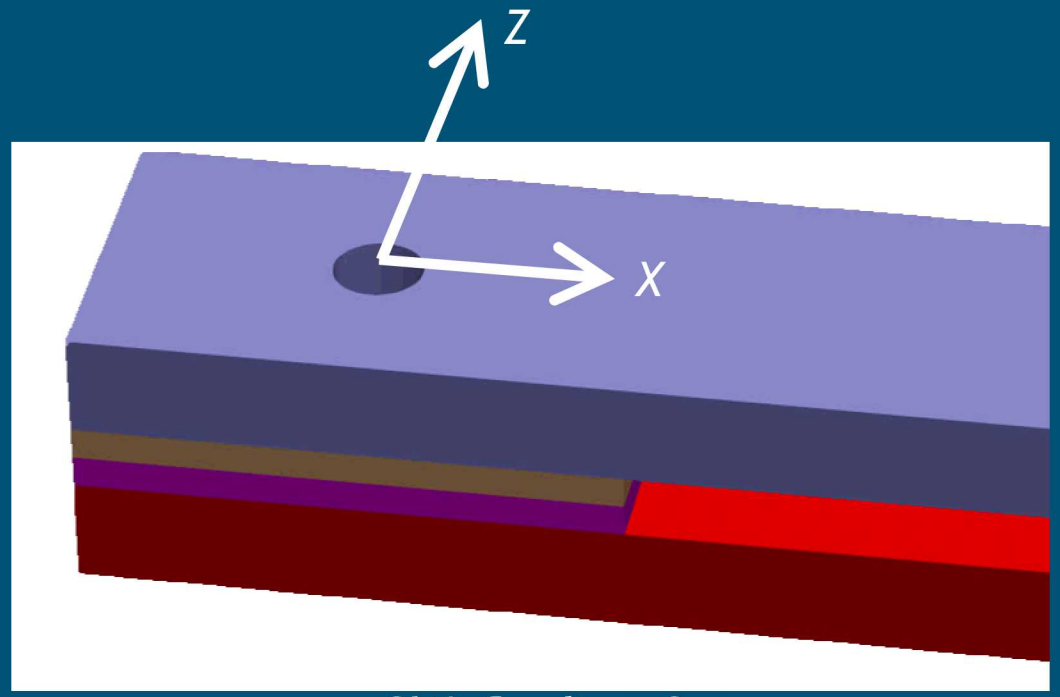
Mode 6 Shape

Shifting Effect

- Assembly tolerances allow for interfaces to shift relative to each other.
- What effect does this shift allow on modal predictions?
  - **Not much effect for this case.**

Surface Shift Percent Difference

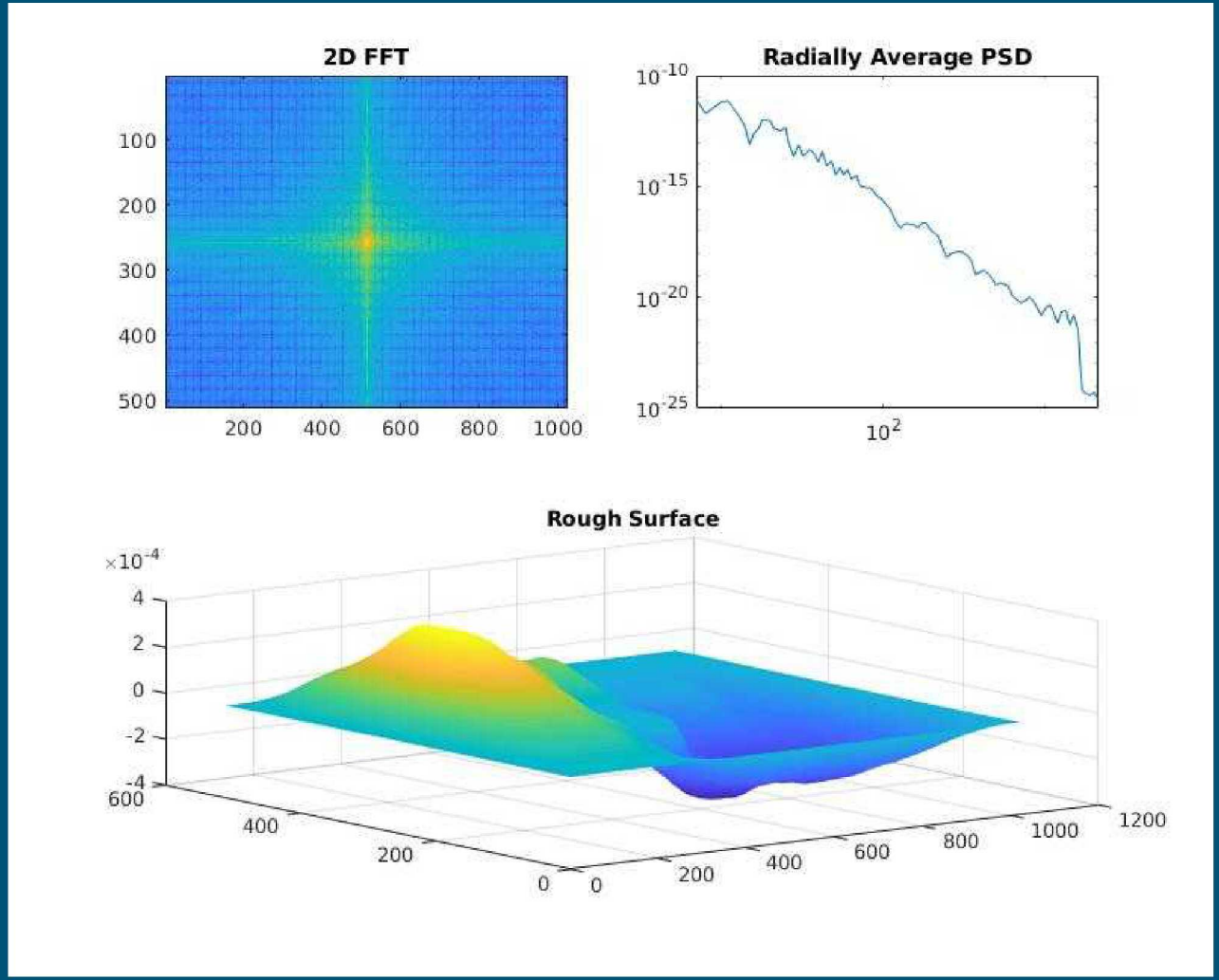
X 0.01	X 0.00	X -0.01	X 0.00
Z 0.00	Z 0.01	Z 0.00	Z -0.01
-0.04	0.07	0.04	0.00
0.00	0.03	0.03	0.03
-0.02	-0.02	-0.02	0.00
0.00	0.00	0.00	0.00
0.00	0.08	0.03	0.03
0.02	0.21	0.03	0.04
0.03	0.04	-0.01	0.03
0.00	0.02	0.01	0.01



Shift Coordinate System

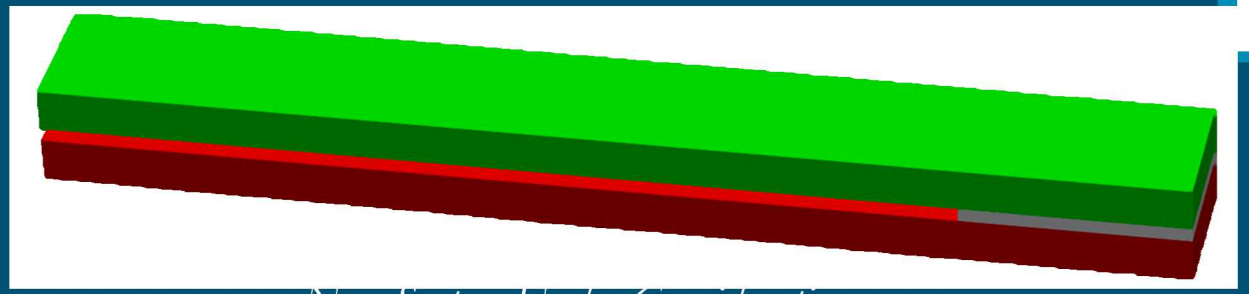
Statistical Surface Representation

- Given a machined surface, or lot of machine surfaces, a frequency domain representation can be calculate.
- Using random phase, new surfaces can be generated from the same Power Spectral Density.
- Do surfaces with identical PSDs produce identical modal responses?

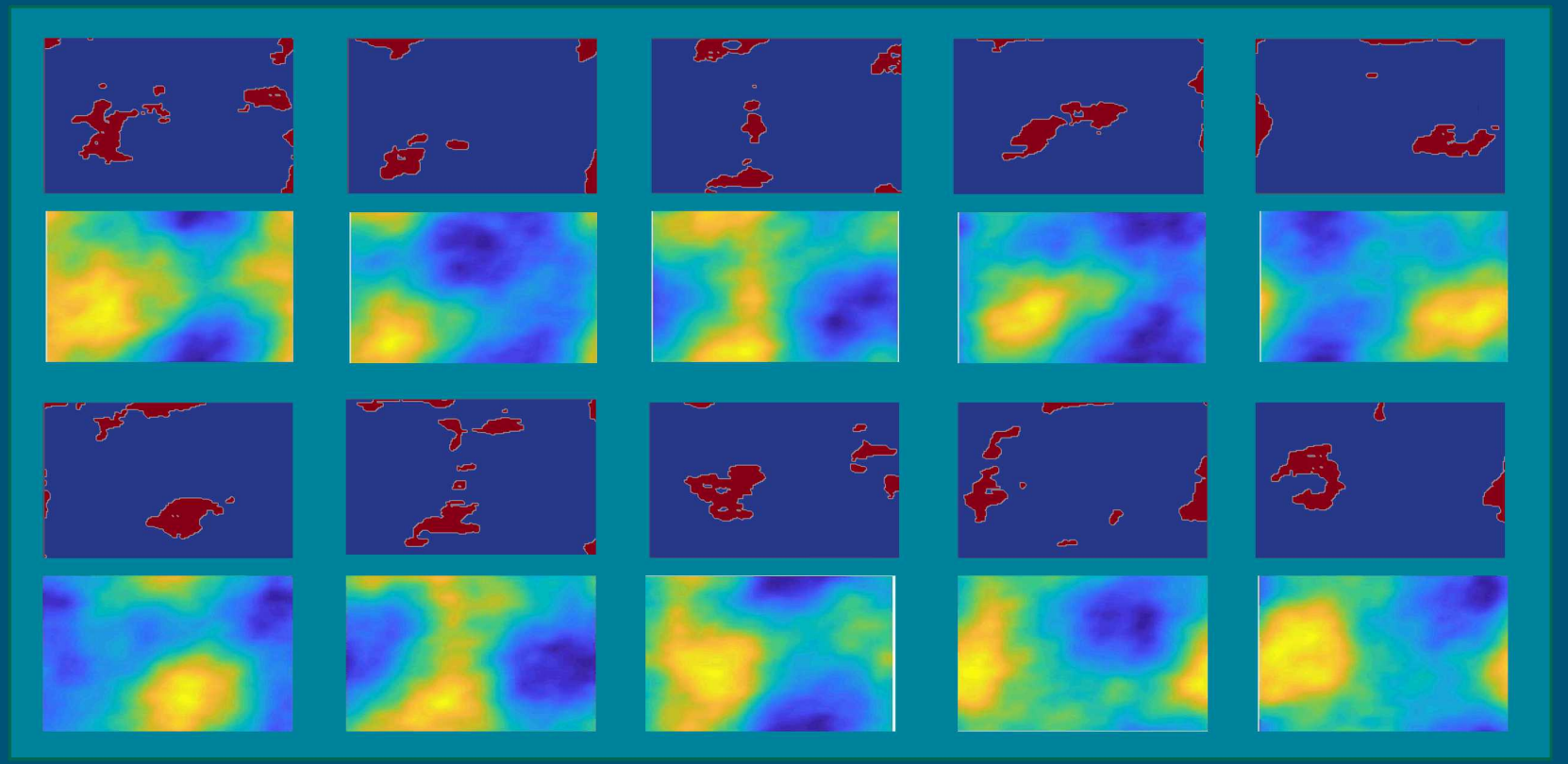


Frequency Domain of Surface

Statistical Surfaces



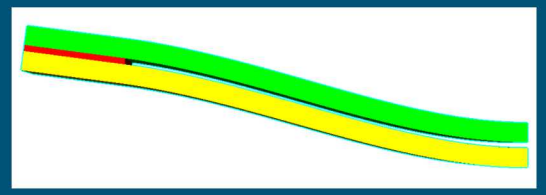
New System Under Consideration



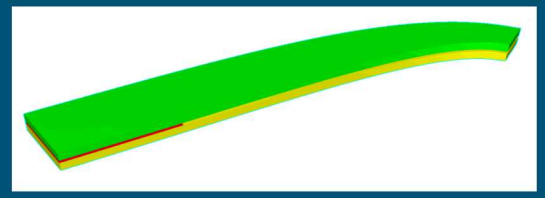
10 Realizations with Identical PSDs

Statistical Surfaces Modal Analysis Results

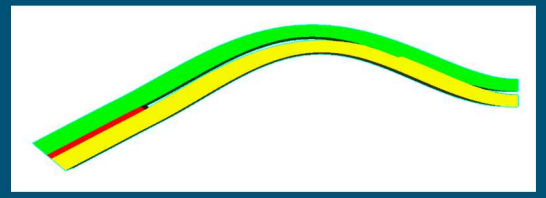
- The surfaces do not produce the same modal results.
- Neither area nor PSD correlate to modal frequency.
- Spatial distribution of contact points plays the largest role in modal frequencies,



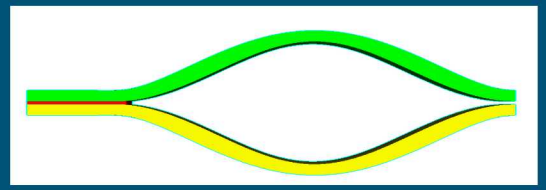
Mode 1



Mode 2



Mode 3



Mode 4

Frequencies of Flat Interfaces

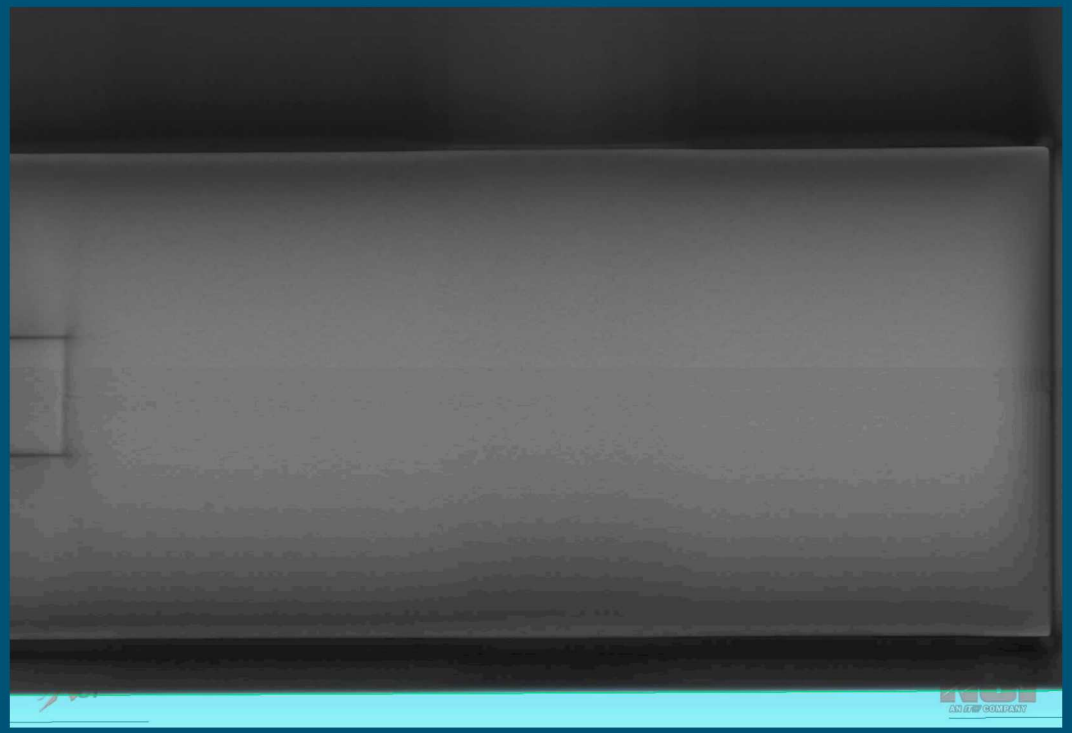
	Edge Tied	Full Tied
Mode 1	191.8	193.5
2	386.3	386.3
3	998.7	1007.1
4	1148	1166.4

Statistics of Surface Response

	Mean	S.D.
Area	0.542	0.071
Mode 1	190.3	1.393
2	386.1	0.107
3	993.8	6.318
4	1123.9	33.248

Conclusions

- Perturbed surface meshes:
  - Are straight forward to generate.
  - Improve modal results over fully tied.
  - Are predictive instead of calibrated.
- Magnitude of preload force is important to the solution
- Assembly tolerances were insignificant for this system
- PSD surface generation is a good way to determine uncertainty in response.



CT Scan of C-Beam Interface