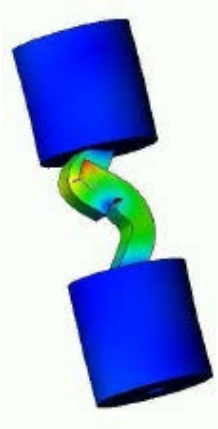
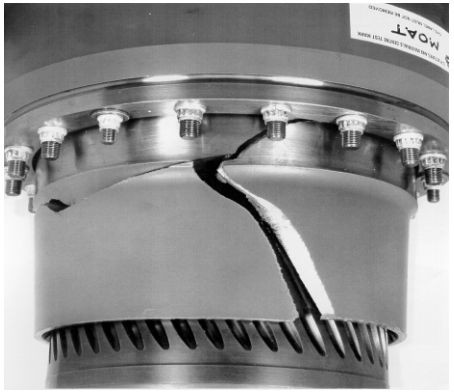
Exceptional service in the national interest





Force Reconstruction at Mechanical Interfaces

Students: Deborah Fowler, Samuel Parker, Matthew Cleal

Mentors: Peter Avitabile (UMass Lowell), Patrick Logan (UMass Lowell), Dan Roettgen (Sandia), Ben Pacini (Sandia), Rob Kuether (Sandia)

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Motivation

- Joints are a source of nonlinearities in many common structures
- The dynamic force due to a joint's bolted area is challenging to predict and confirm experimentally
- Better techniques are needed to analyze the effects of a bolted joint on a structure

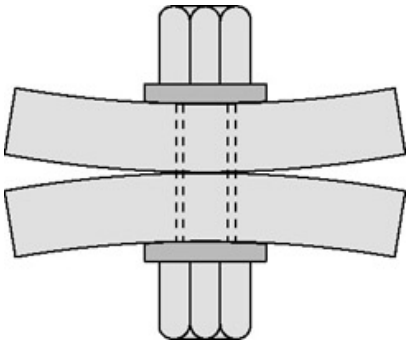


Image from Spacecraft Thermal Control Handbook, Vol. 1

Image from smartbolts.com

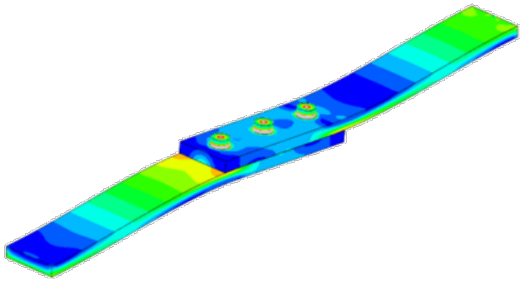
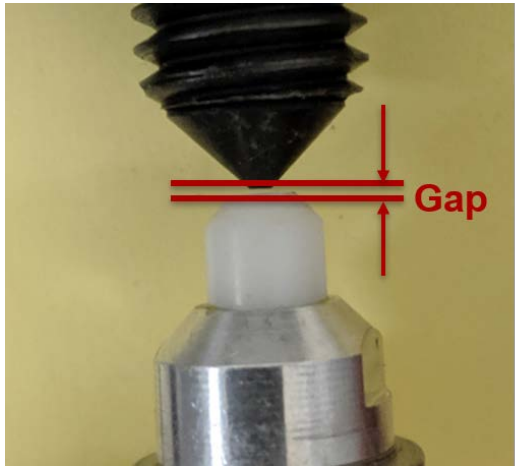


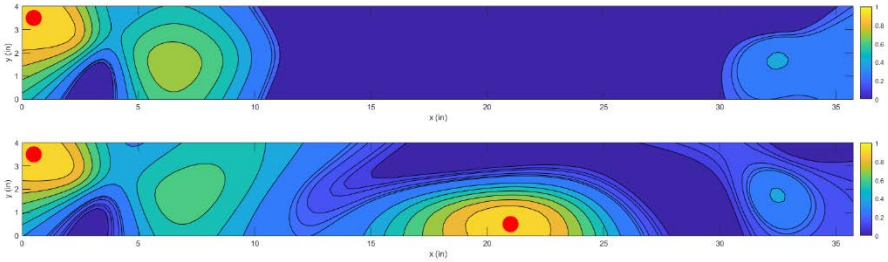
Image from simuleon.com

To explore these applications, a force reconstruction technique will be used to reconstruct the nonlinear contact forces from a mechanical interface

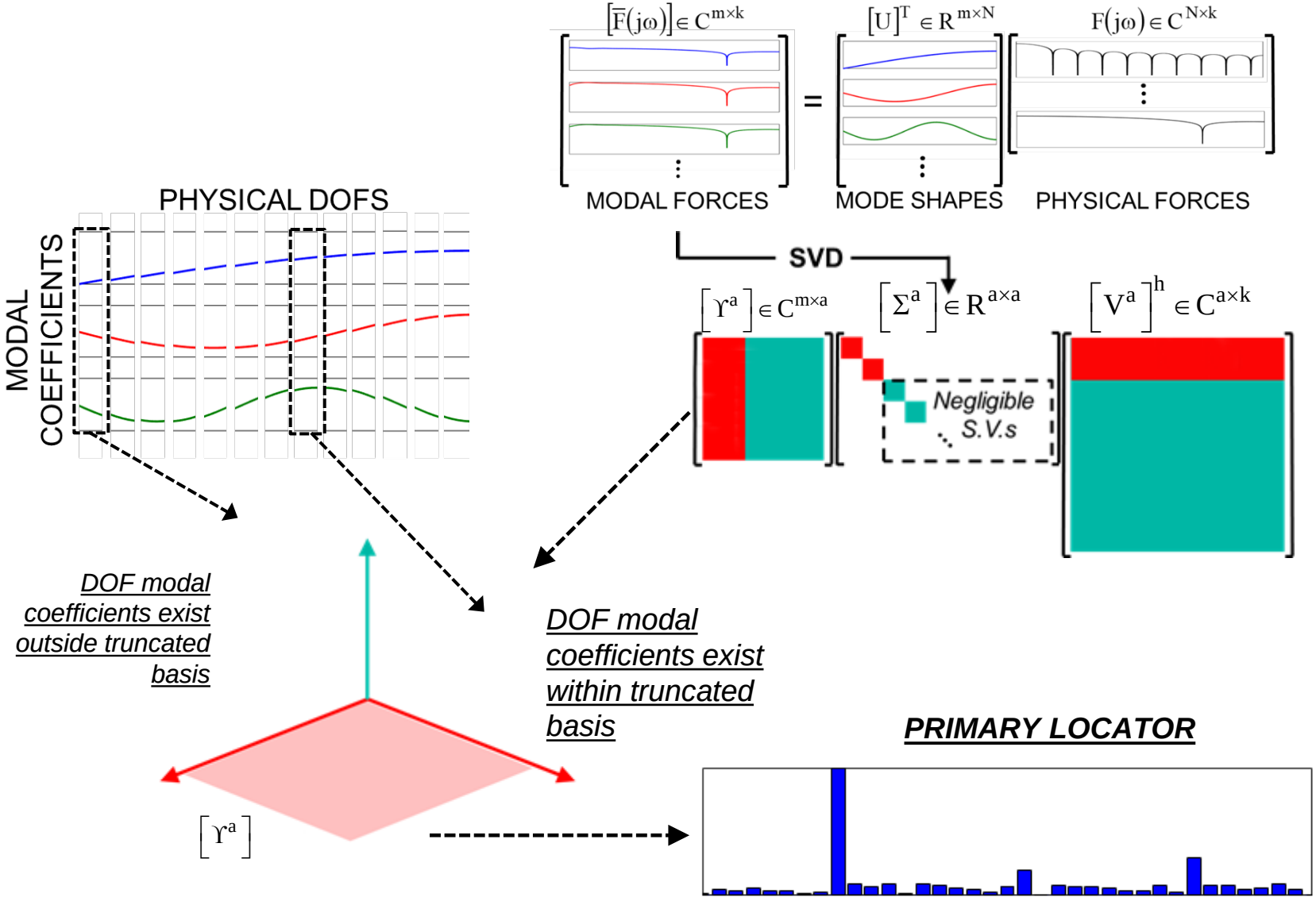
Presentation Outline

- Theory
- Analytical Case Studies
- Experimental Case Studies
- Summary and Conclusions

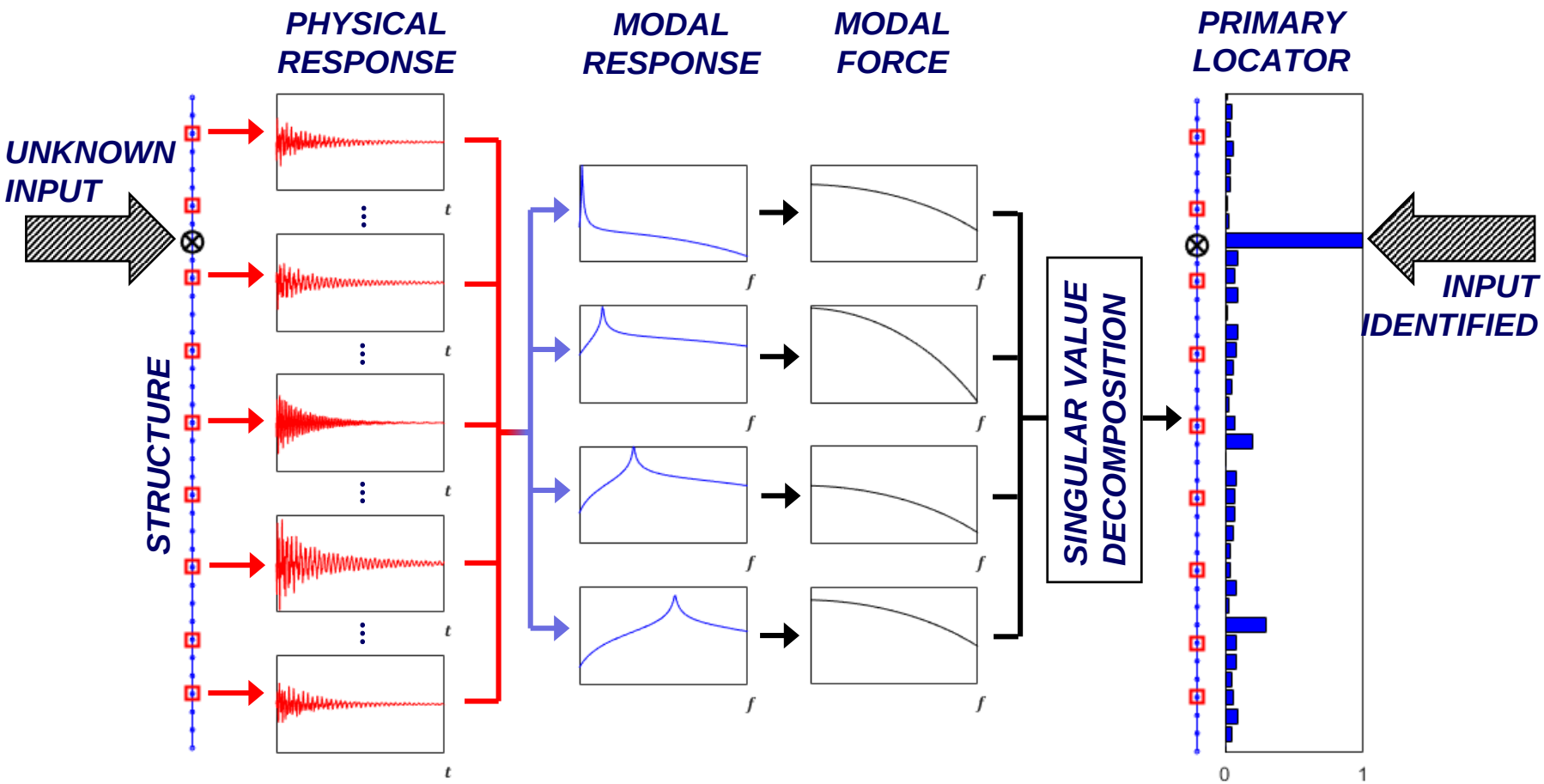




Source Identification



Reconstruction Process



Analytical Case Studies

Guiding Questions

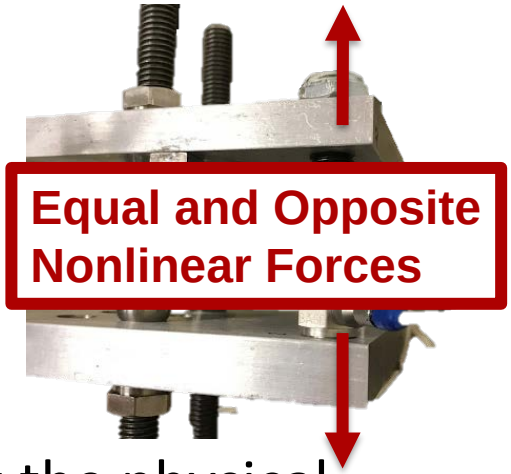
- Can internal forces due to nonlinear gap contacts be identified?
- What should be the focus of experimental cases?

Selected Case Studies

- **Case 1:** Reconstruction of single input
- **Case 2:** Reconstruction of multiple uncorrelated inputs
- **Case 3:** Reconstruction of multiple correlated inputs

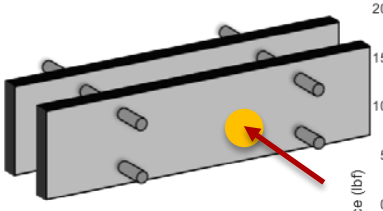
Model Description

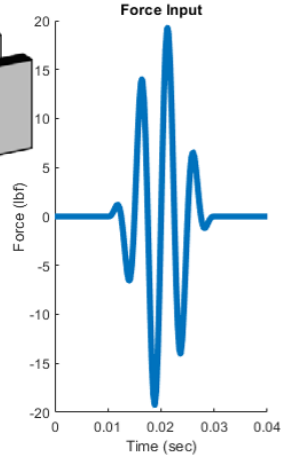
To study the reconstruction of internal, nonlinear forces, a structure was designed with a mechanical interface that exhibits nonlinear gap contact behavior

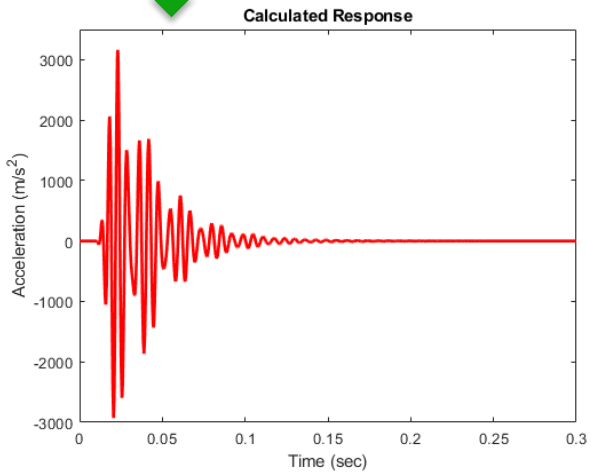


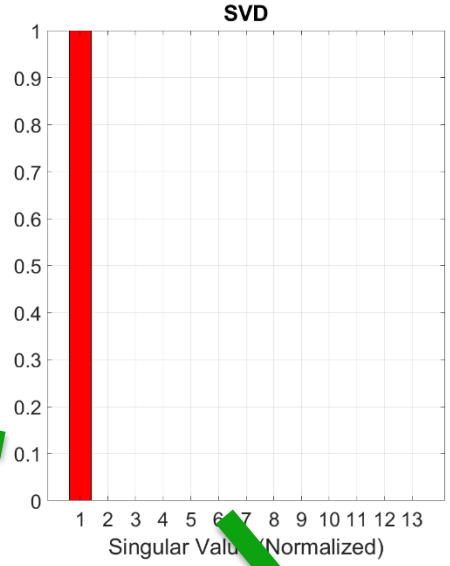
A simplified FEA model was developed to represent the physical structure, which is used for the following analytical cases

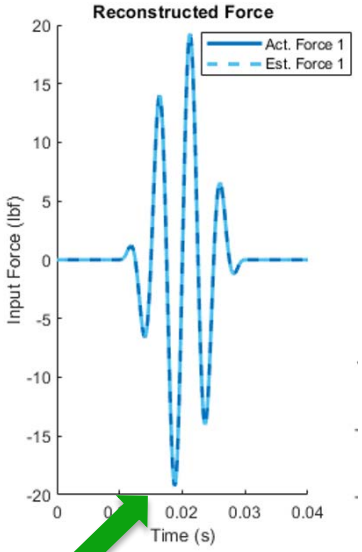
Case 1: Single input

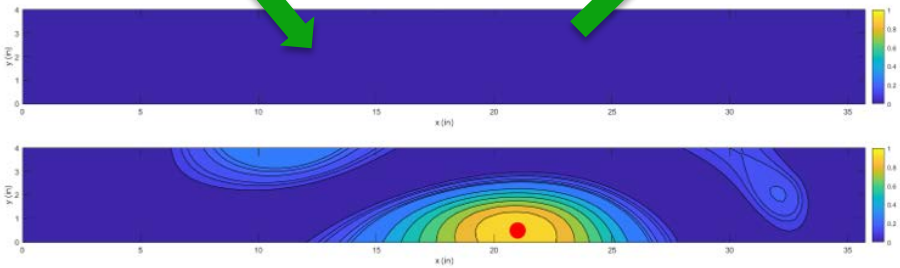






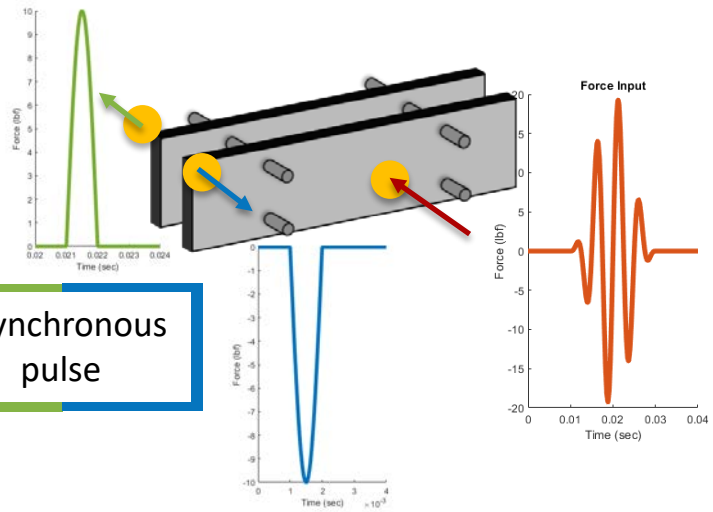




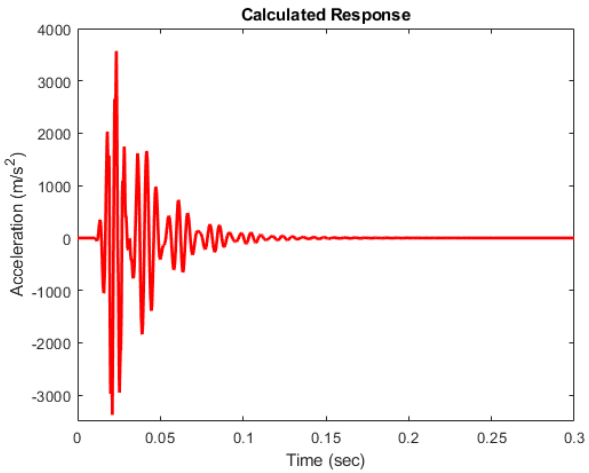


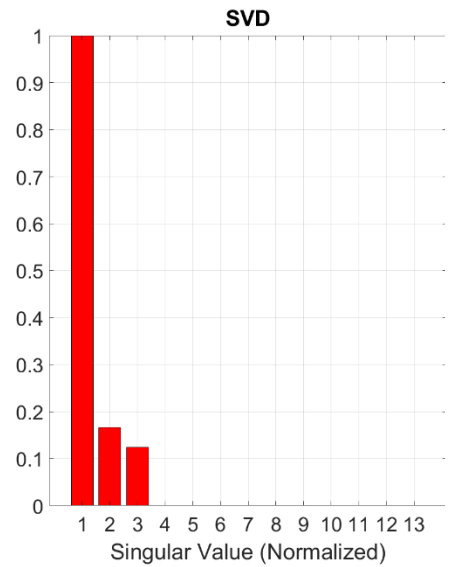
Correct location and reconstruction

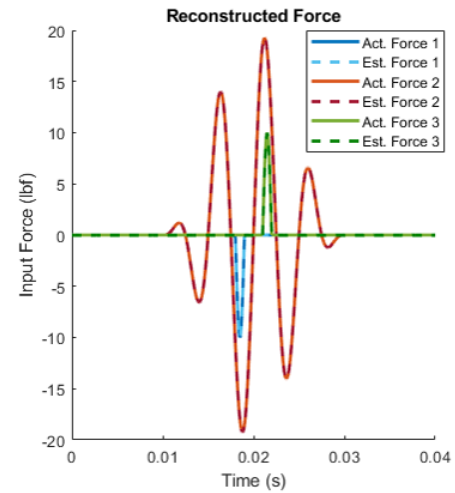
Case 2: Multiple input, uncorrelated

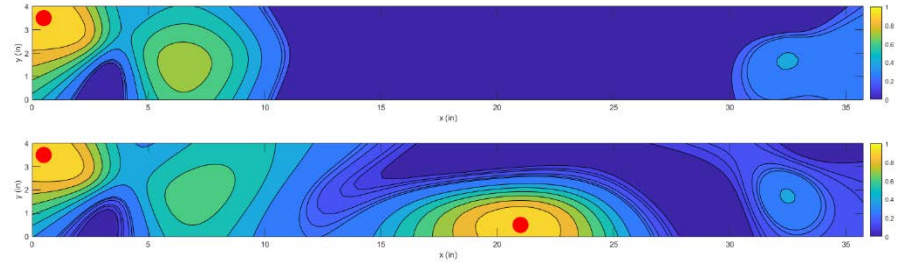


Asynchronous pulse



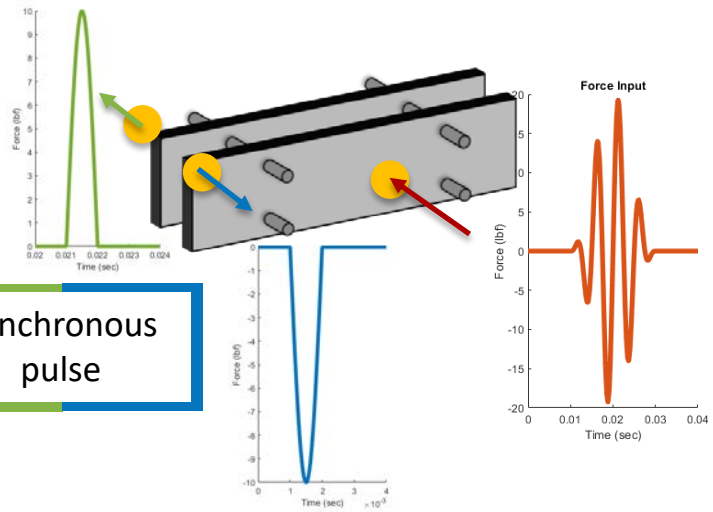




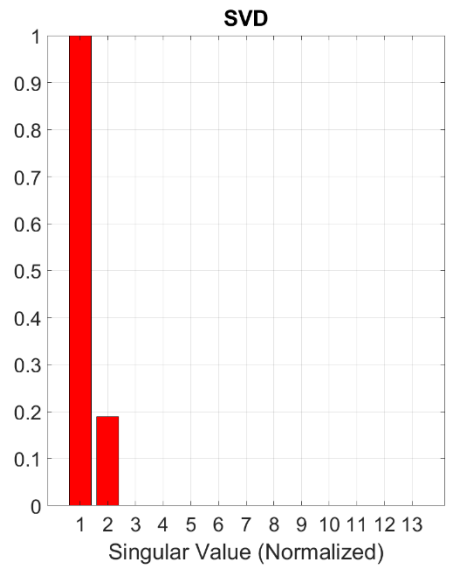


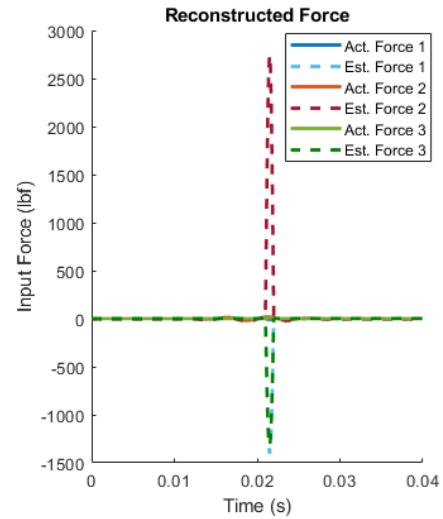
Correct location and reconstruction

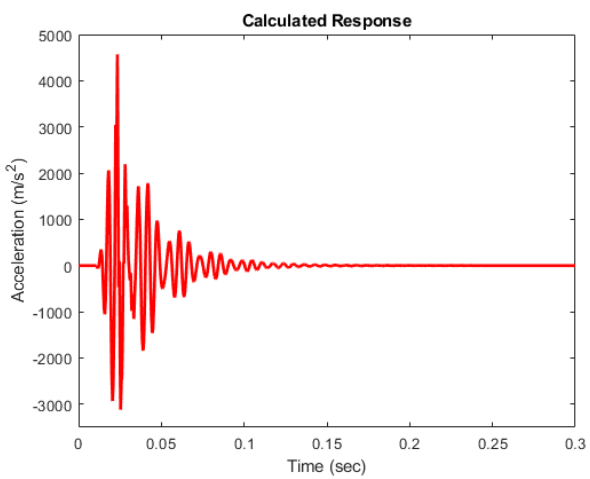
Case 3: Multiple input, correlated

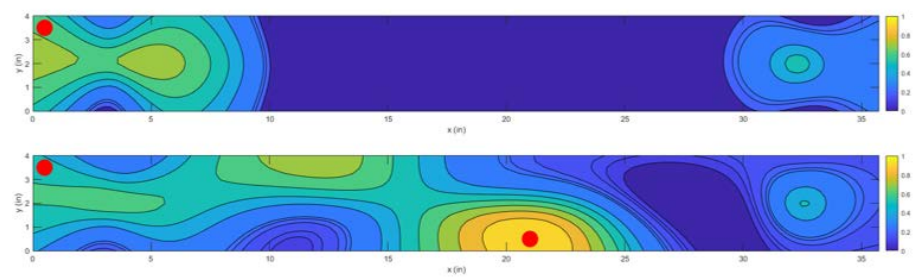


Synchronous pulse



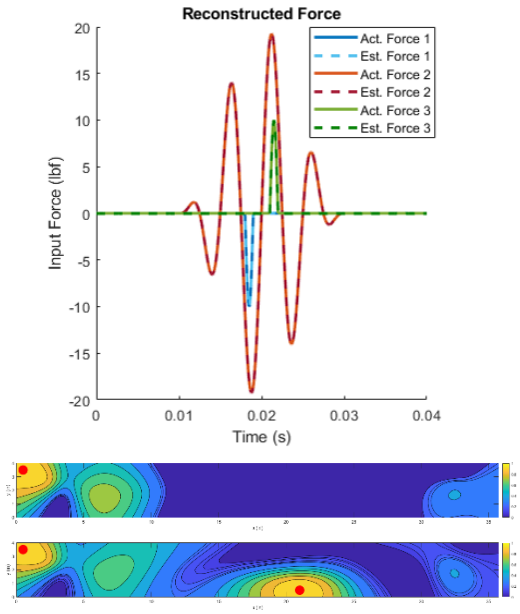




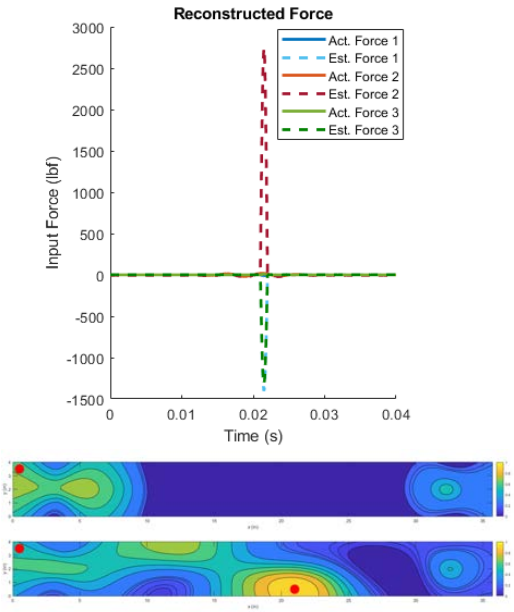


Incorrect location and reconstruction

Analytical Results



Uncorrelated forces can be correctly located and reconstructed…



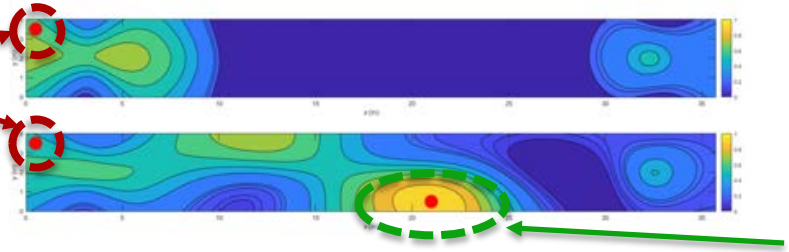
…but difficulty arises when forces are correlated

Modifications to the existing locator function are needed to correctly locate correlated forces

Composite Locator Function

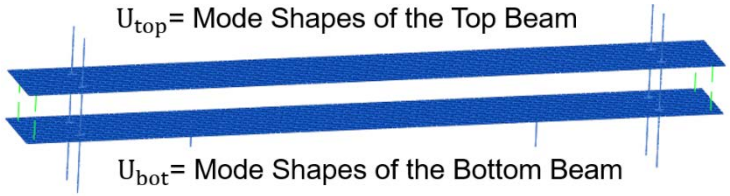
Case 3: Multiple input, correlated

Fails to locate correlated forces



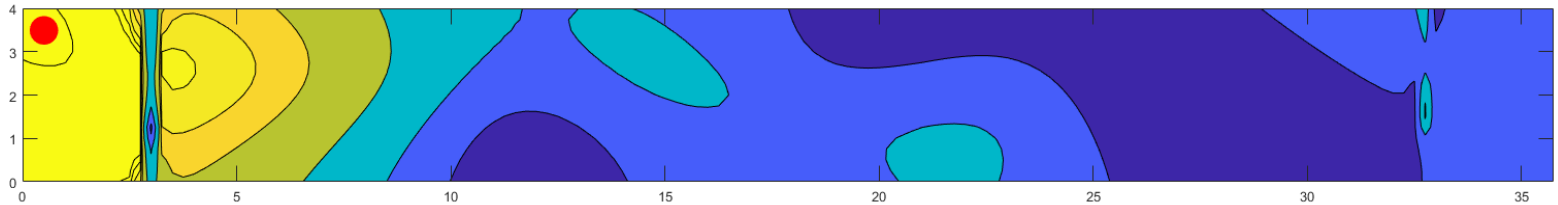
Correctly locates uncorrelated forces

Composite Locator Function



$$U_{diff} = U_{bot} - U_{top} \qquad PLF(U_{diff})$$

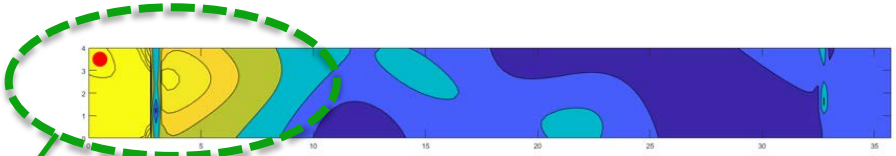
Correctly locates correlated forces!

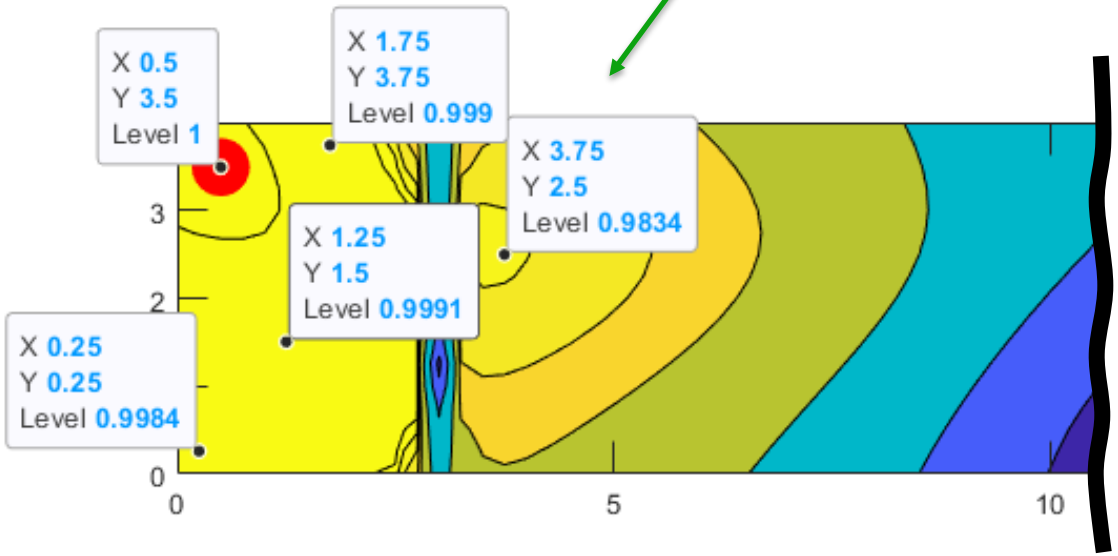


Composite Locator Function

Case 3: Multiple input, correlated

For this structure's dynamics in the frequency range studied, the estimation is accurate but less precise



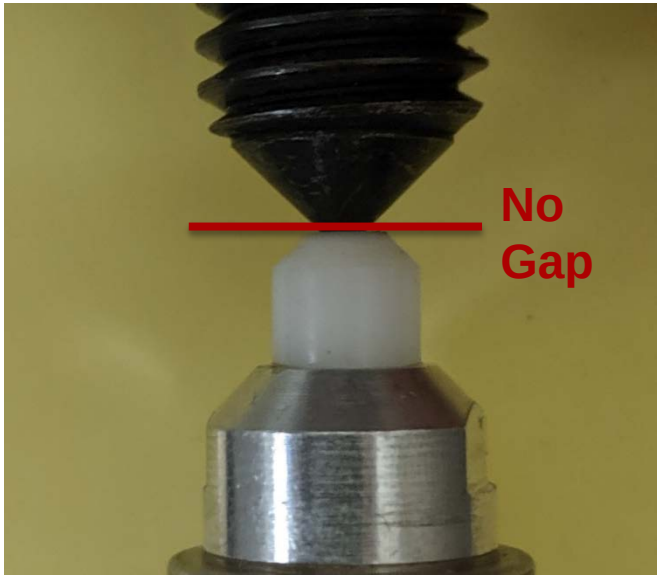


Experimental Case Studies

- Case 1: Linear Hammer Impact
- Case 2: Nonlinear Single Gap Impact
- Case 3: One Preloaded Point
- Case 4: Two Preloaded Points

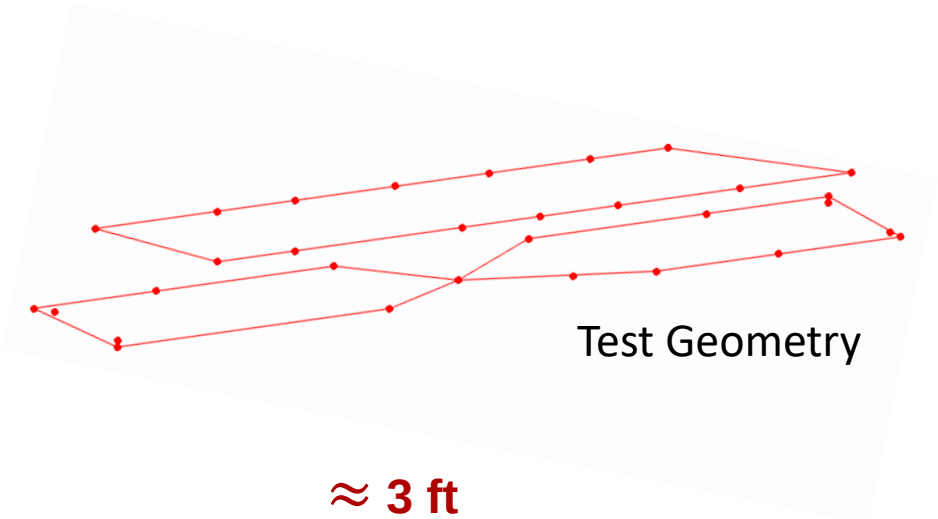
0.07mm Nonlinear Gap Connection

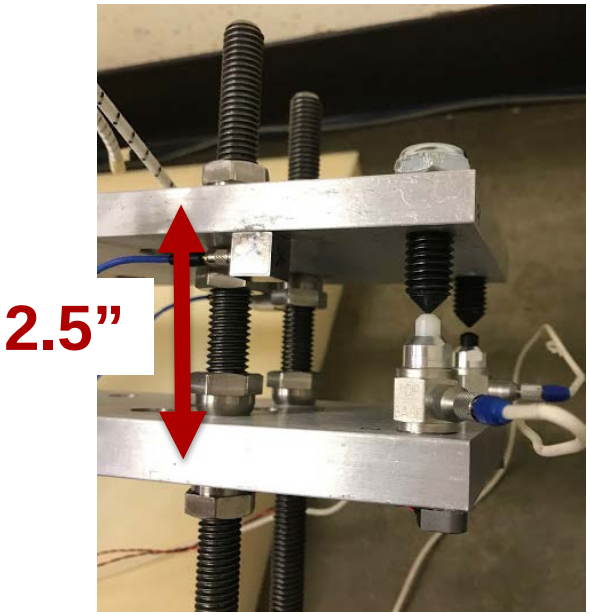
Preloaded Connection



Test Setup

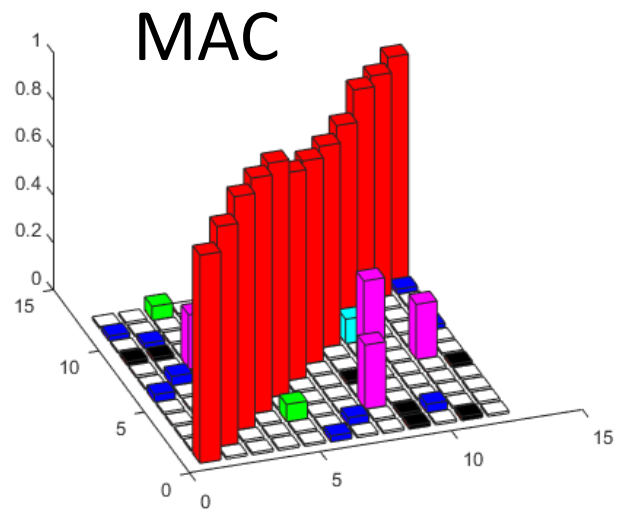
- The structure was instrumented with 13 uniaxial accelerometers, 4 triaxial accelerometers, and 4 force gages integrated in the nonlinear mechanical interface

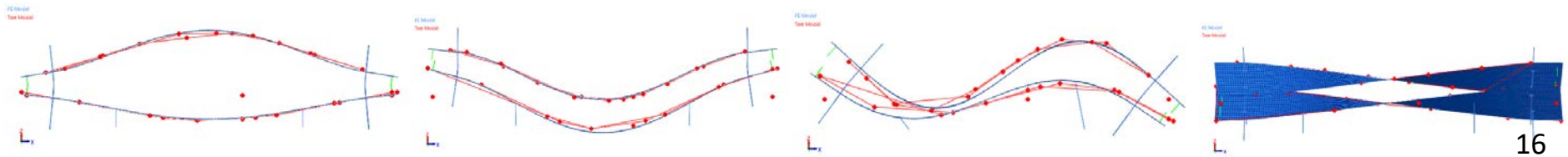




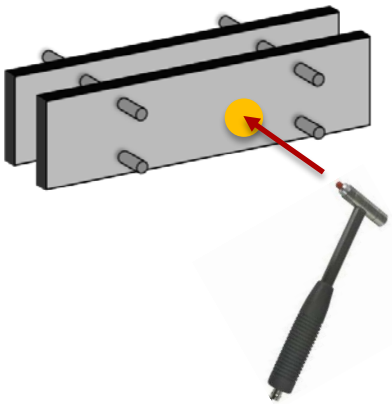
FE Model and Correlation

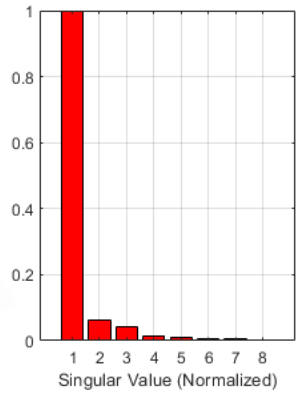
FEA	Hz	EMA	Hz	Diff. (%)	MAC (%)	POC (%)
1	96.933	1	85.197	13.77	98.9	99.7
2	155.52	2	151.07	2.94	99.4	99.8
3	199.16	3	189.1	5.32	98.3	99.3
4	262.88	4	257.07	2.26	99.1	99.8
5	282.69	5	261.22	8.22	96.8	99.2
6	422.62	6	413.76	2.14	98.8	99.5
9	555.55	7	487.55	13.95	96.9	98.5
7	518.25	8	509.08	1.8	76.1	96.4
9	538.84	9	513.77	4.88	97.4	91.3
8	549.84	10	540.05	1.81	13.6	83.6
11	678.5	11	608.52	11.5	98.4	99.8
12	743.8	12	690.98	7.64	98.3	98.9
13	877.86	13	744.65	17.89	94.5	94.8

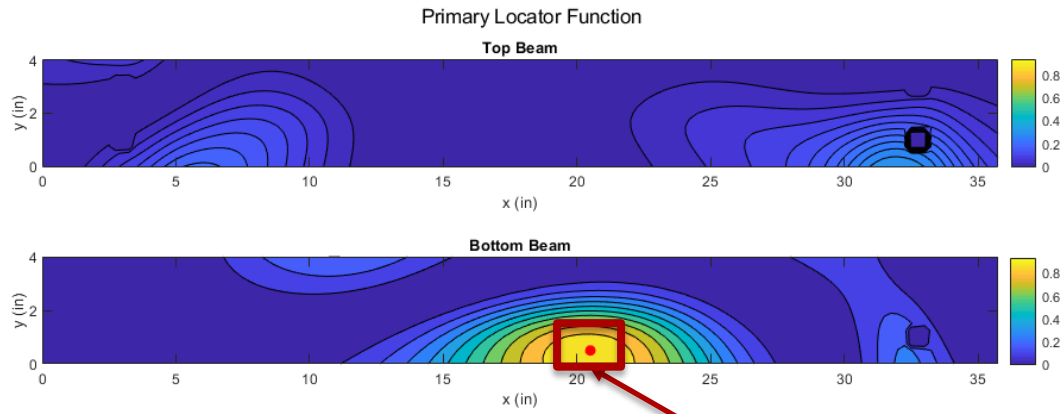


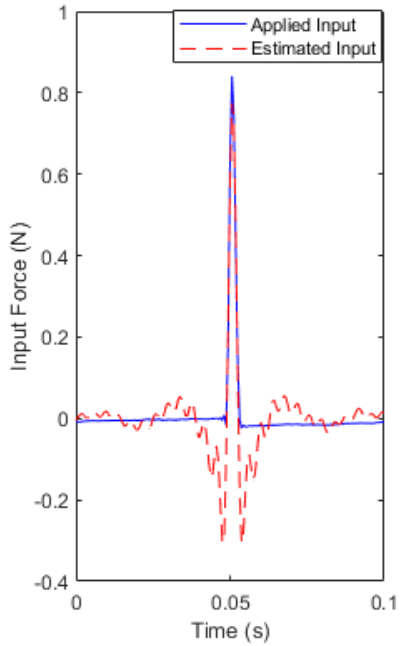


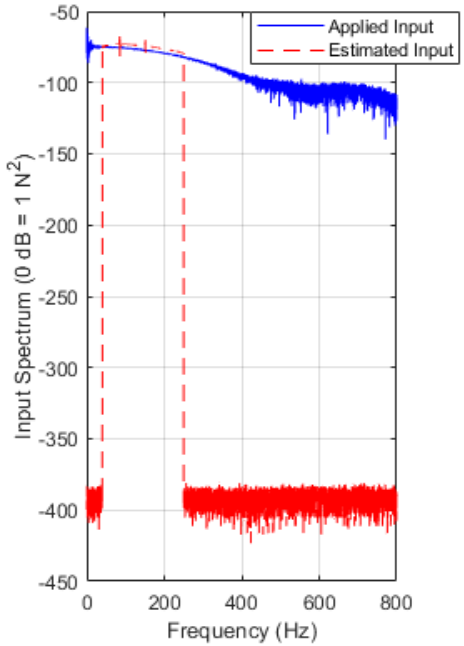
Case 1: Linear Hammer Impact

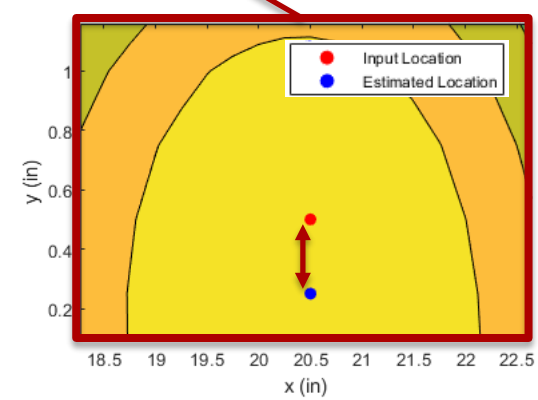










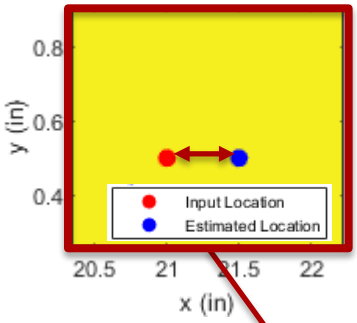


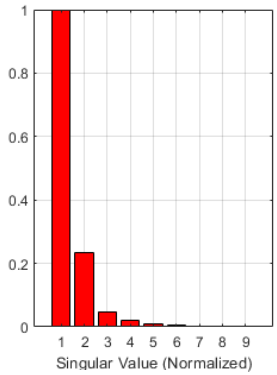
0.7% Error

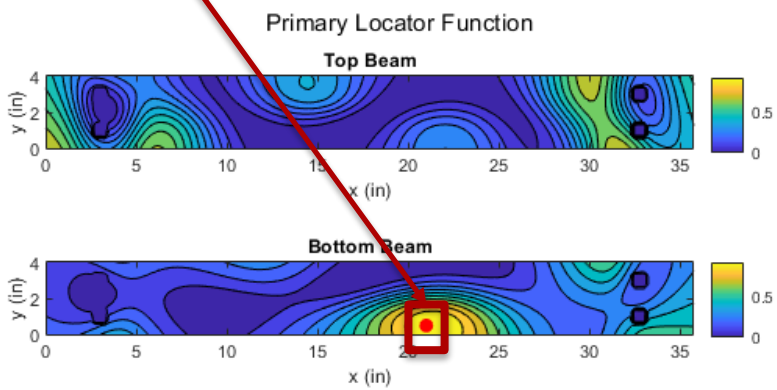
Case 2: Nonlinear Single Gap Impact

Reconstructing Shaker Input Force

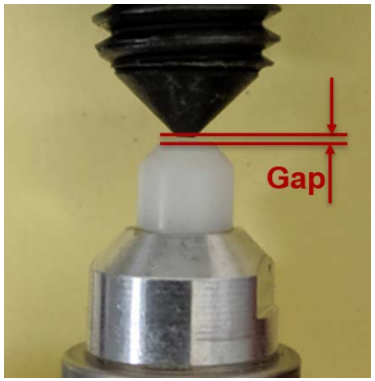
1.4% Error



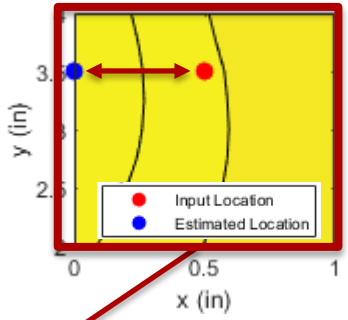


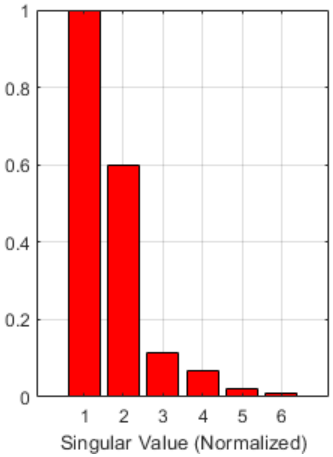


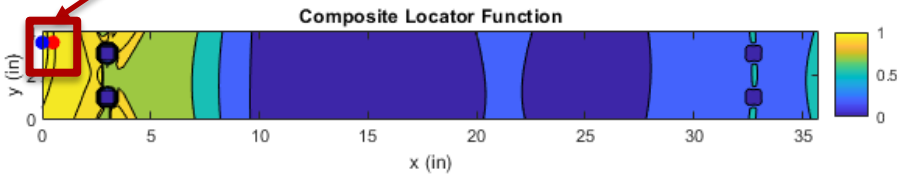
Reconstructing Nonlinear Contact Force



1.4% Error



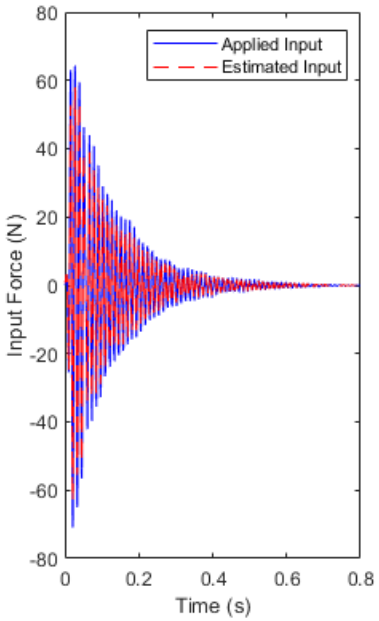




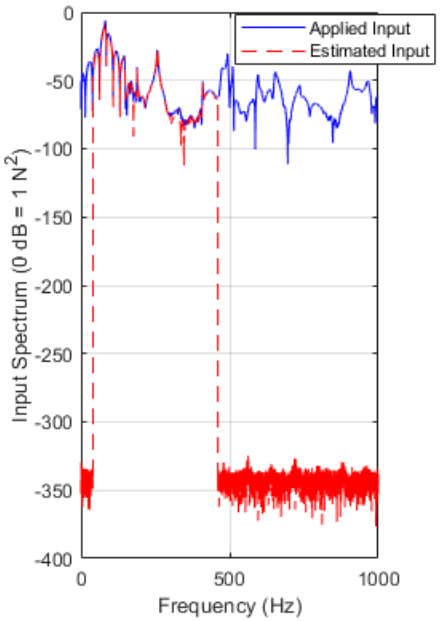
Case 2: Nonlinear Single Gap Impact

Reconstructing Shaker Input Force

99% TRAC

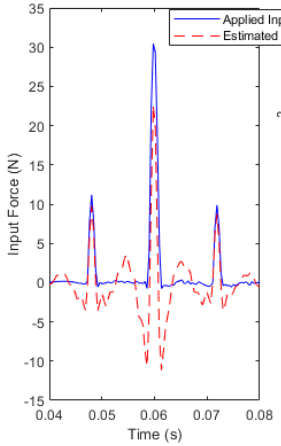


99.8% FRAC

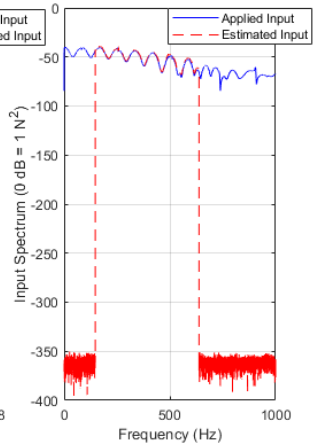


Reconstructing Nonlinear Contact Force

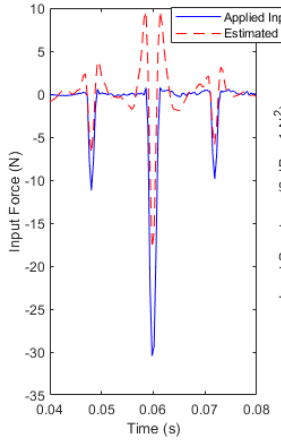
53% TRAC



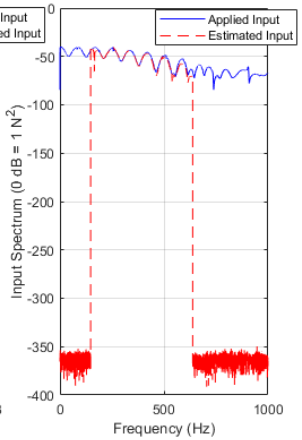
95% FRAC



57% TRAC

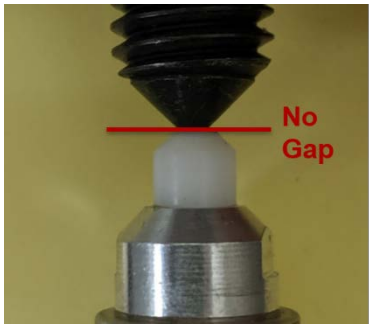


99% FRAC

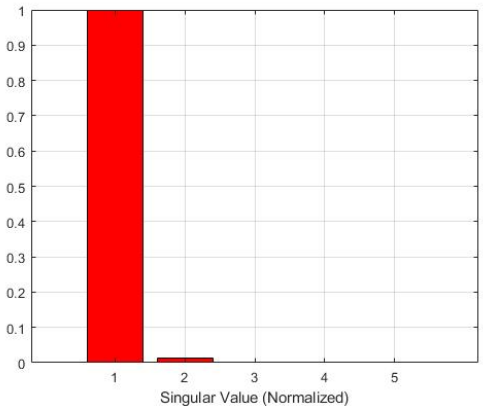


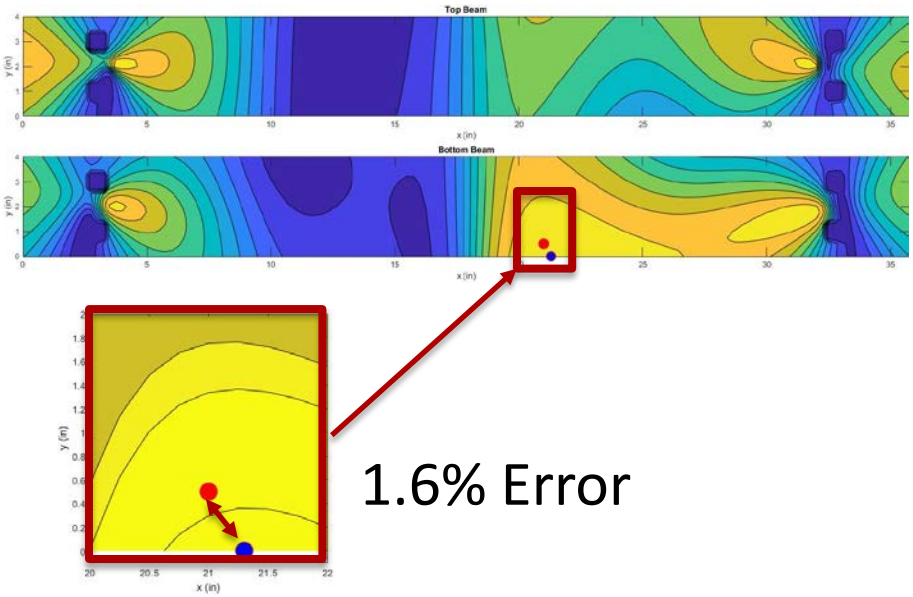
The frequency domain reconstruction is highly accurate, indicating time domain error is due to frequency truncation.

Case 3: One Preloaded Point



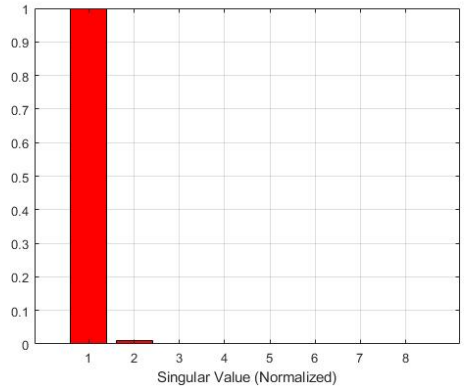
Locating Shaker Input Force

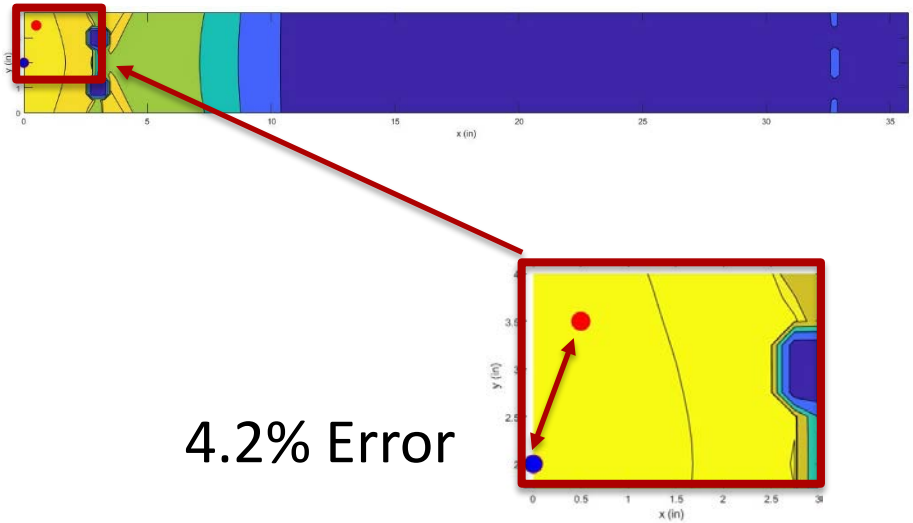




1.6% Error

Locating Contact Force





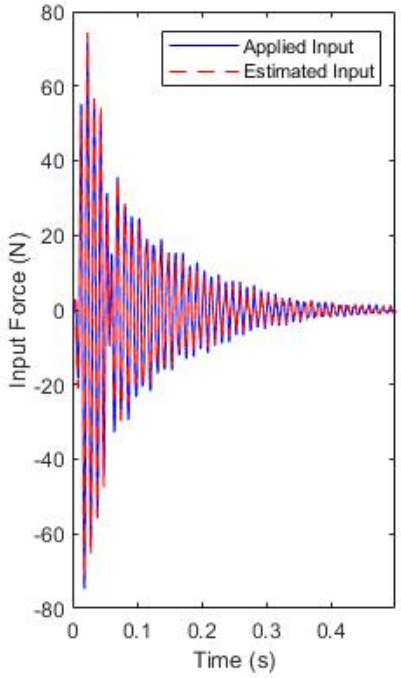
4.2% Error

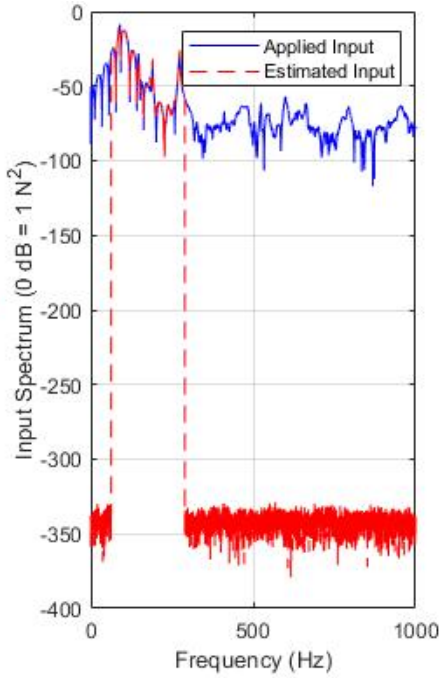
Case 3: One Preloaded Point

Reconstructing Shaker Input Force

TRAC: 98%

FRAC: 98%

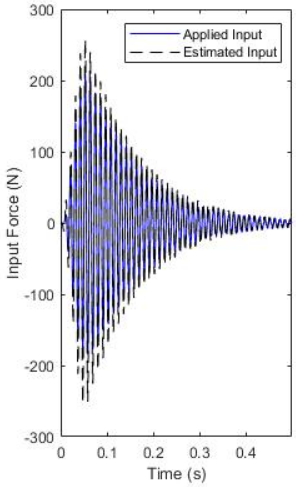


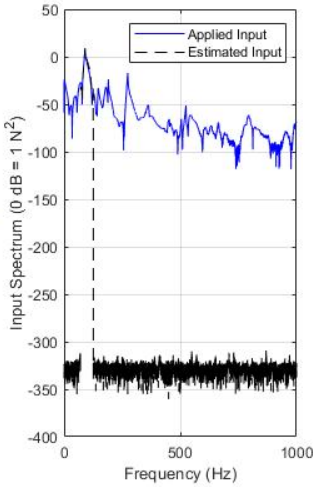


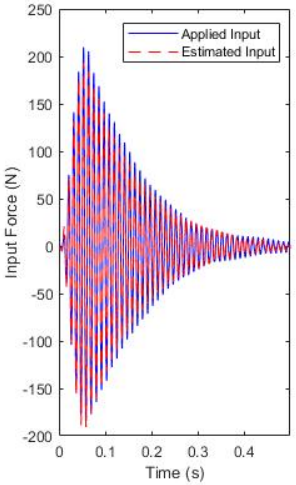
The reconstruction was highly accurate for the preloaded contact forces

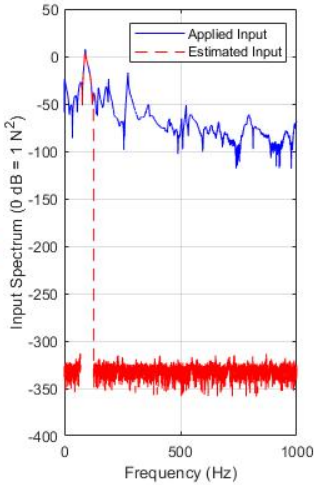
Reconstructing Contact Force

Top Beam
TRAC: 97%
FRAC: 99%



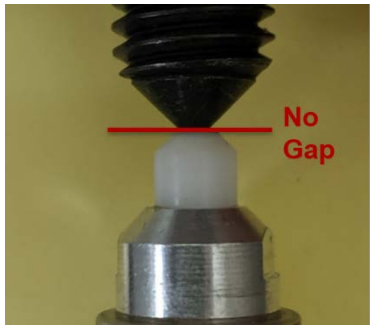




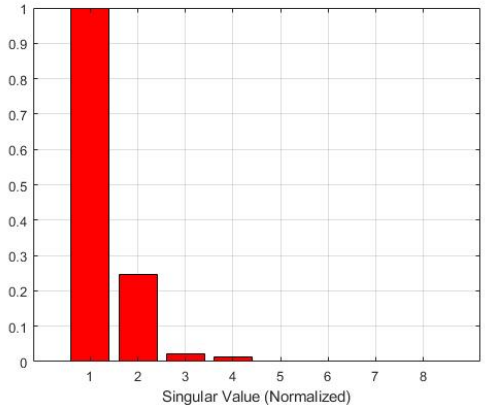


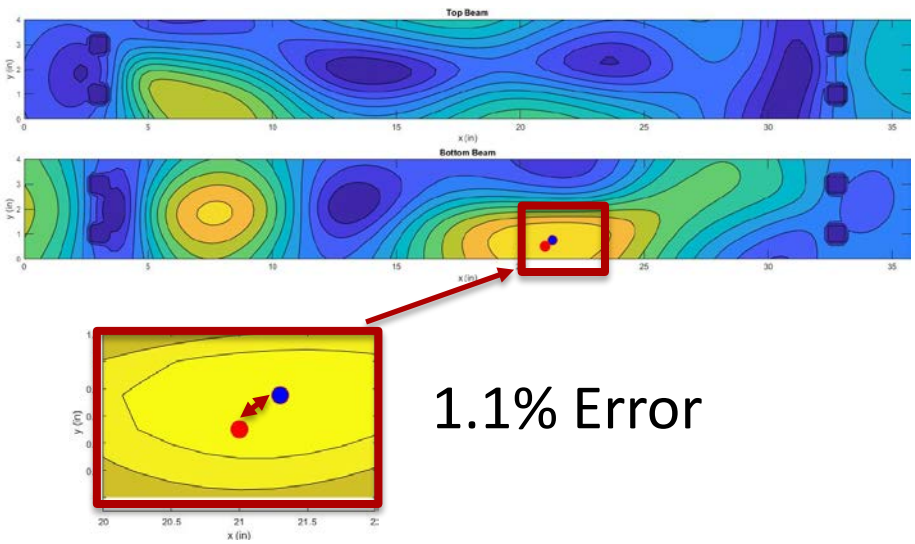
Bot Beam
TRAC: 98%
FRAC: 99%

Case 4: Two Preloaded Points



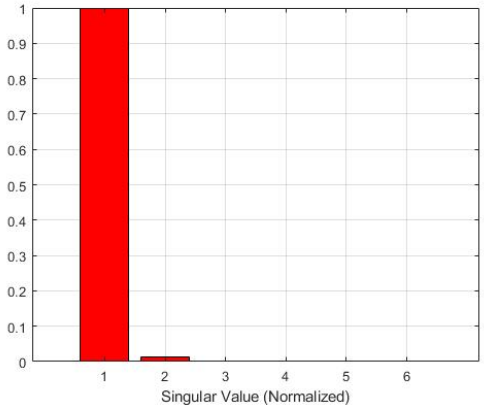
Locating Shaker Input Force

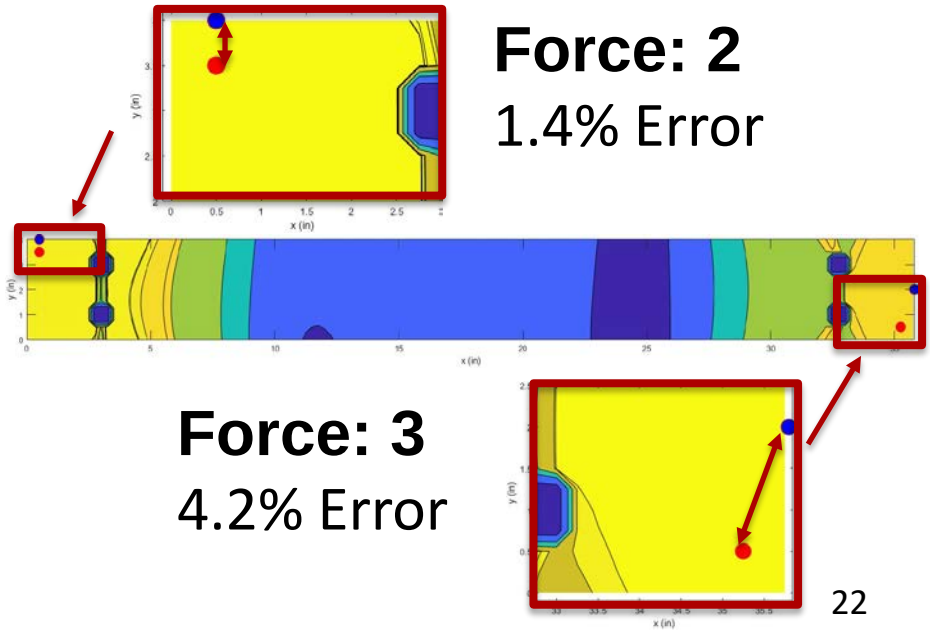




1.1% Error

Locating Contact Force





Force: 2

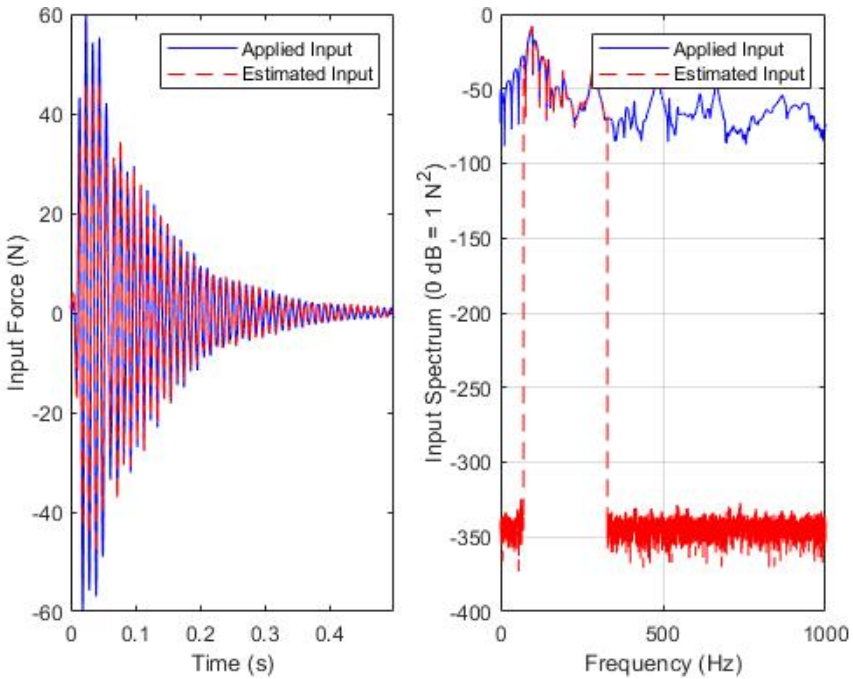
1.4% Error

Force: 3

4.2% Error

Case 4: Two Preloaded Points

Reconstructing Shaker Input Force



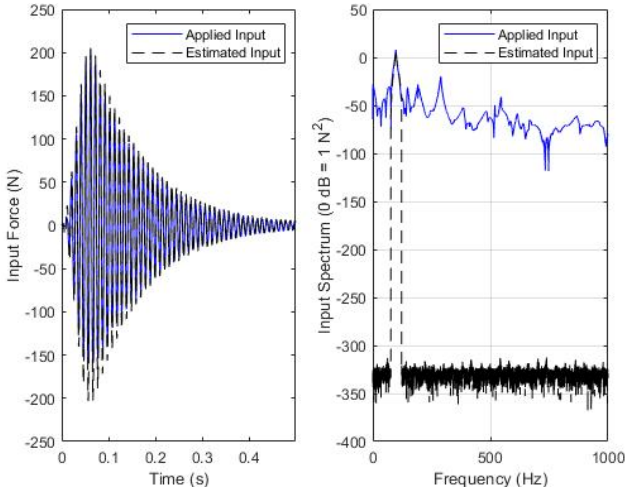
TRAC: 95%

FRAC: 97%

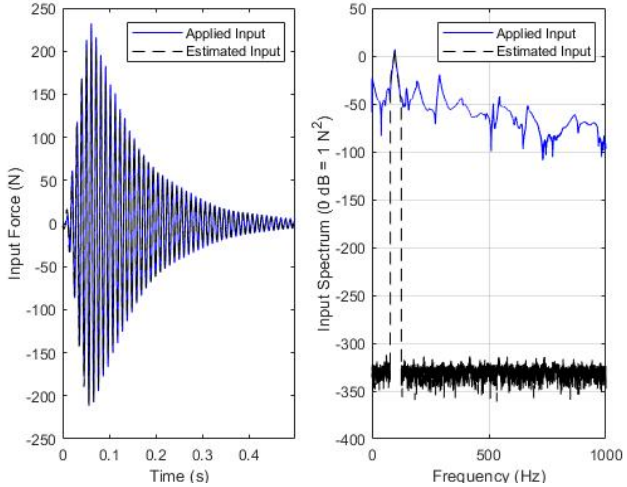
Case 4: Two Preloaded Points

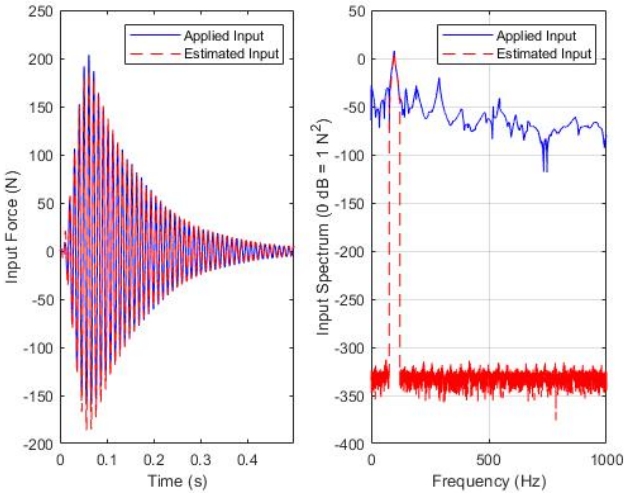
Reconstructing Contact Force

Force 2
Top Beam
TRAC: 98%
FRAC: 98%

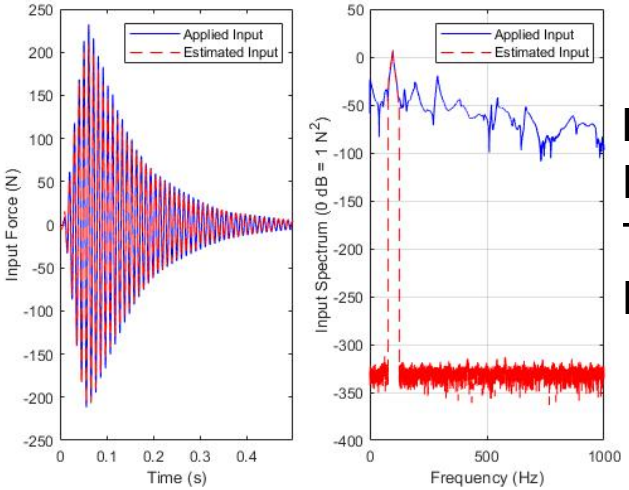


Force 3
Top Beam
TRAC: 99%
FRAC: 99%





Force 2
Bot Beam
TRAC: 98%
FRAC: 98%



Force 3
Bot Beam
TRAC: 99%
FRAC: 99%

Summary and Conclusions

- The Primary Locator Function is an effective tool for locating forces applied to a system
- The Composite Locator Function allows for the localization of internal, correlated forces
- Nonlinear gap impacts from the mechanical interface were successfully located and reconstructed
- Force resulting from an uncharacterized, preloaded contact was reconstructed with a high degree of accuracy

Acknowledgements

- This research was conducted at the 2019 Nonlinear Mechanics and Dynamics Research Institute supported by Sandia National Laboratories and hosted by the University of New Mexico.
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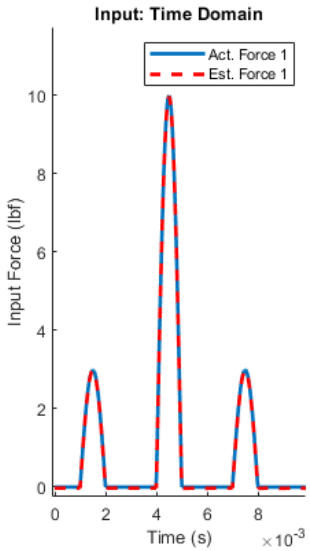
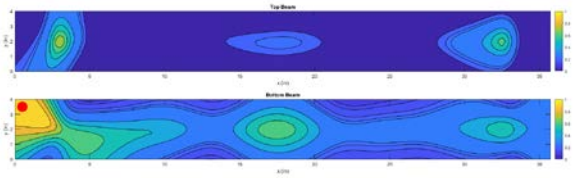
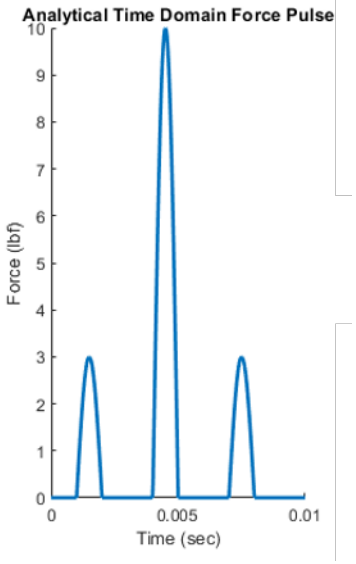
Experimental Force Reconstruction

Effect of inadequately characterizing modal information on reconstruction

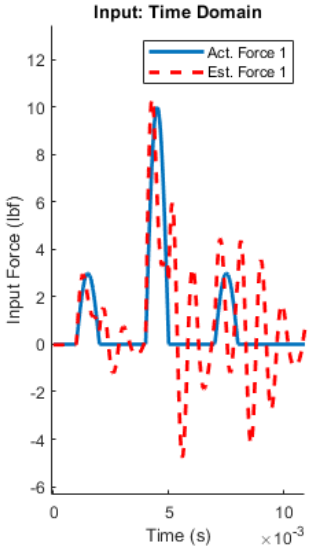
Modal Response: 20
Reconstruction: 20

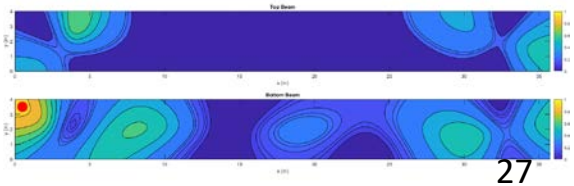






Modal Response: 20
Reconstruction: 13





Improper characterization leads to errors in reconstruction