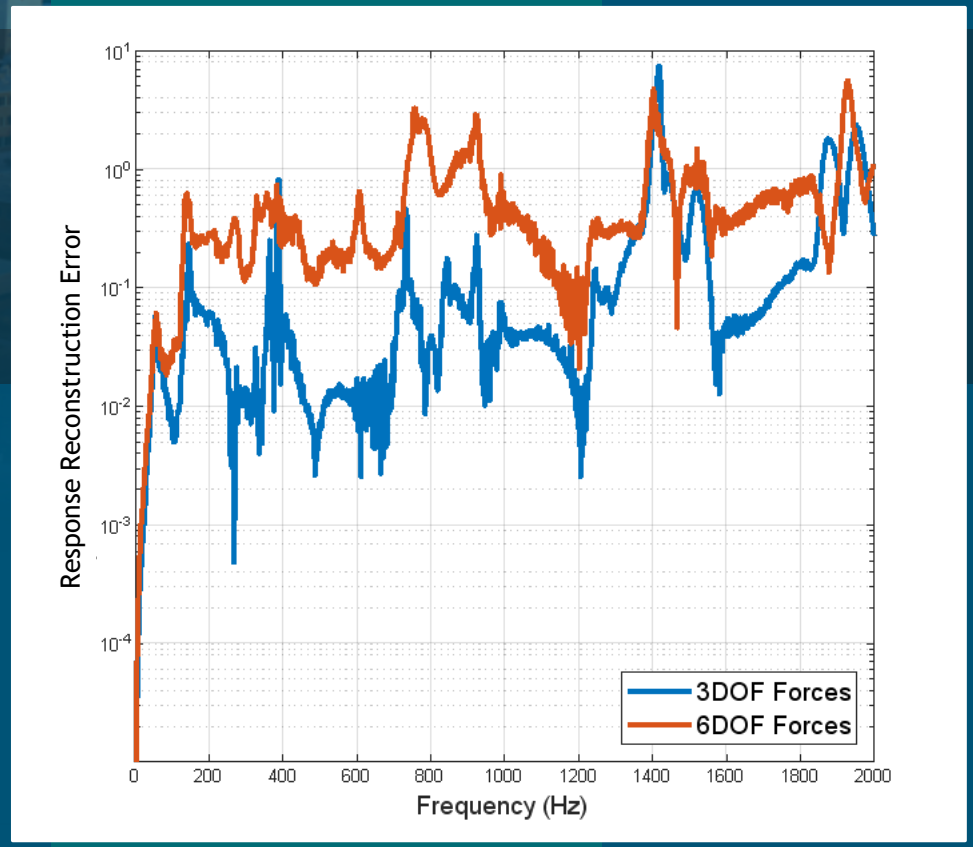
SAND2022-11090C

Sandia National Laboratories

Errors Using 6DOF Force Estimates to Translate Environments System-to-System



Presenter: Steven Carter, spcarte@sandia.gov

Co-Author: Brian Owens, bcowens@sandia.gov

U.S. DEPARTMENT OF ENERGY | NNSA

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Background and Introduction

Component-based TPA provides a theoretical framework for translating vibration environments system-to-system

Based on inverse force estimation

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Based on inverse force estimation:

$$F_{Estimated} = [H_{Original}]^{+}[X_{Original}][H_{Original}]^{+*}$$

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Translation

$$\boldsymbol{X_{New}} = [\boldsymbol{H_{New}}][\boldsymbol{F_{Estimated}}][\boldsymbol{H_{New}}]^{*}$$

Background and Introduction – **General Assumptions about the Forces**

The estimated forces are typically validated by comparing the reconstructed response to the measured response

TPA generally uses 3DOF force estimates, although 6DOF force estimates are considered more complete

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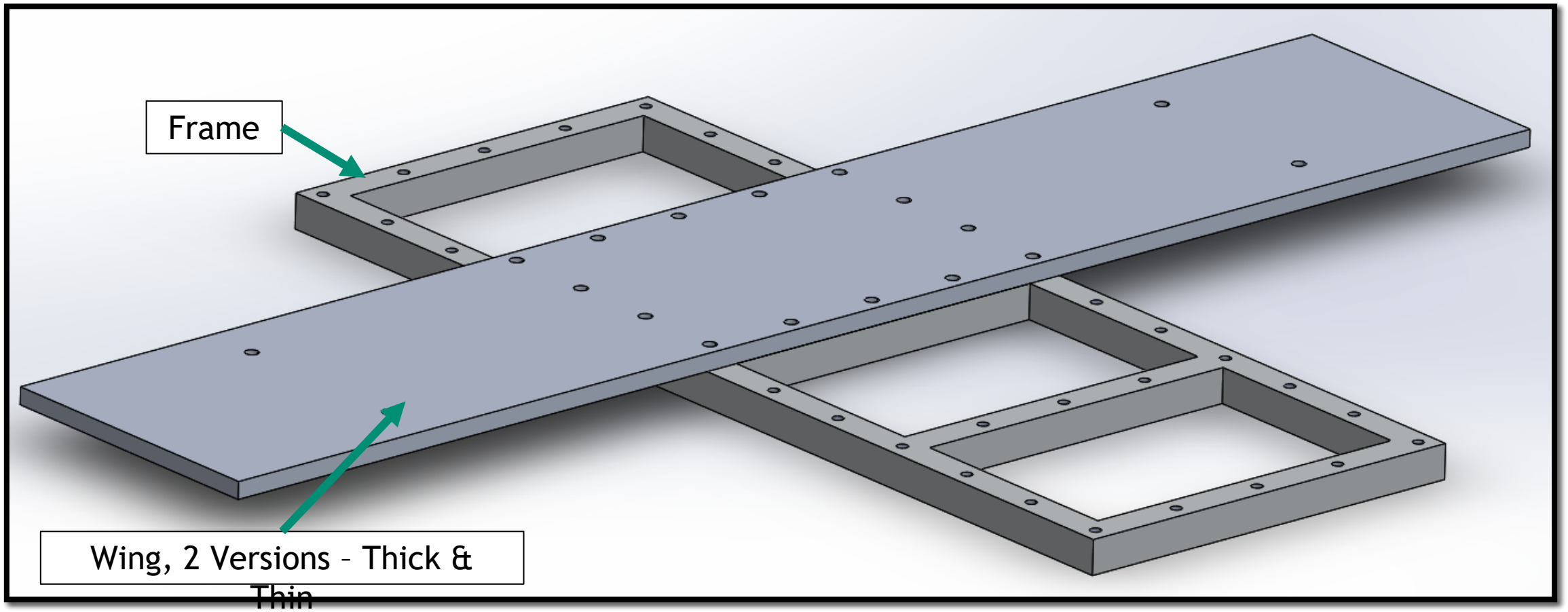
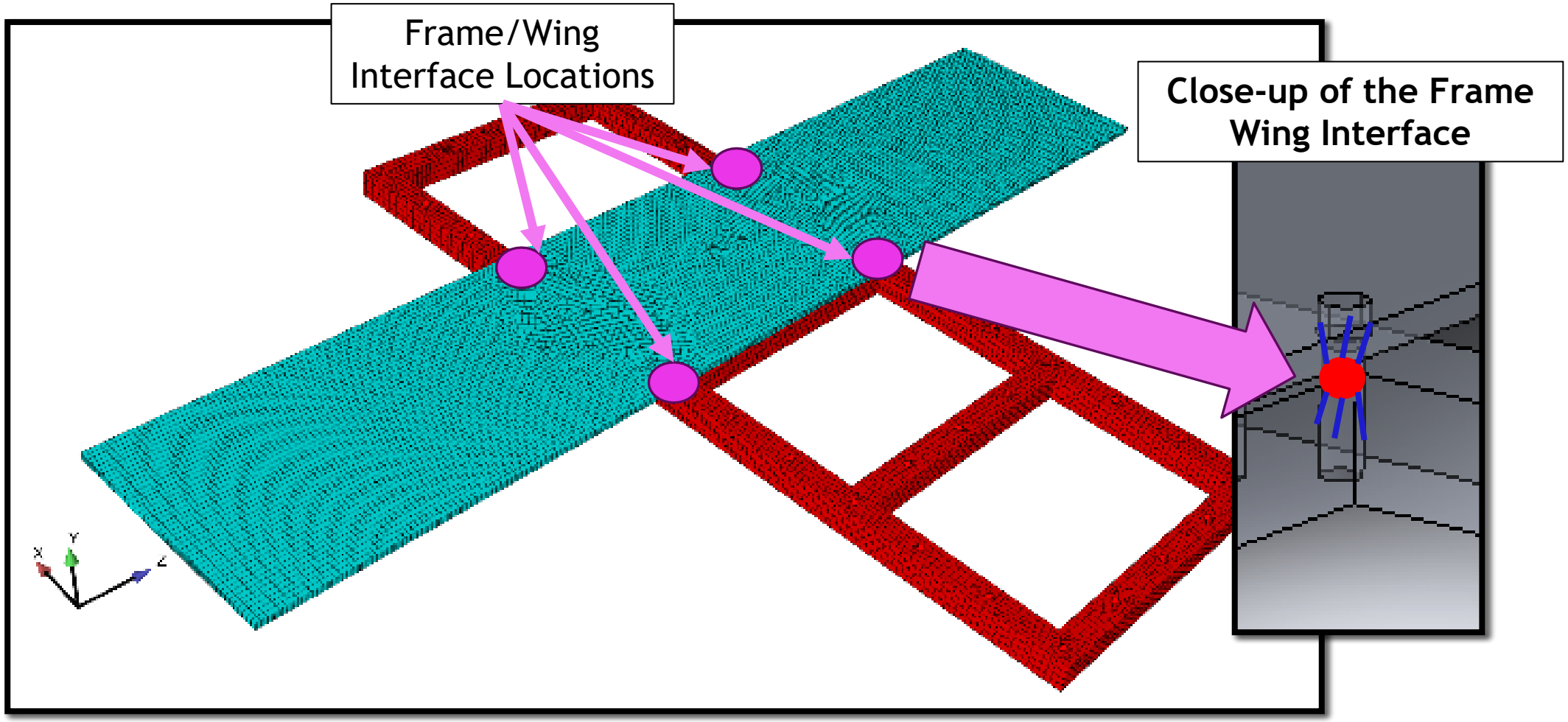
This work presents an example that contradicts these assumptions

System Under Study



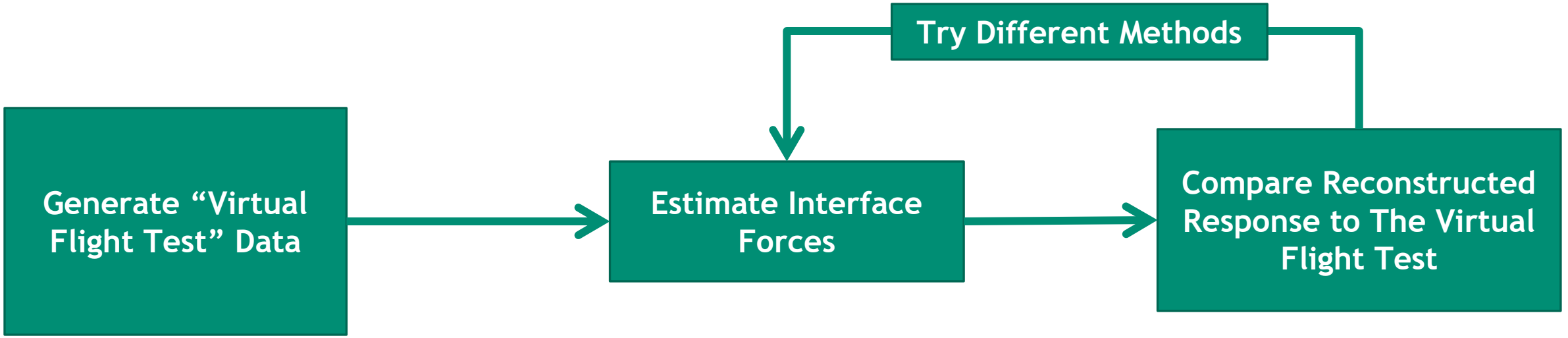
The system is the Round Robin System from the SEM Substructuring Technical Division

System Under Study – FE Model

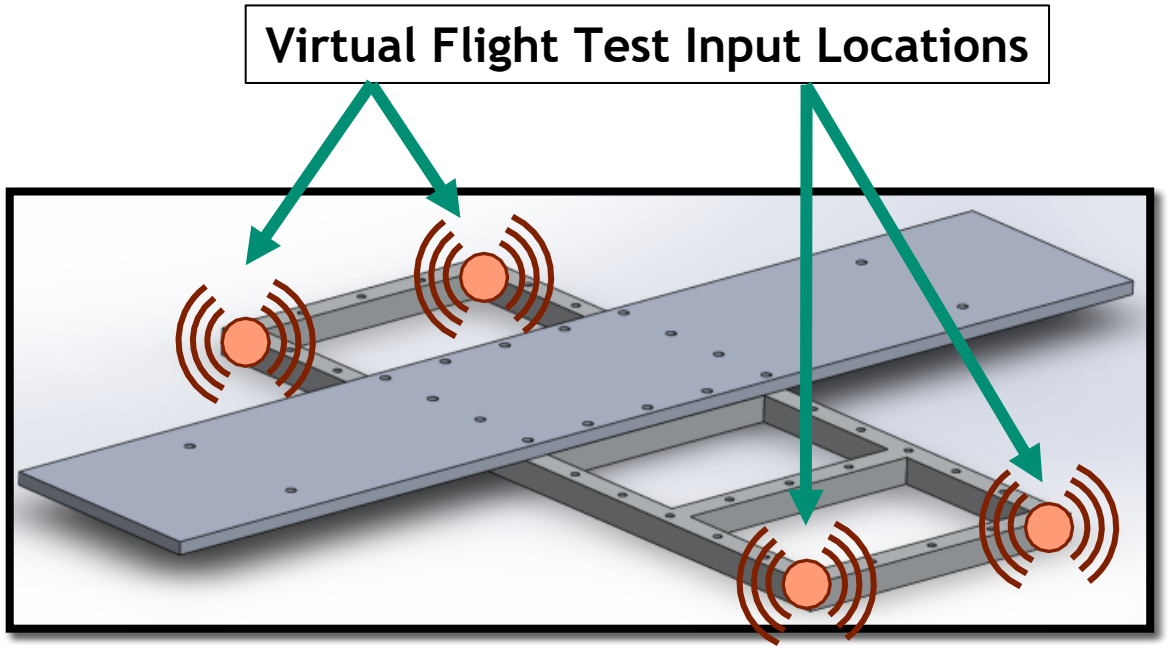


The frame/wing interface is modeled with a JOINT2G element that is analogous to a Nastran CBUSH

System Under Study – Workflow for Evaluating Force Estimation Methods

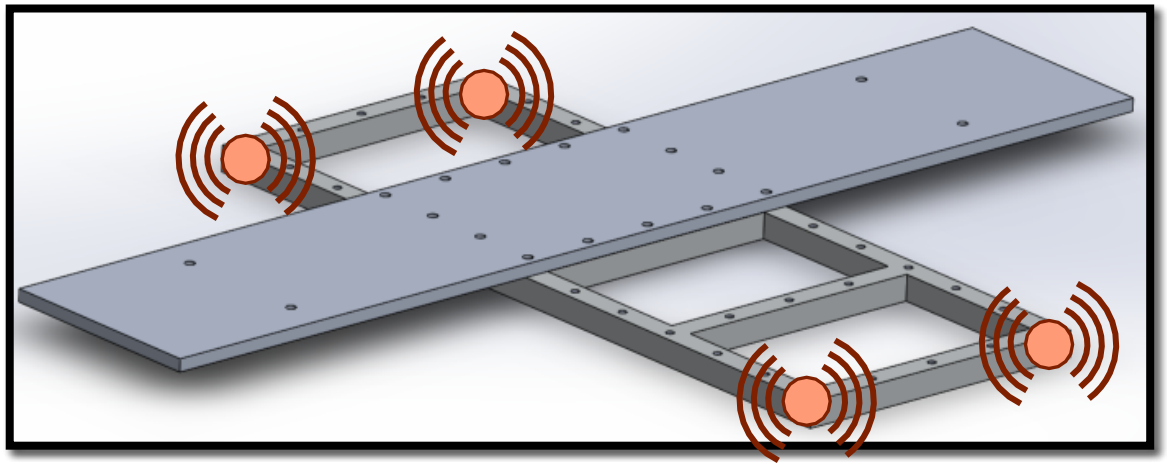


System Under Study – Generating “Virtual Flight Test” Data

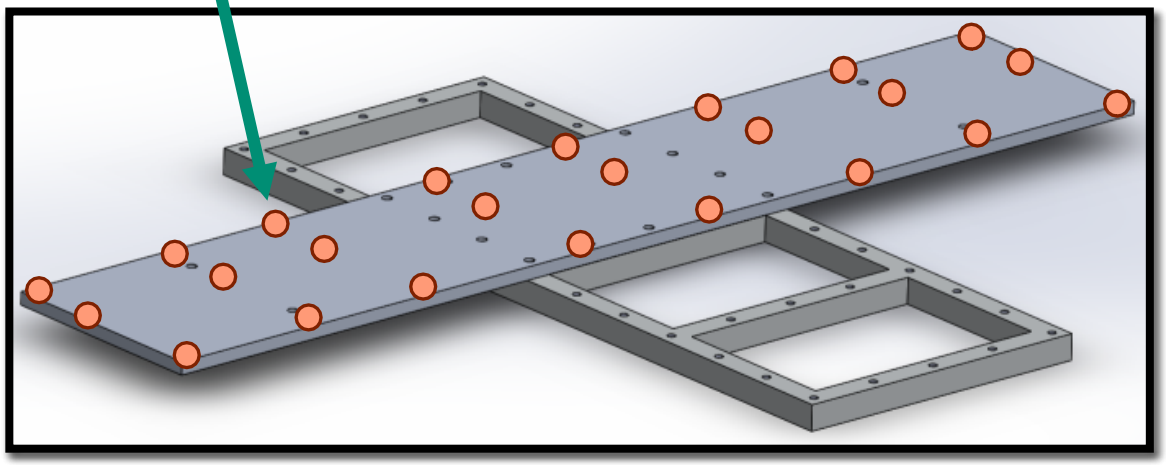


System Under Study – Generating “Virtual Flight Test” Data

Virtual Flight Test Input Locations



Response locations distributed over the wing



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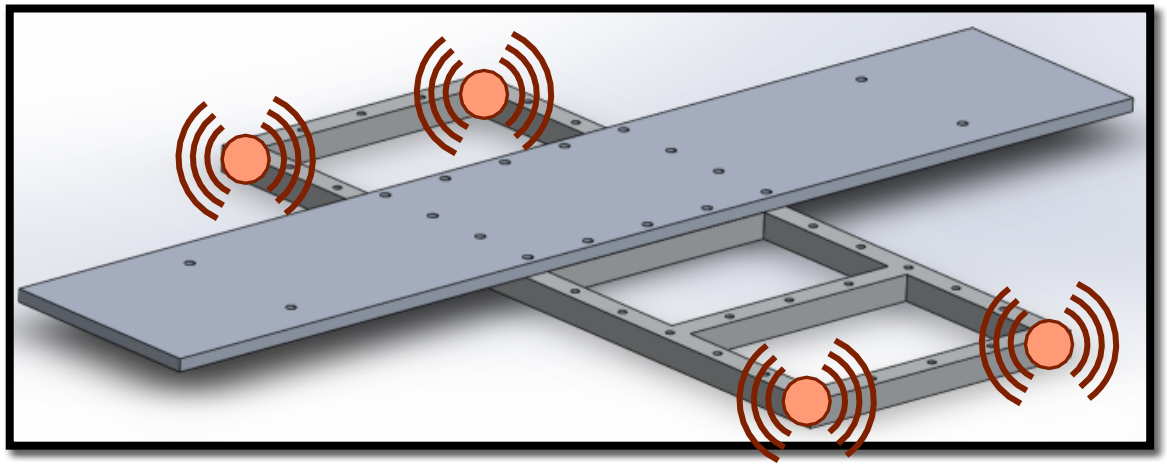

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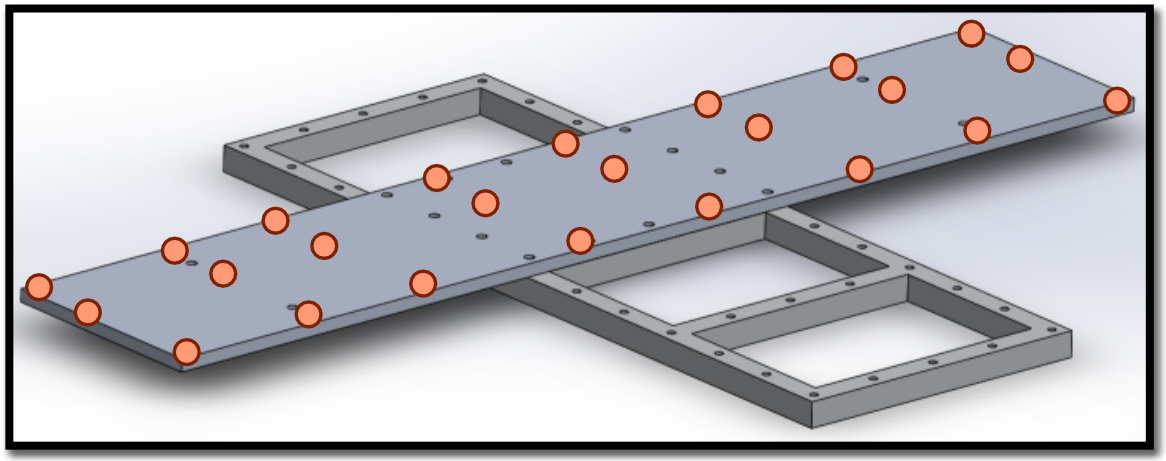
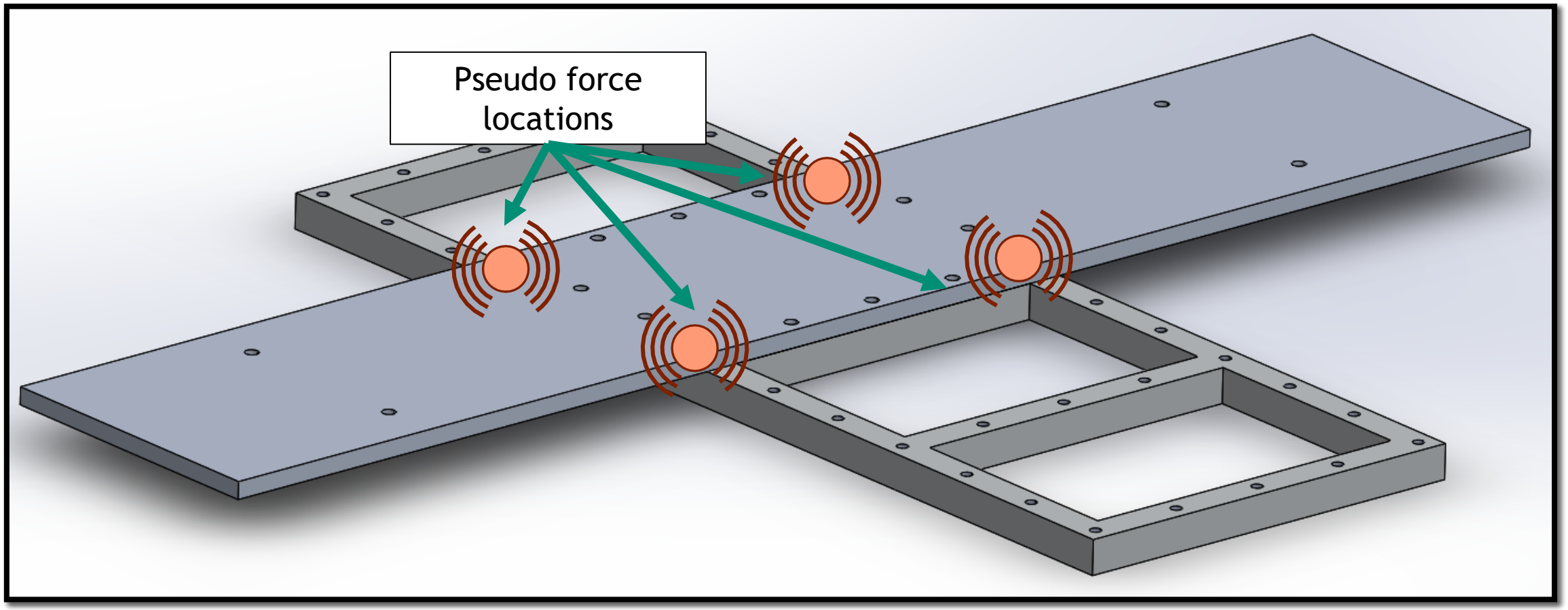


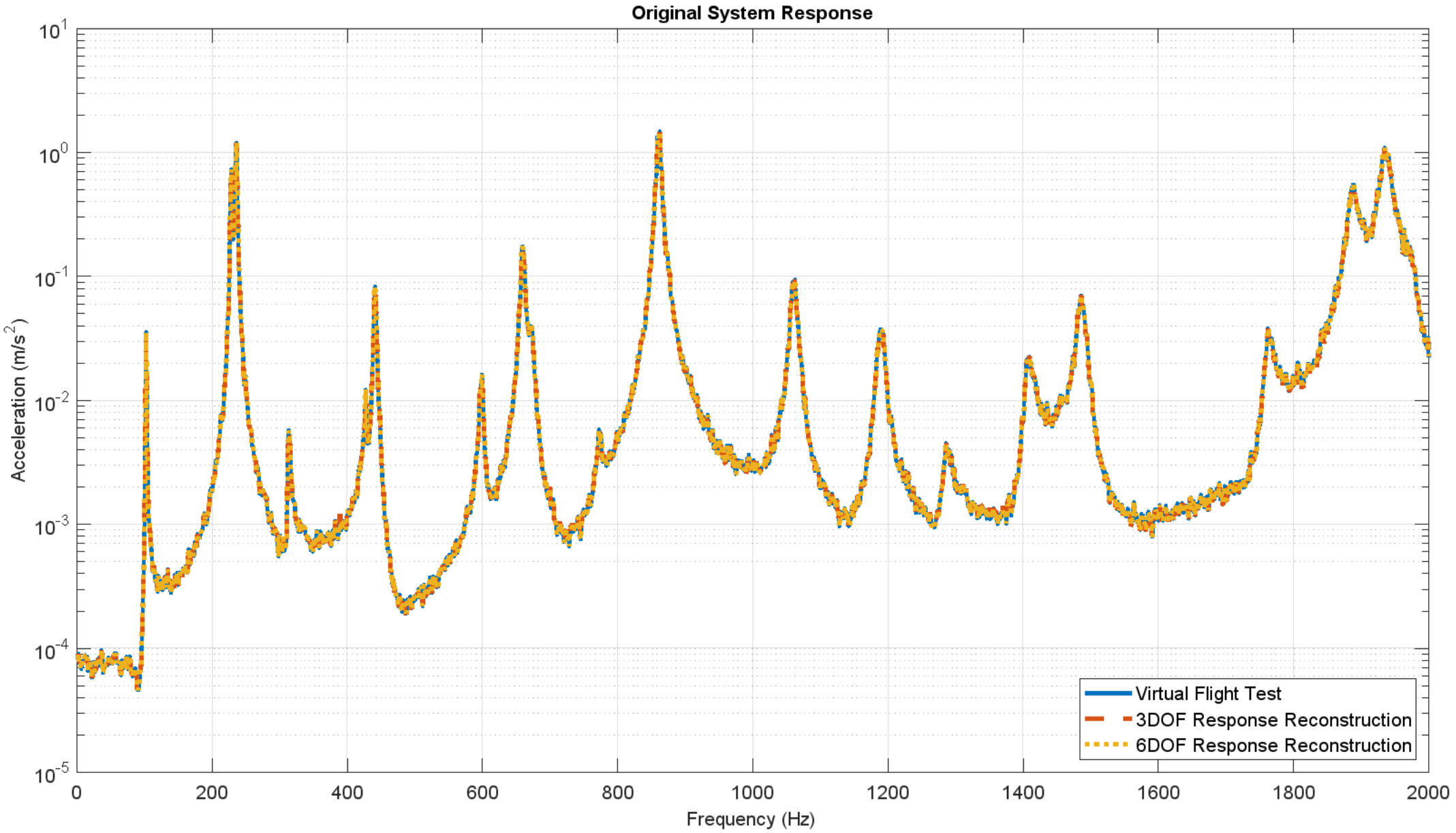
Broadband excitation is applied to the corners of the frame and response were computed at locations on the wing to generate truth data for both versions of the system

System Under Study – Estimating Interface Forces



3DOF & 6DOF pseudo forces were estimated at the interface between the frame and wing

Results – Standard Force Estimation



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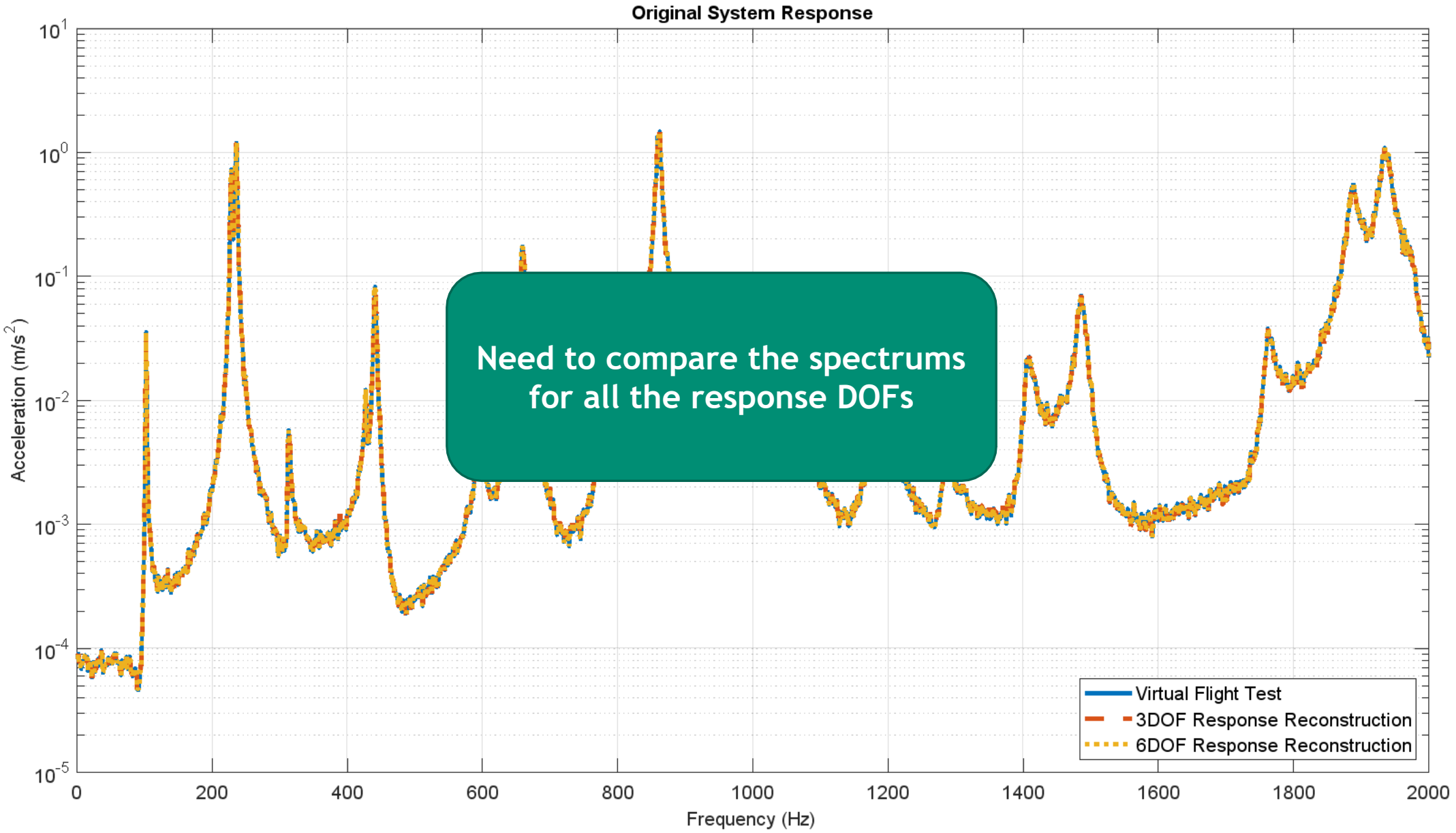

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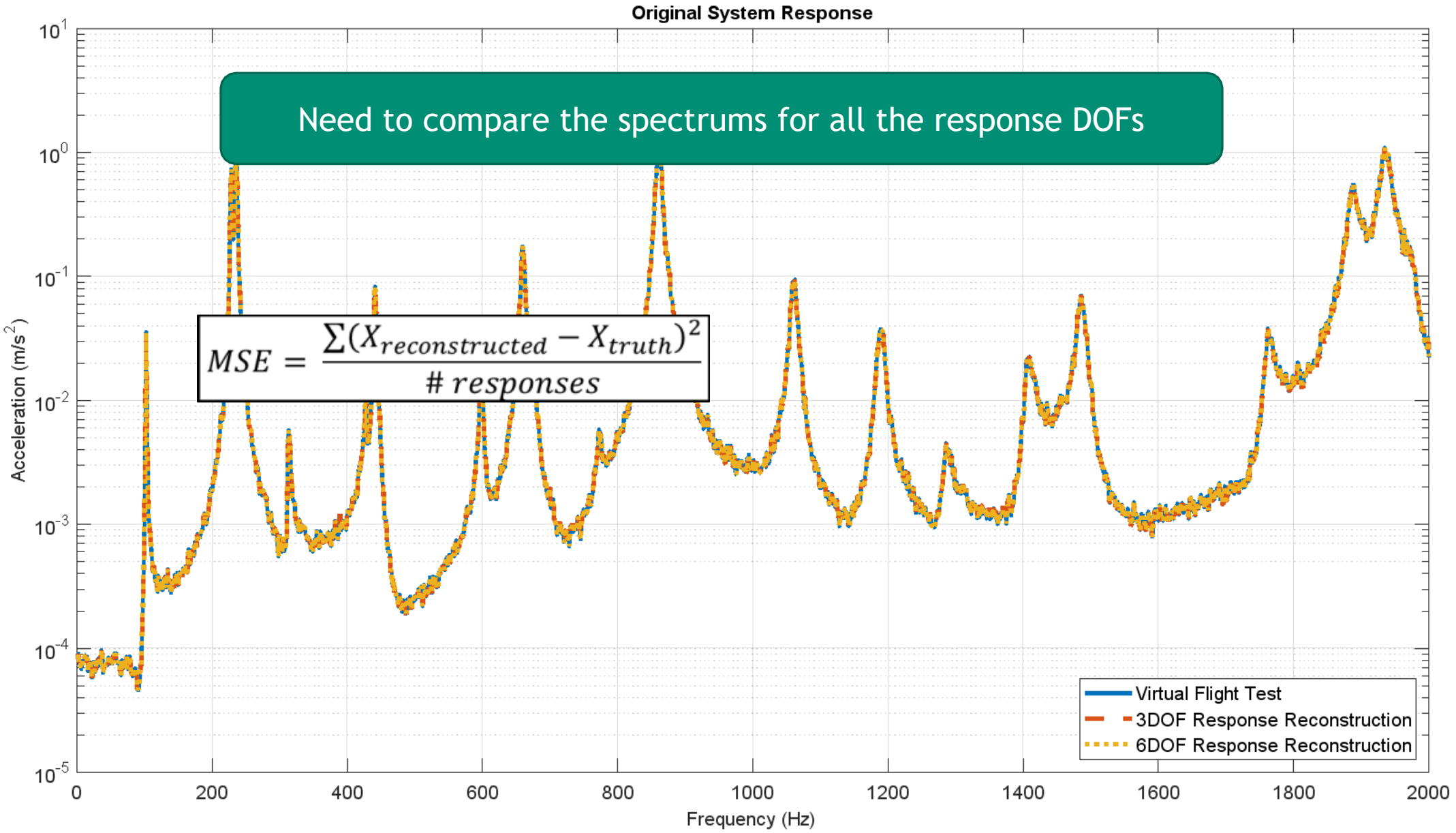

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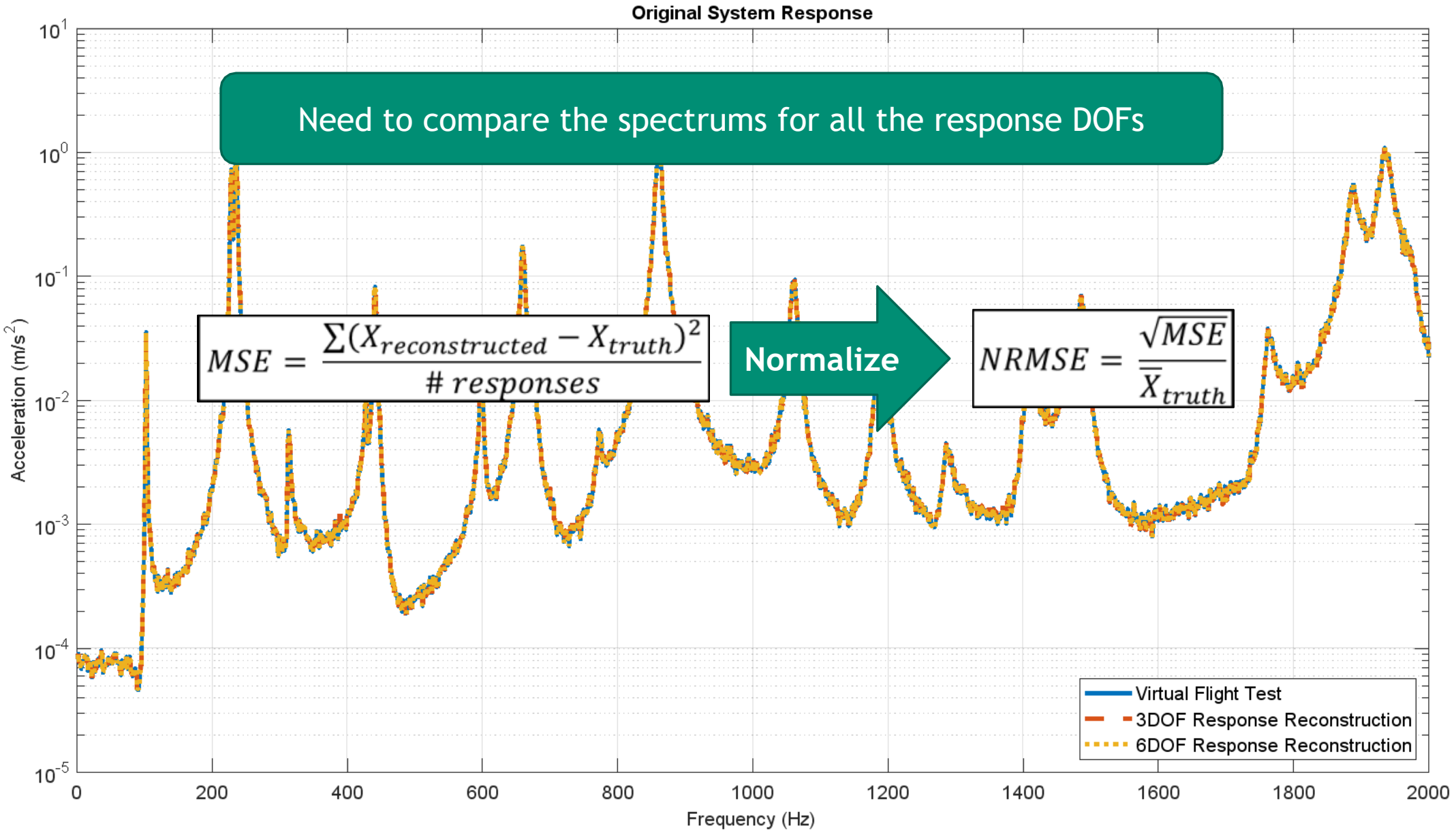

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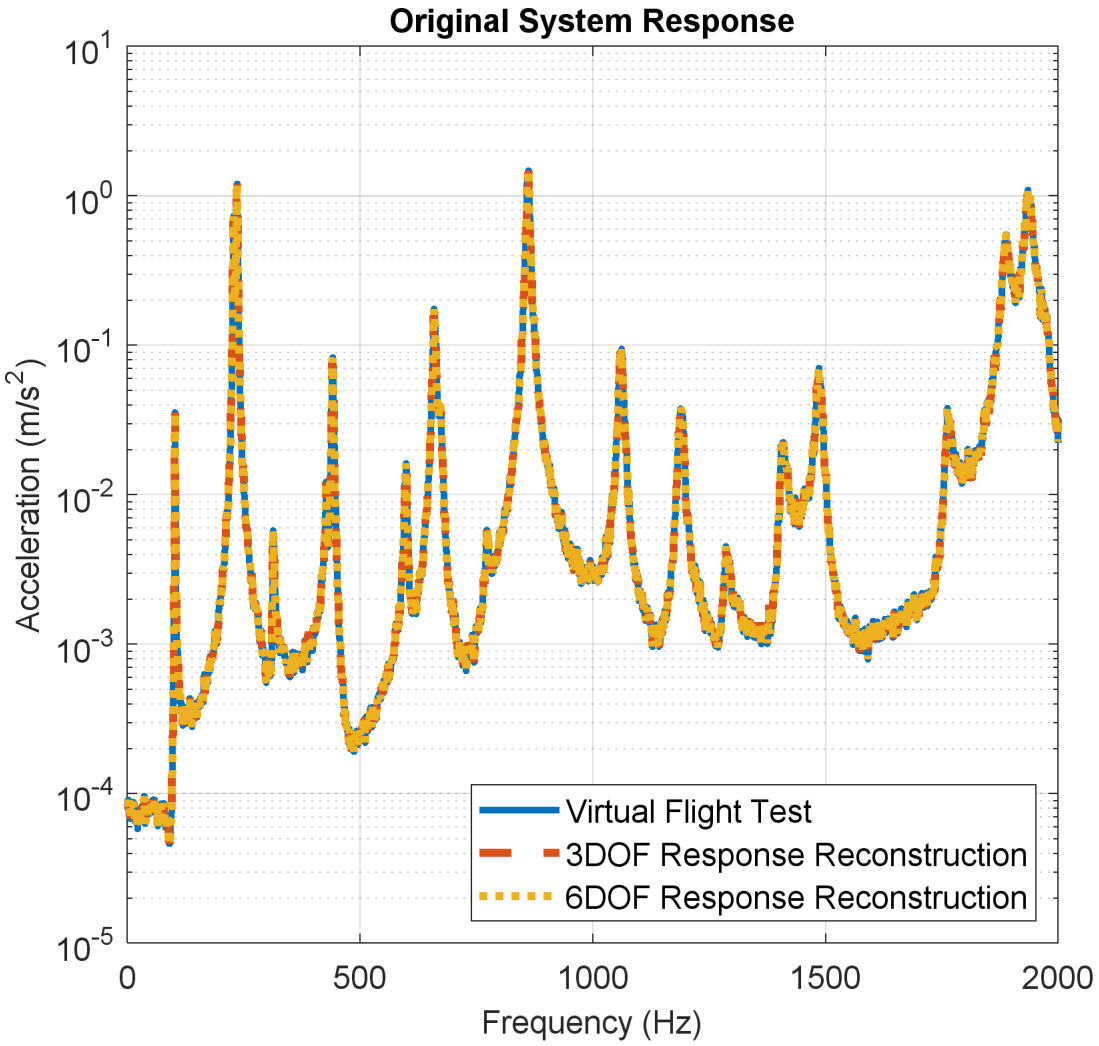

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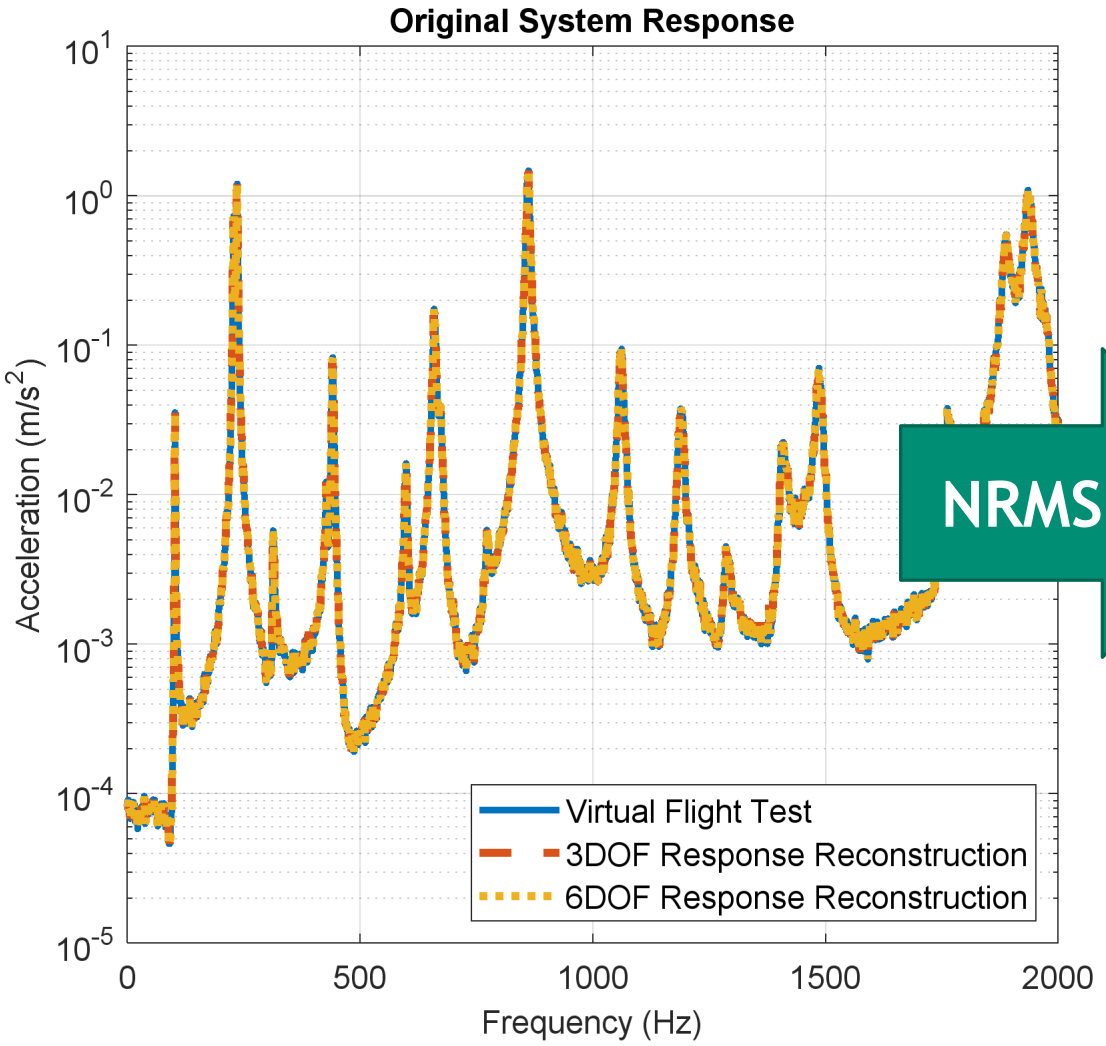
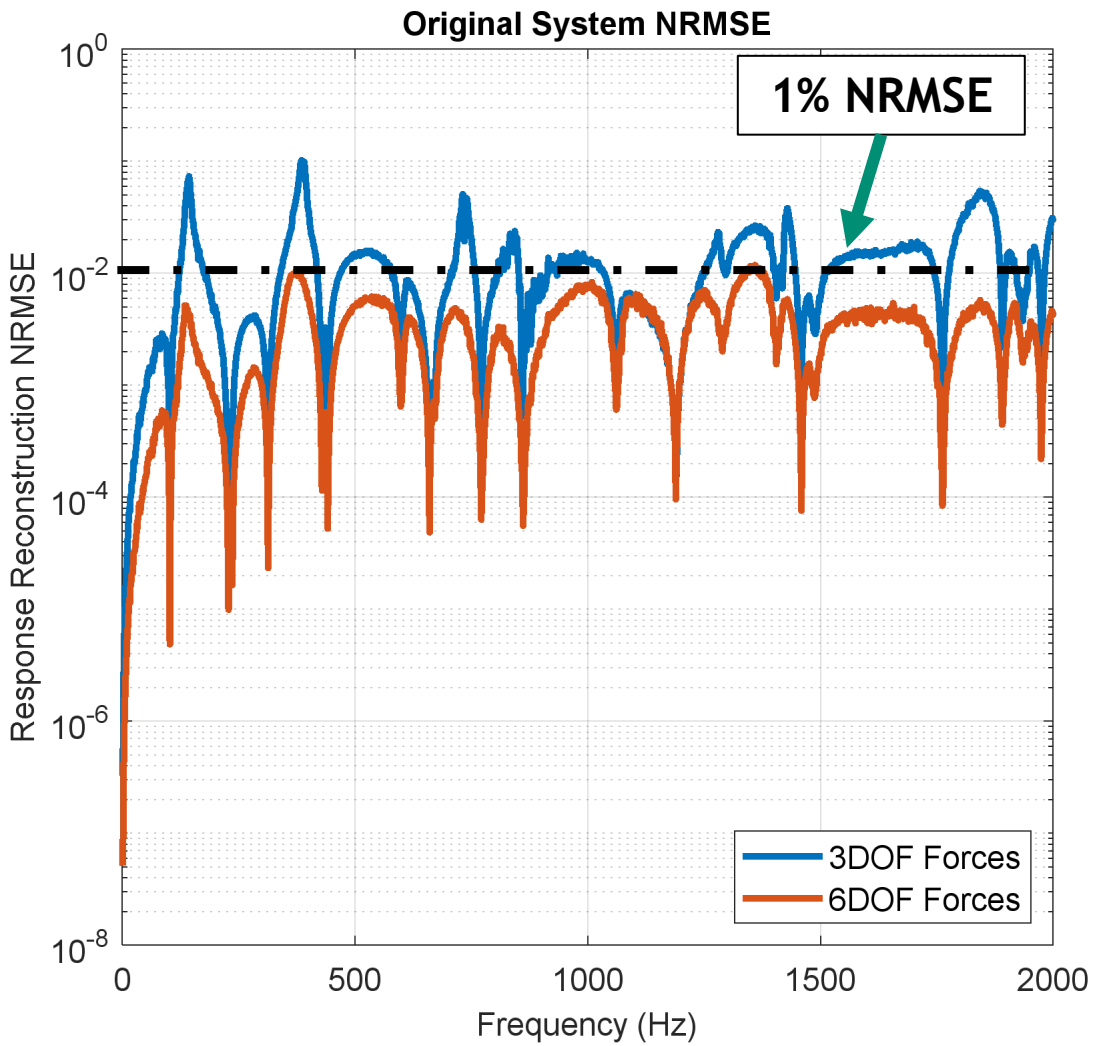


NRMSE



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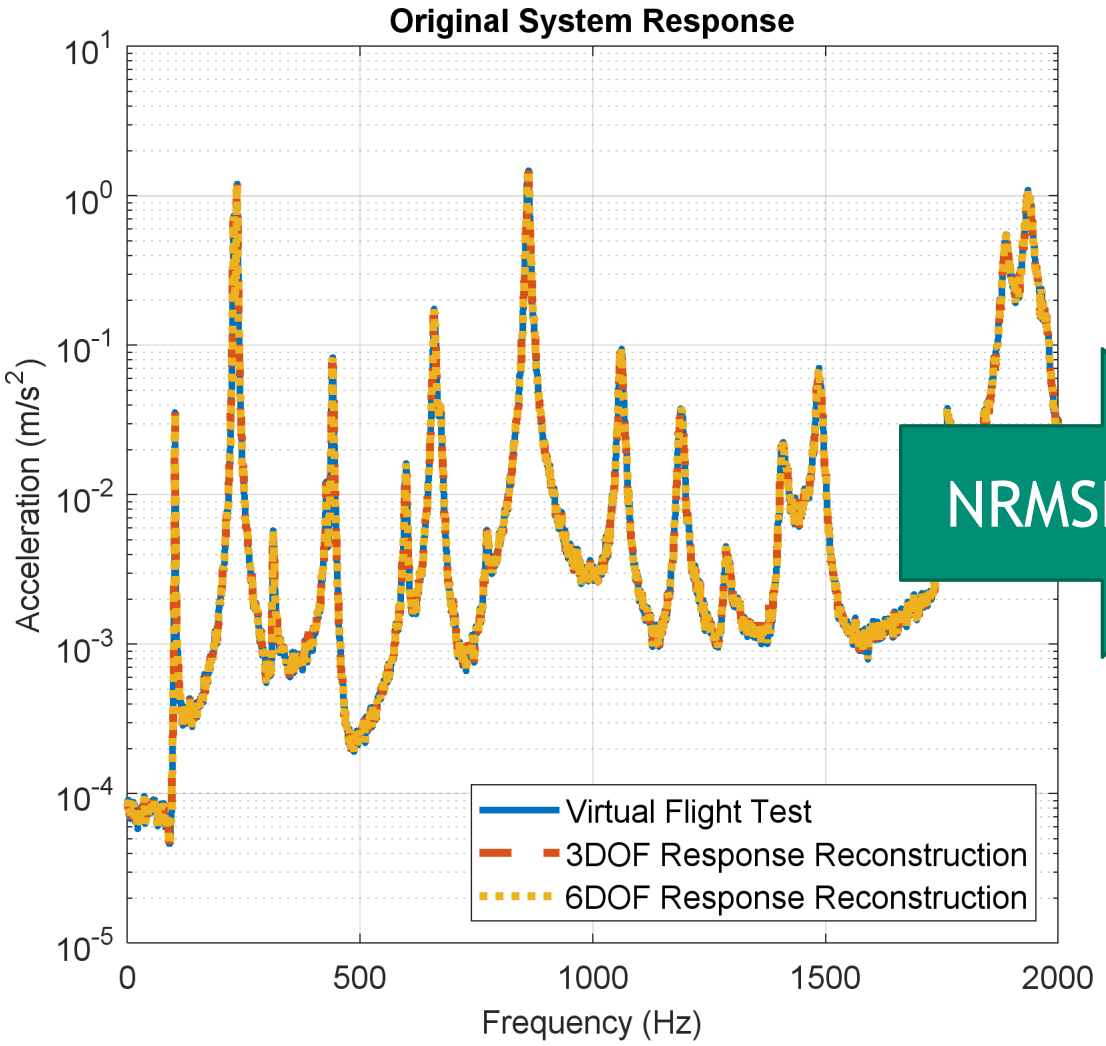
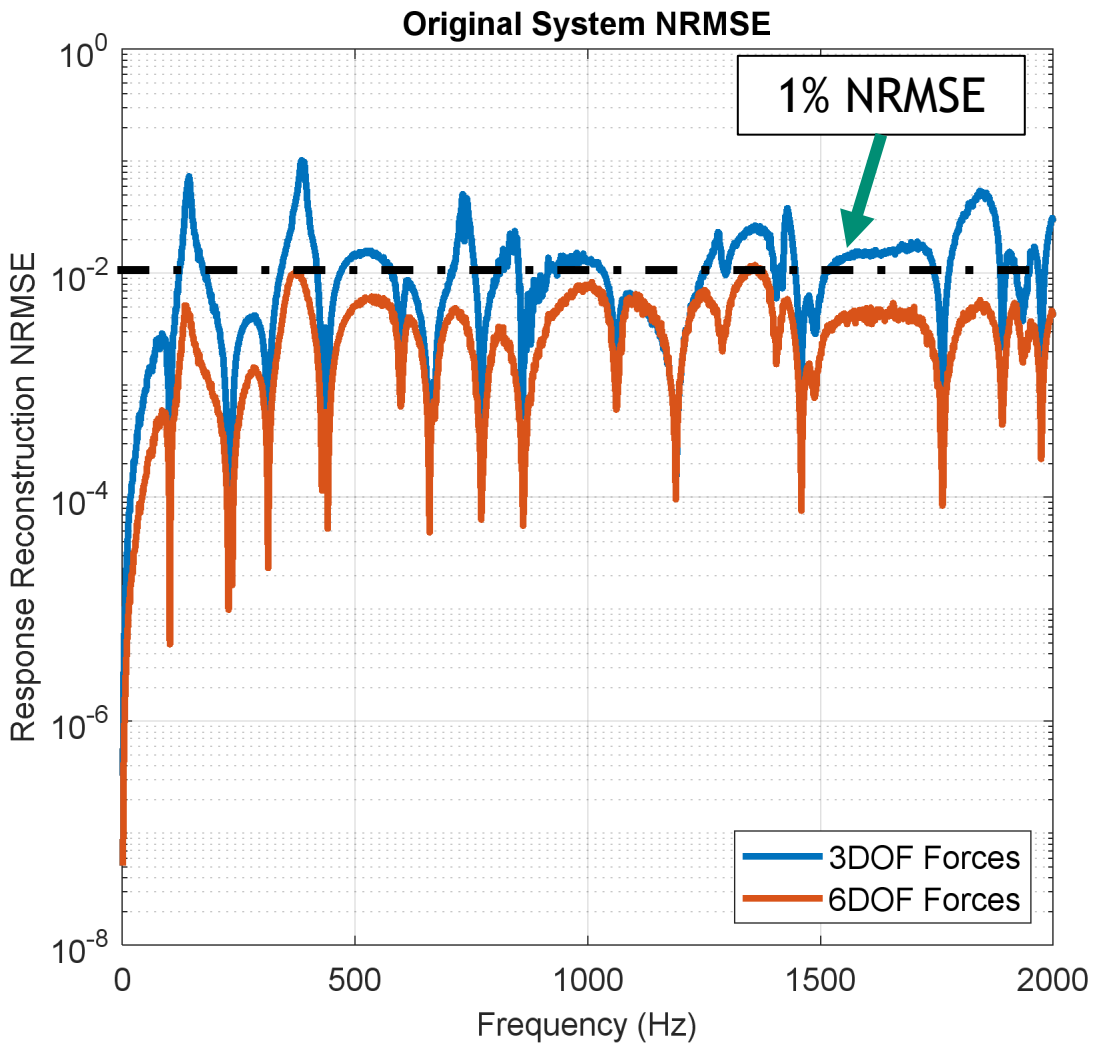


NRMSE



Both response reconstructions are accurate, but the 6DOF reconstruction is slightly better

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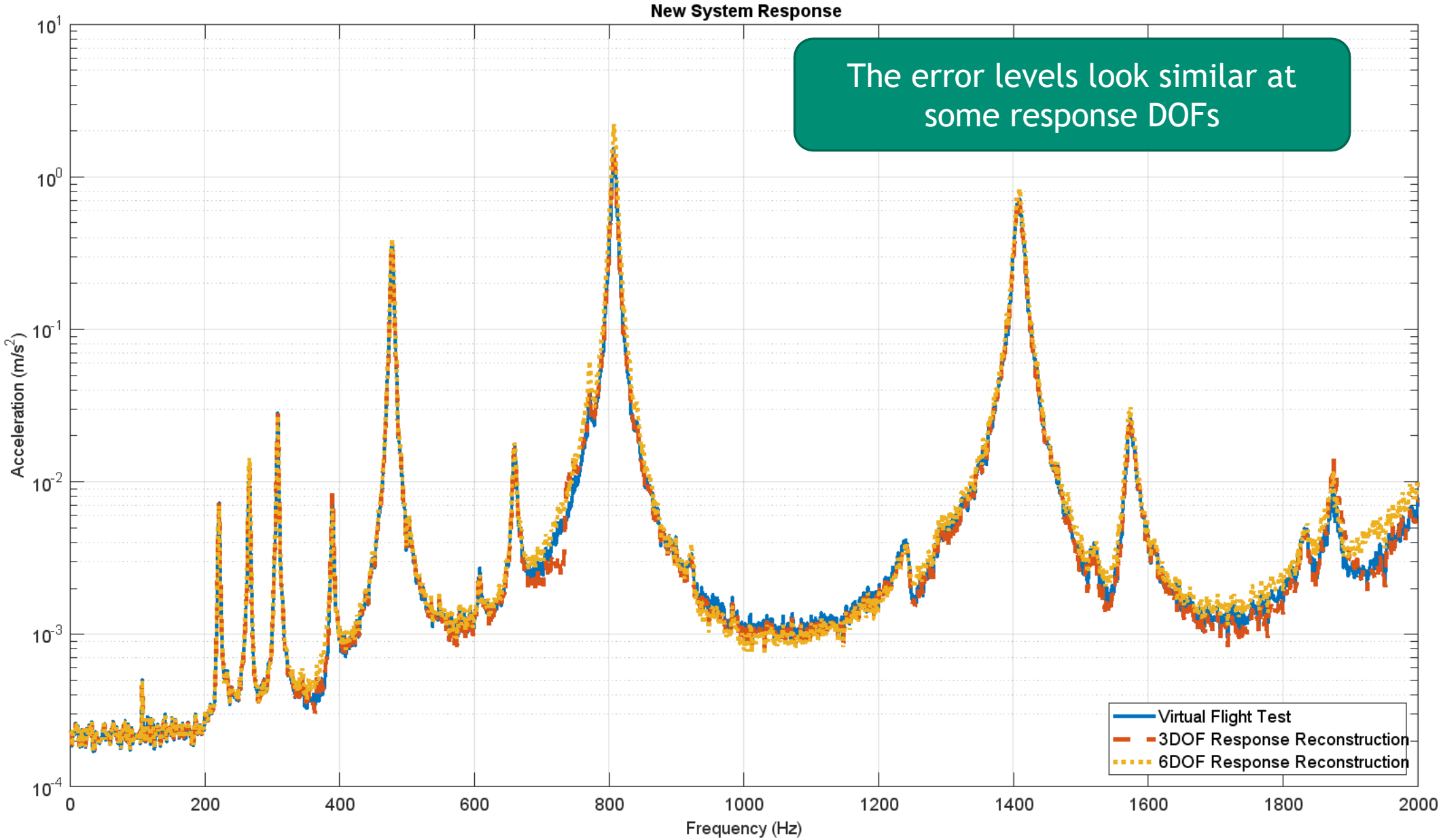

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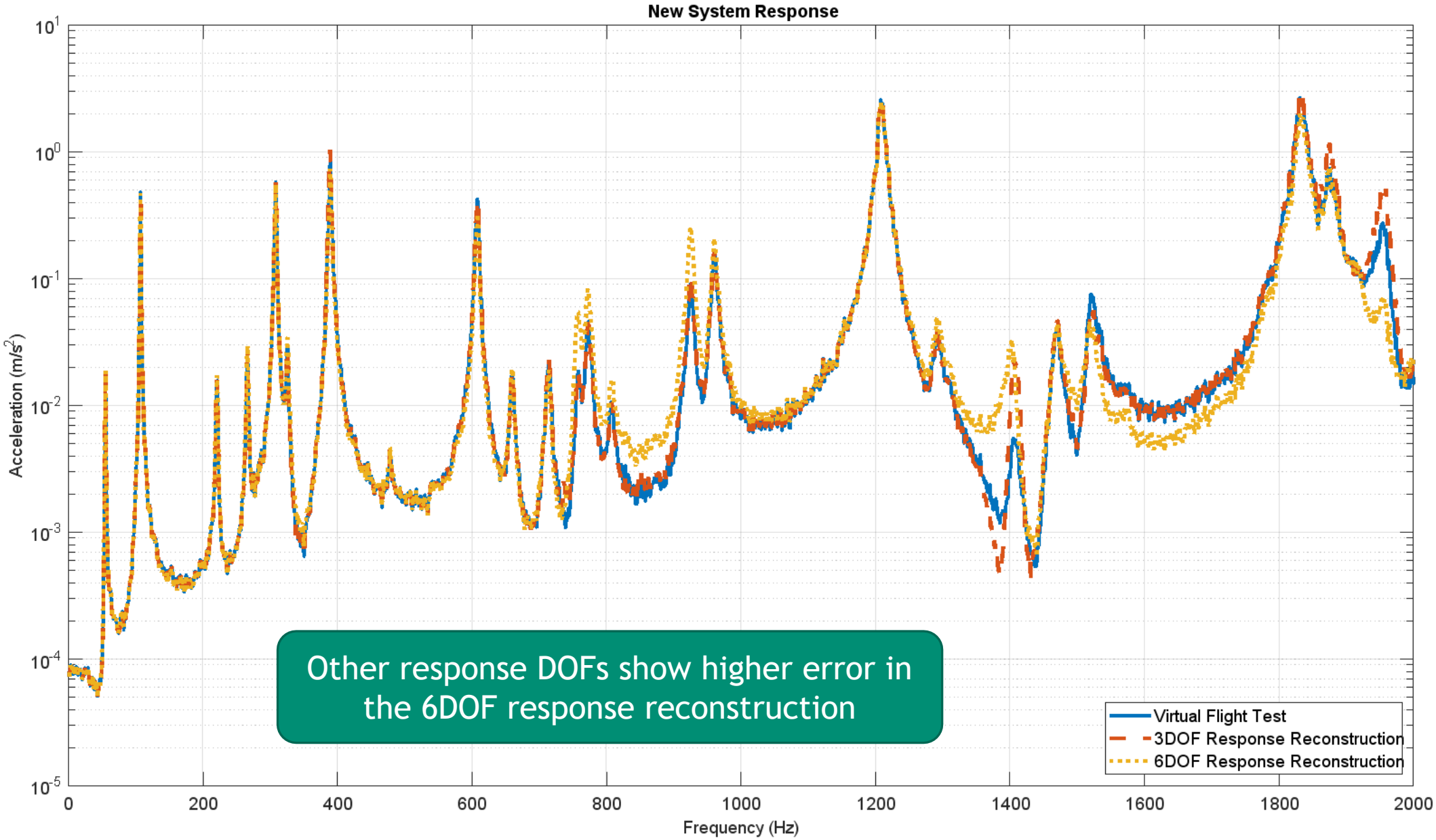

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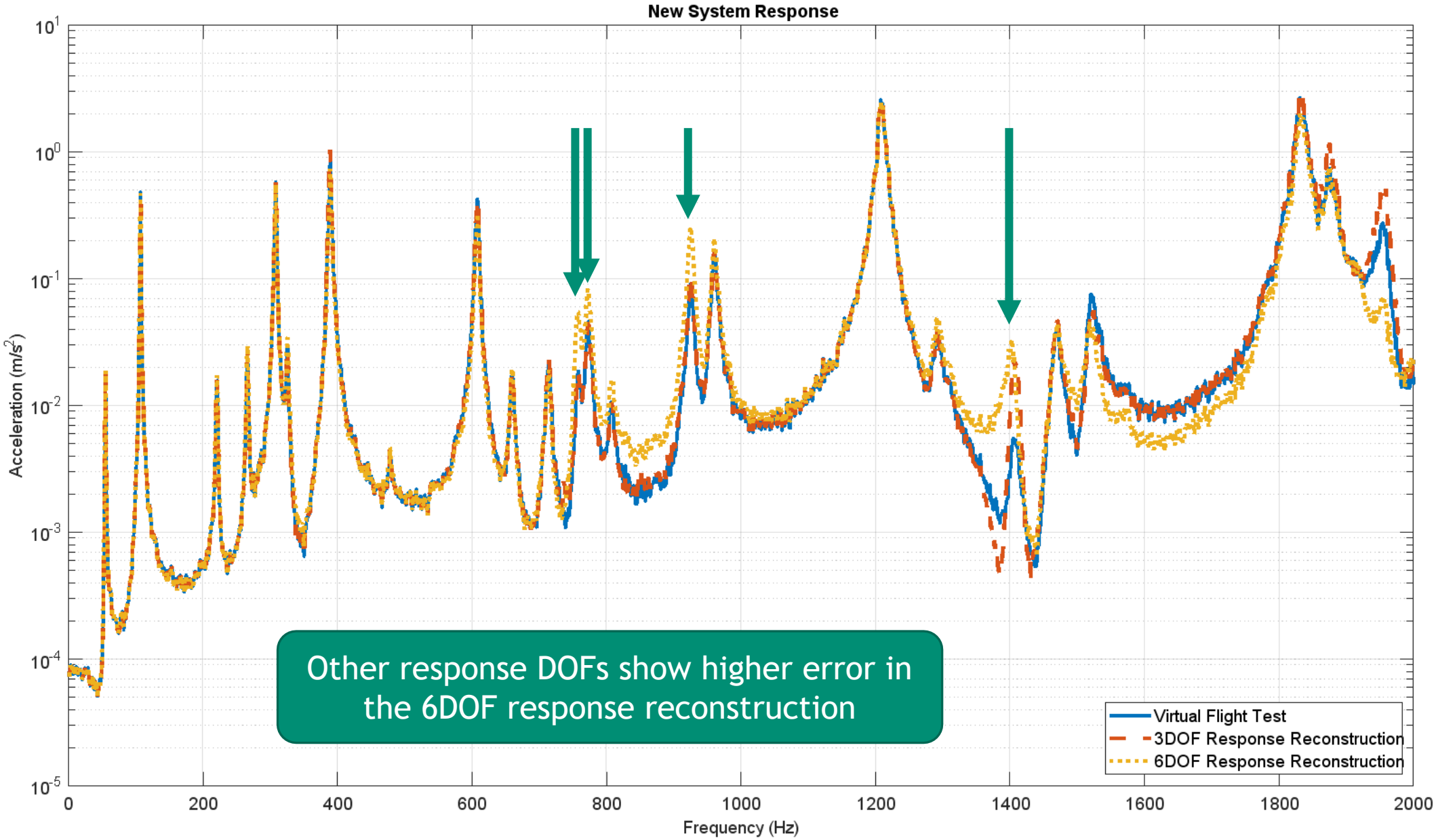

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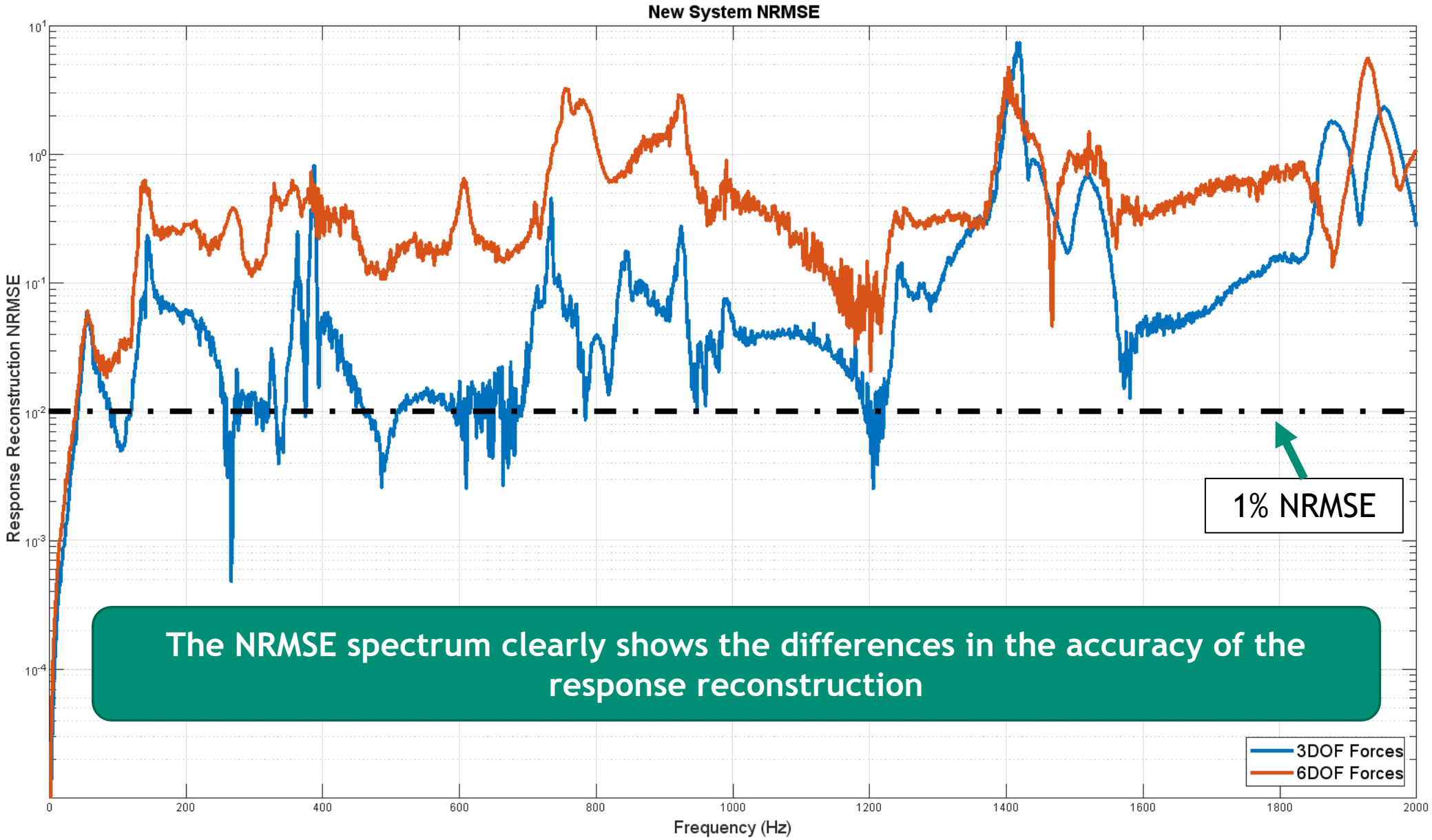

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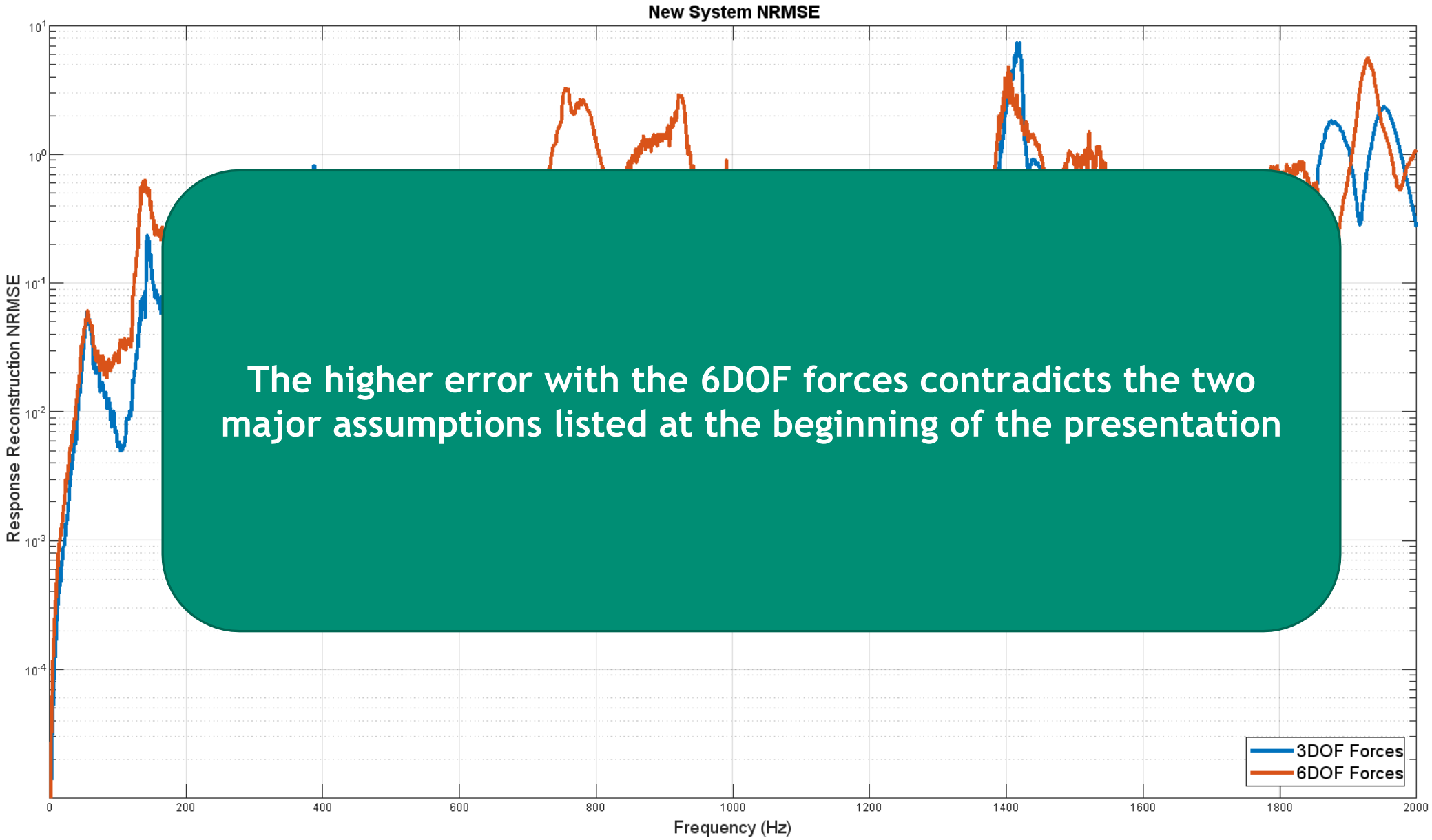

The higher error with the 6DOF forces contradicts the two major assumptions listed at the beginning of the presentation

Results – Trouble Shooting the Issue

Swapping the Original and New Systems

Validating the Model Rotations

Singular Value Rejection and Regularization

Adding More Response DOFs to the 6DOF Estimate

Evaluating the Possibility of an Overfit Solution

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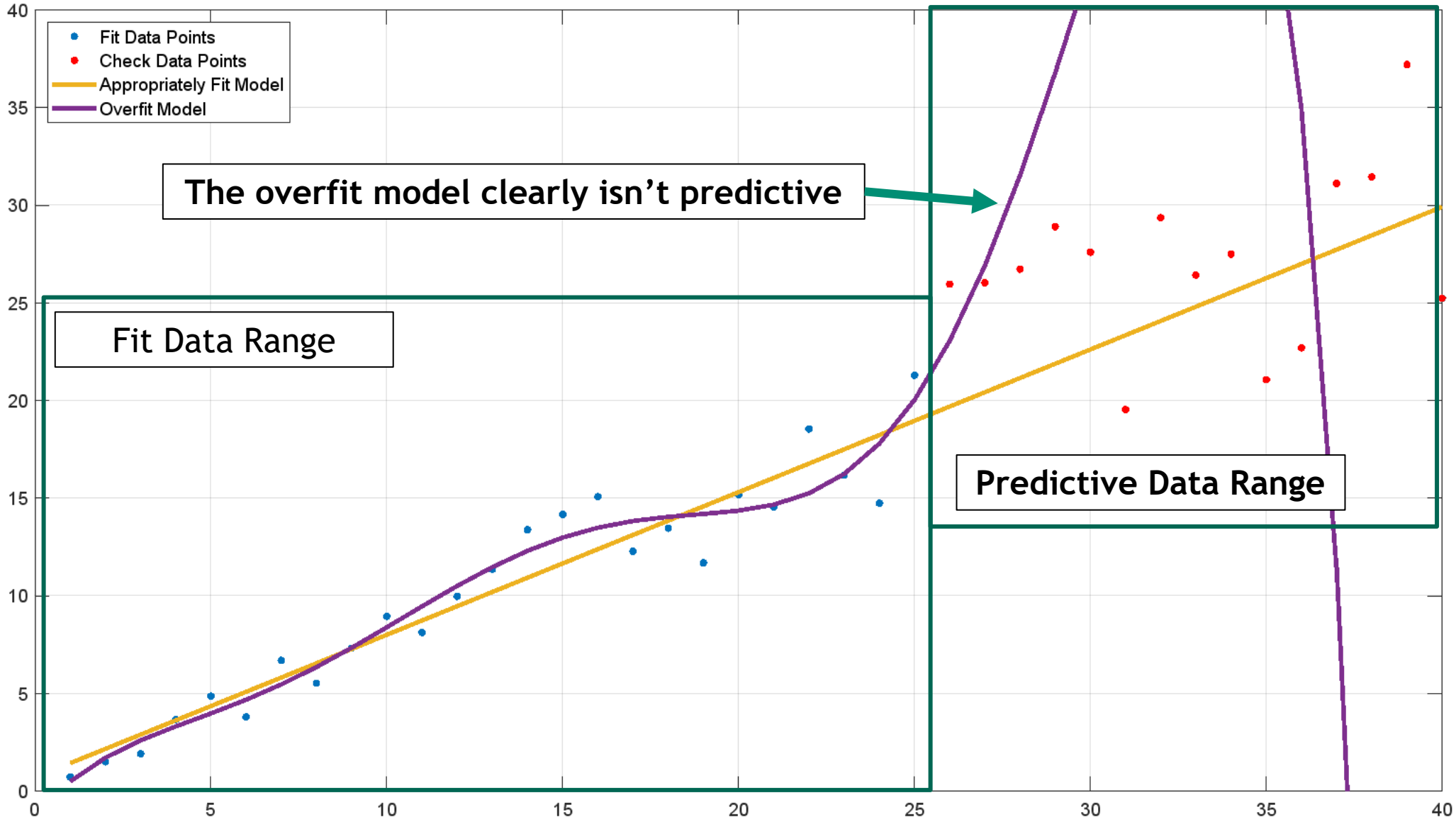
Evaluating the Possibility of an Overfit Solution

- **This seems to provide the best explanation for the errors that are being seen**

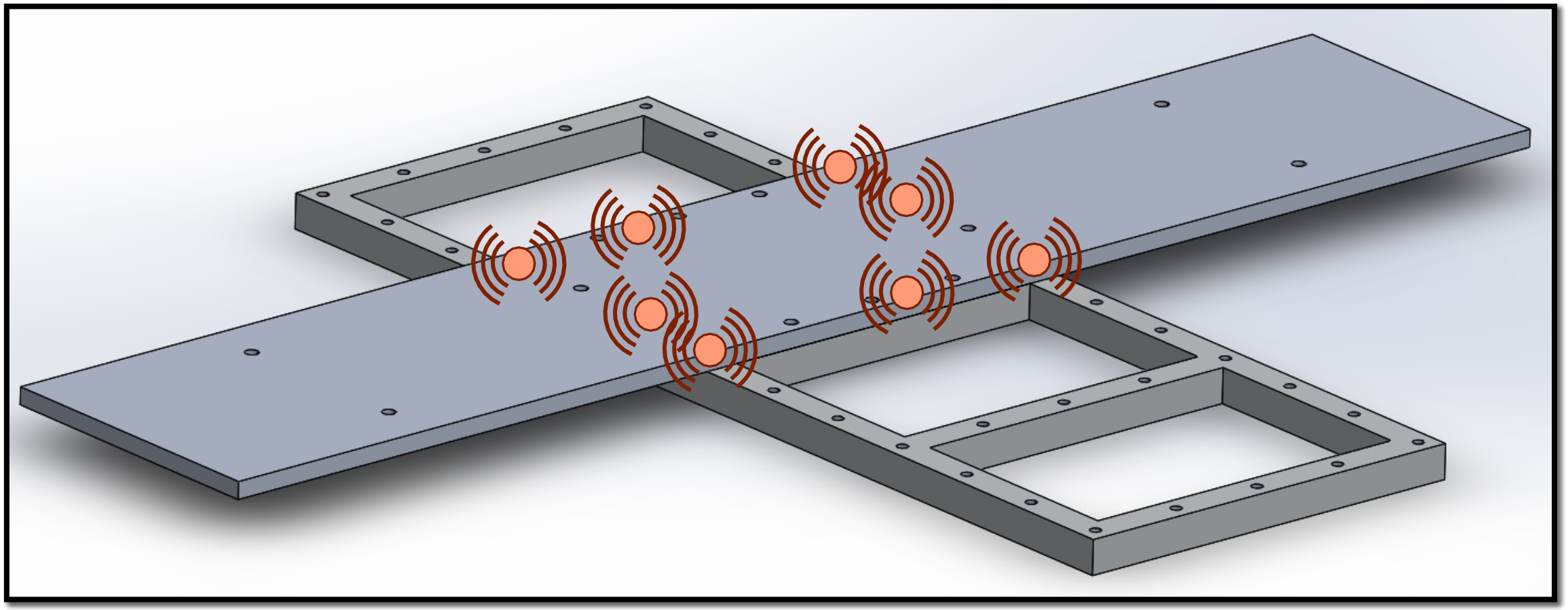
Example of an Overfit Solution on 2D Data



Testing for the Possibility of an Overfit Solution

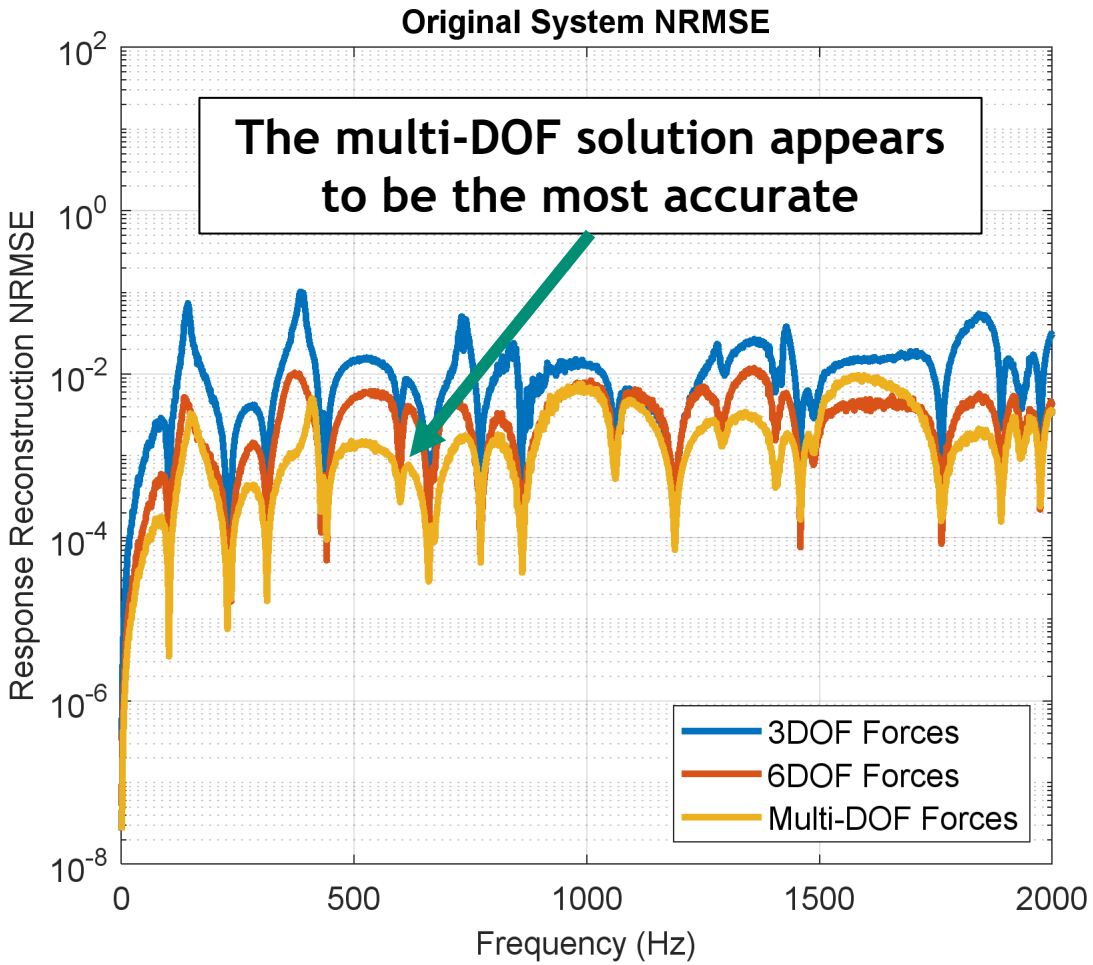
Overfit Solution Hypothesis: Adding more 3DOF references into the force estimation should provide similar results to the 6DOF solution

Testing for the Possibility of an Overfit Solution – Model Setup



Several 3DOF references were used on the frame to match the number of refence DOFs in the 6DOF estimate

Testing for the Possibility of an Overfit Solution – Results



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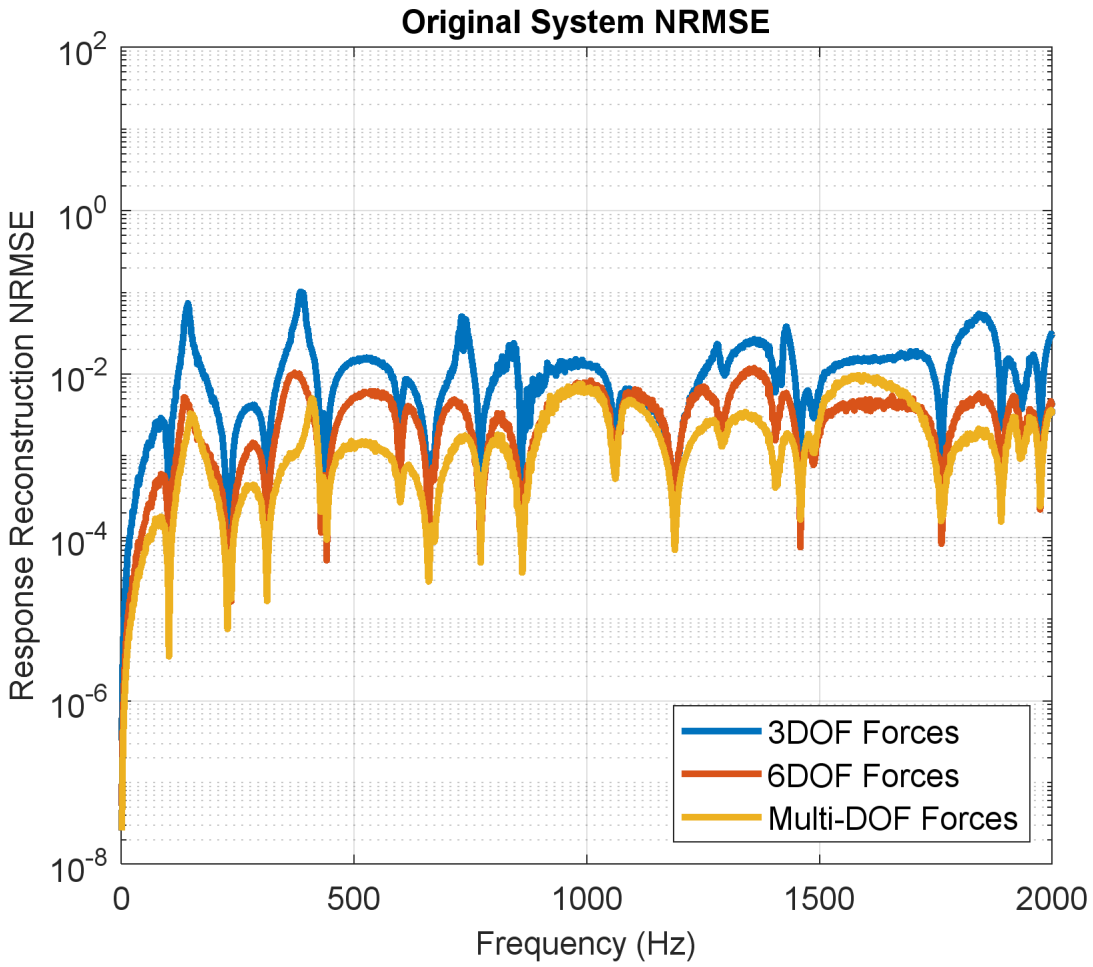

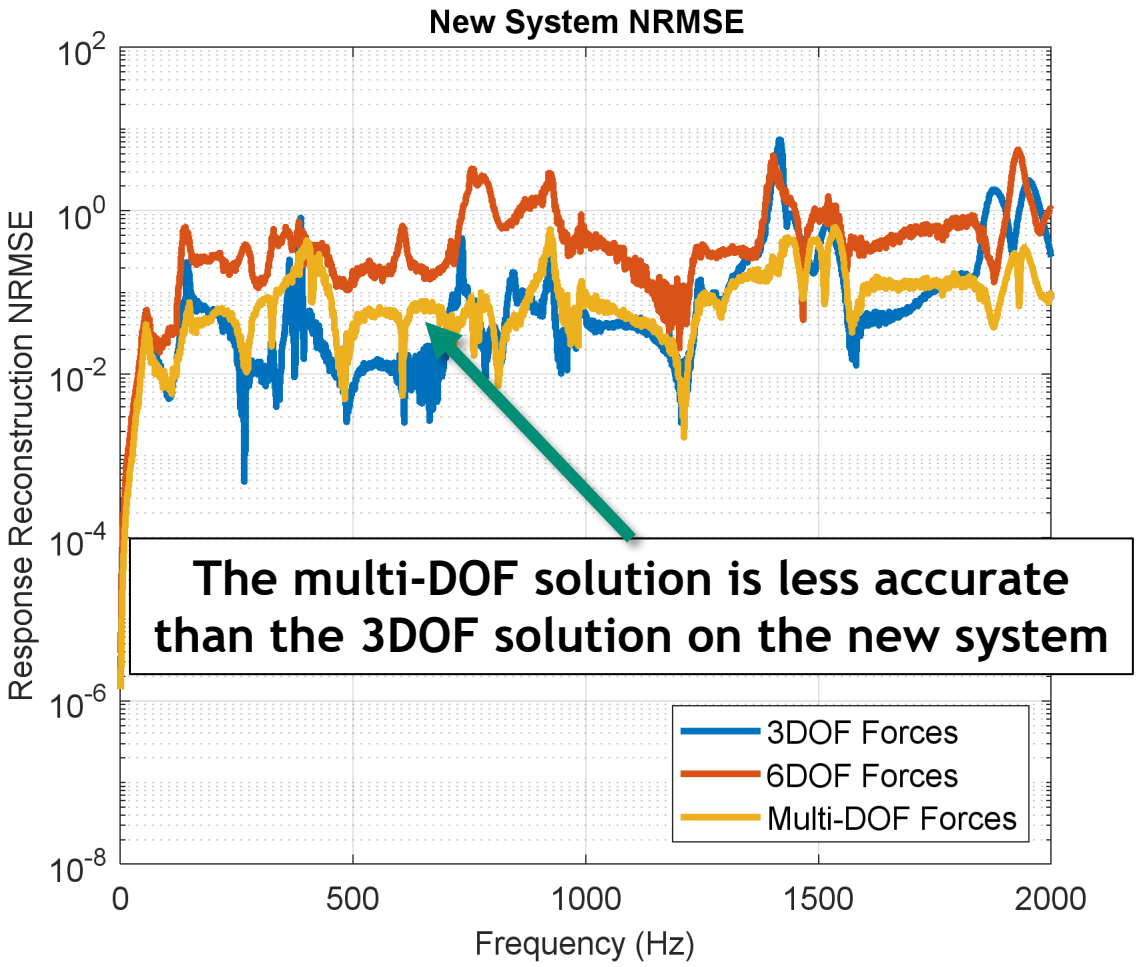

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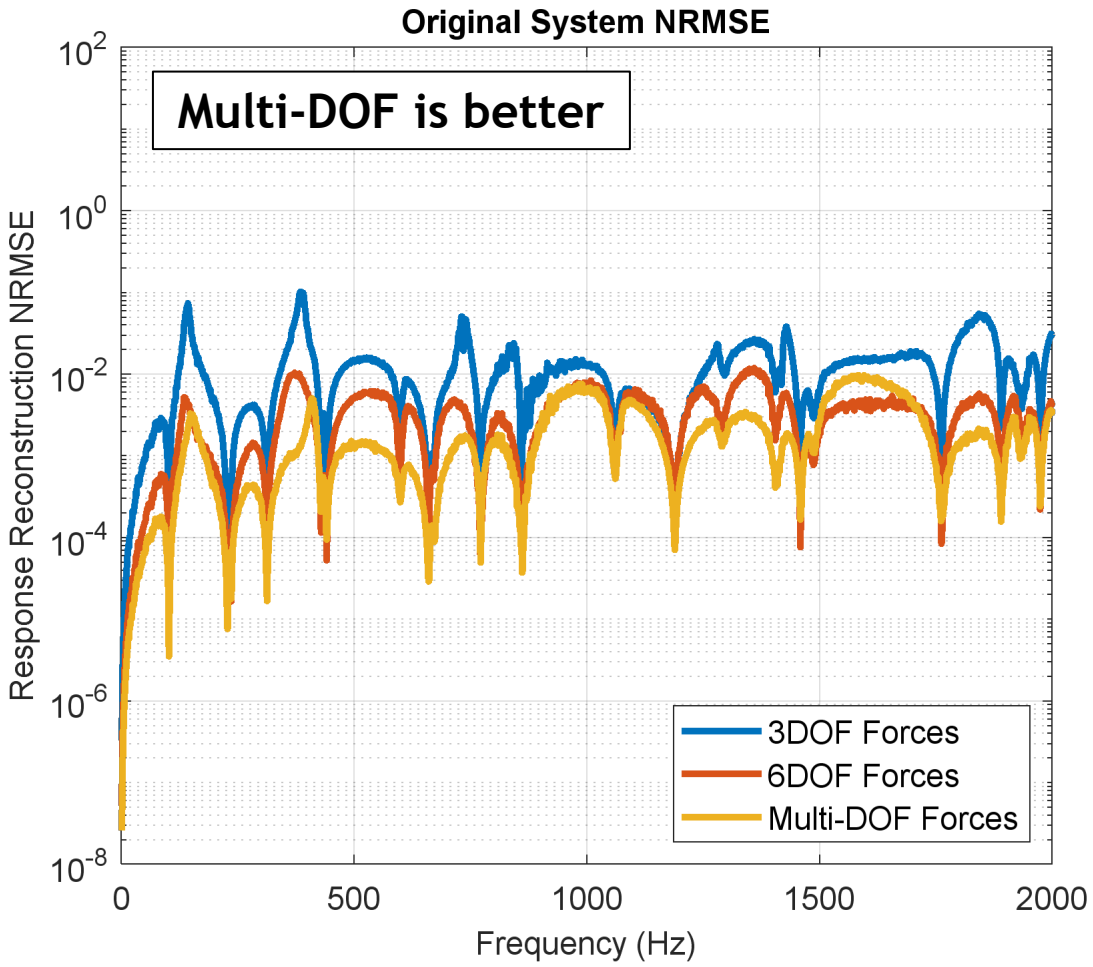
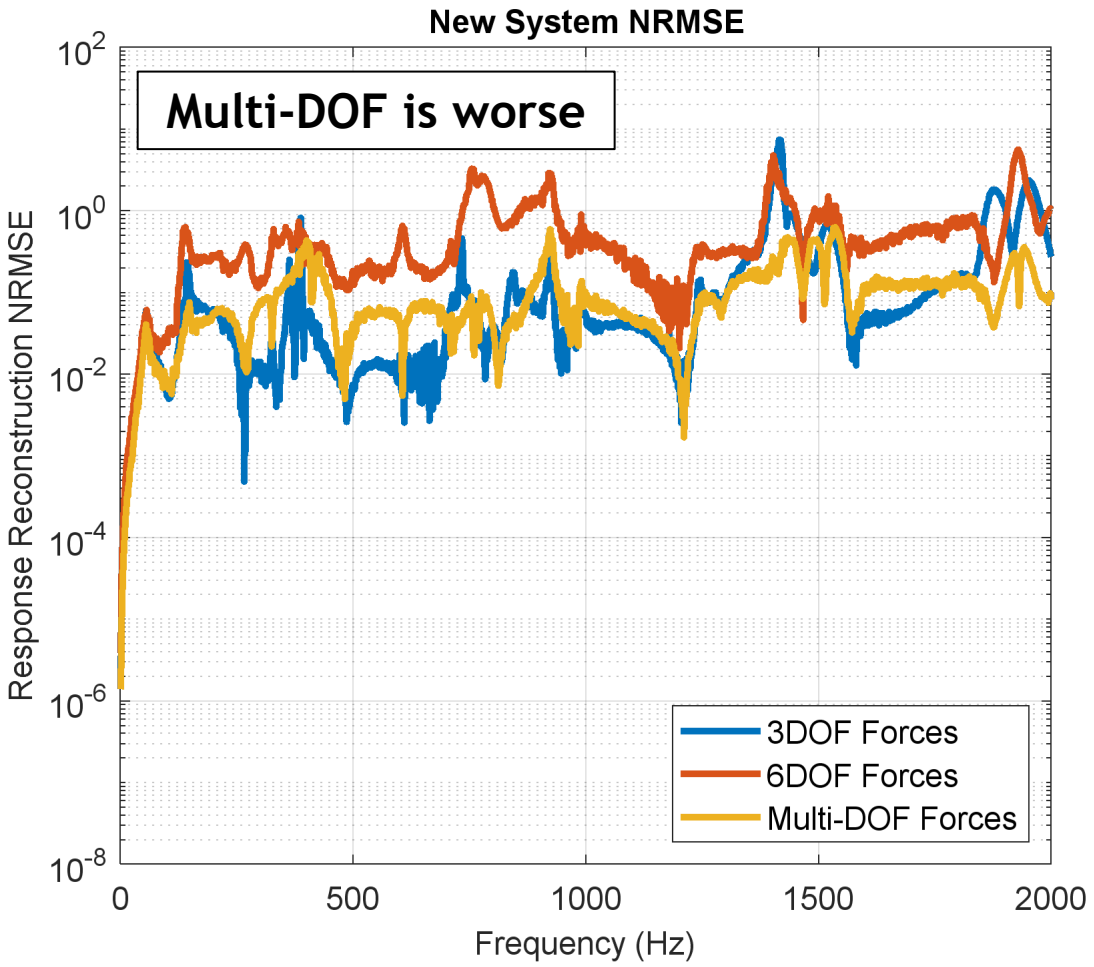


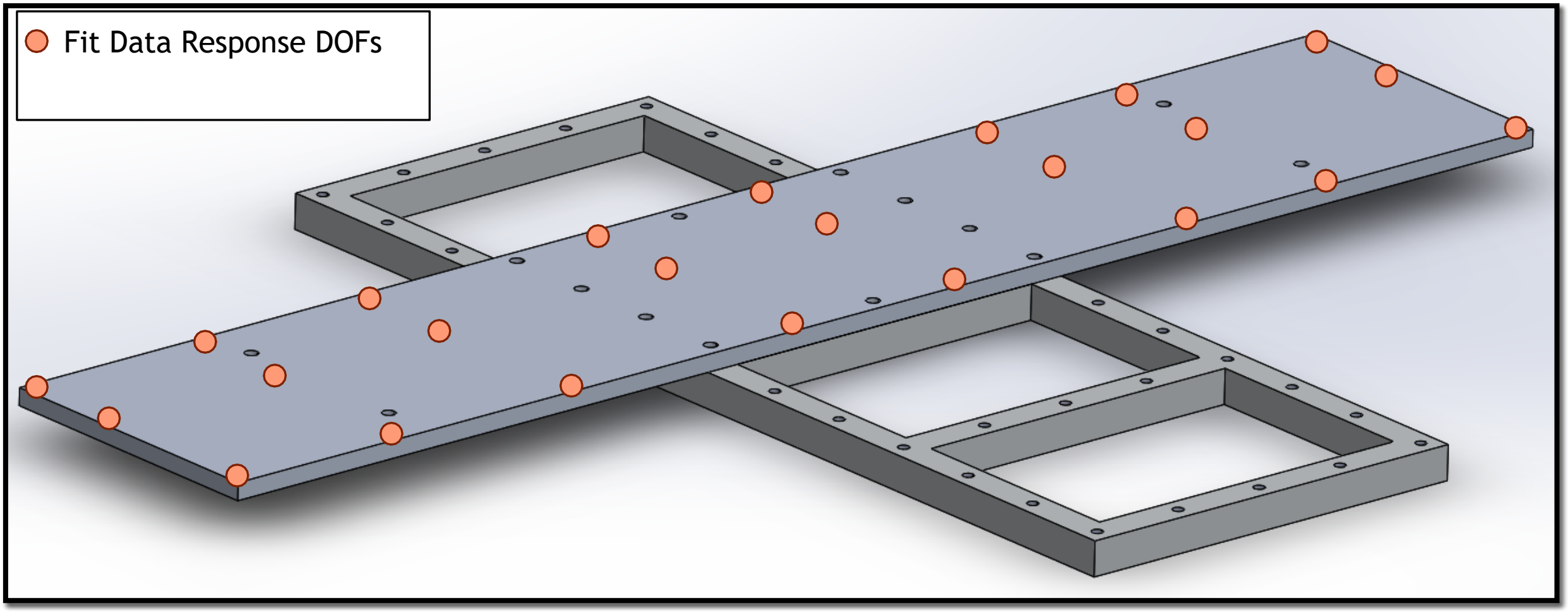


The multi-DOF solution shows similar trends to the 6DOF solution, indicating that the trends are due to an overfit solution

Using Sample Splitting to Check for Overfitting

Could sample splitting be used to check for overfit solutions?

Testing for the Possibility of an Overfit Solution – Sample Splitting Setup



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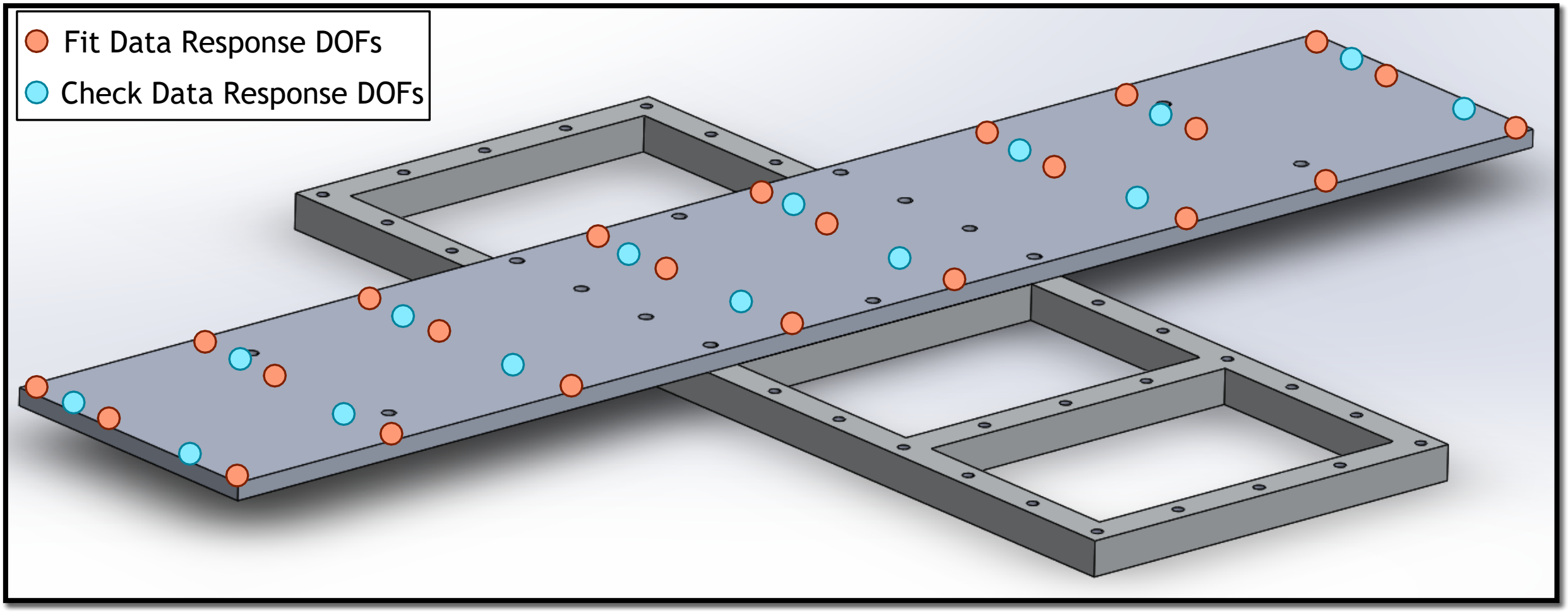
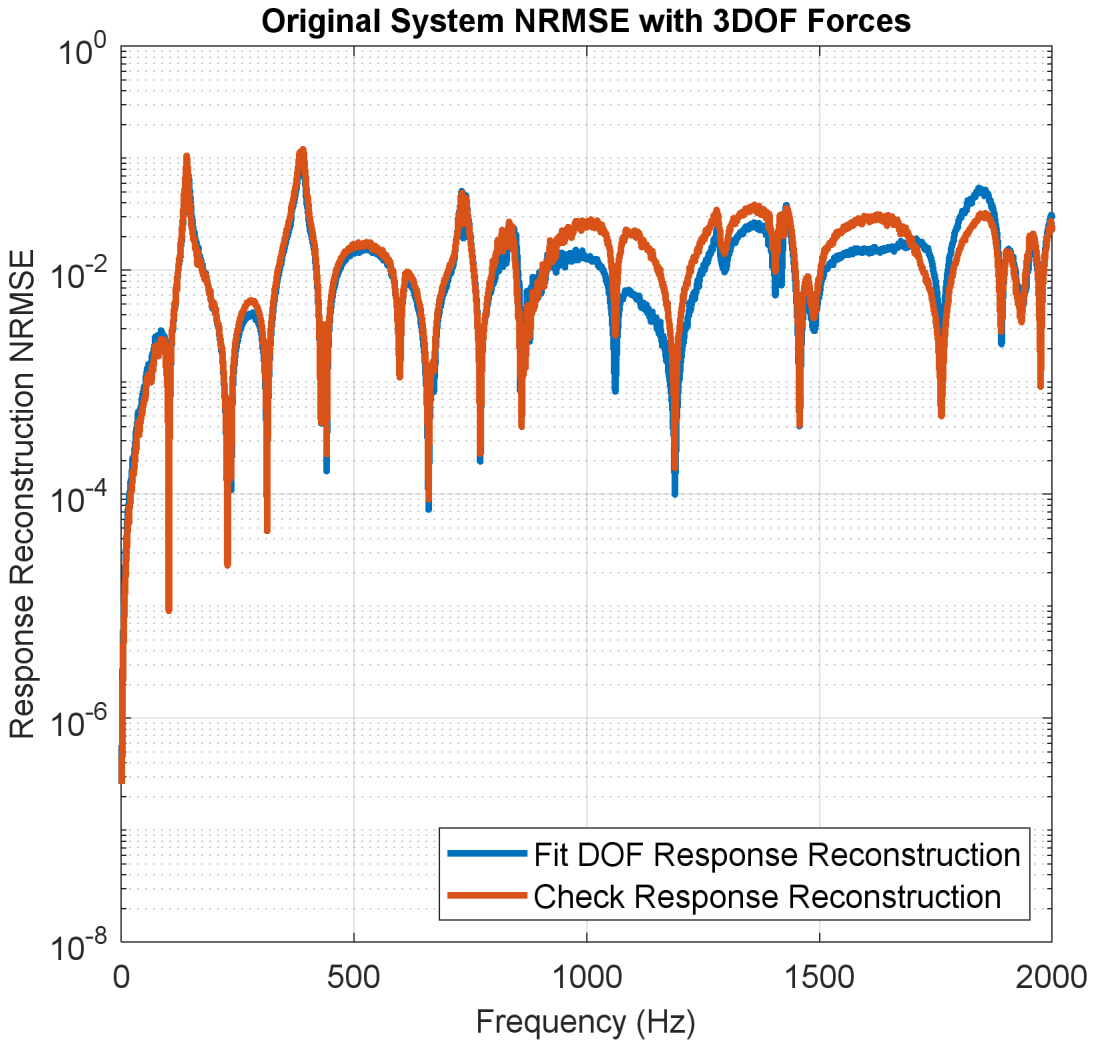
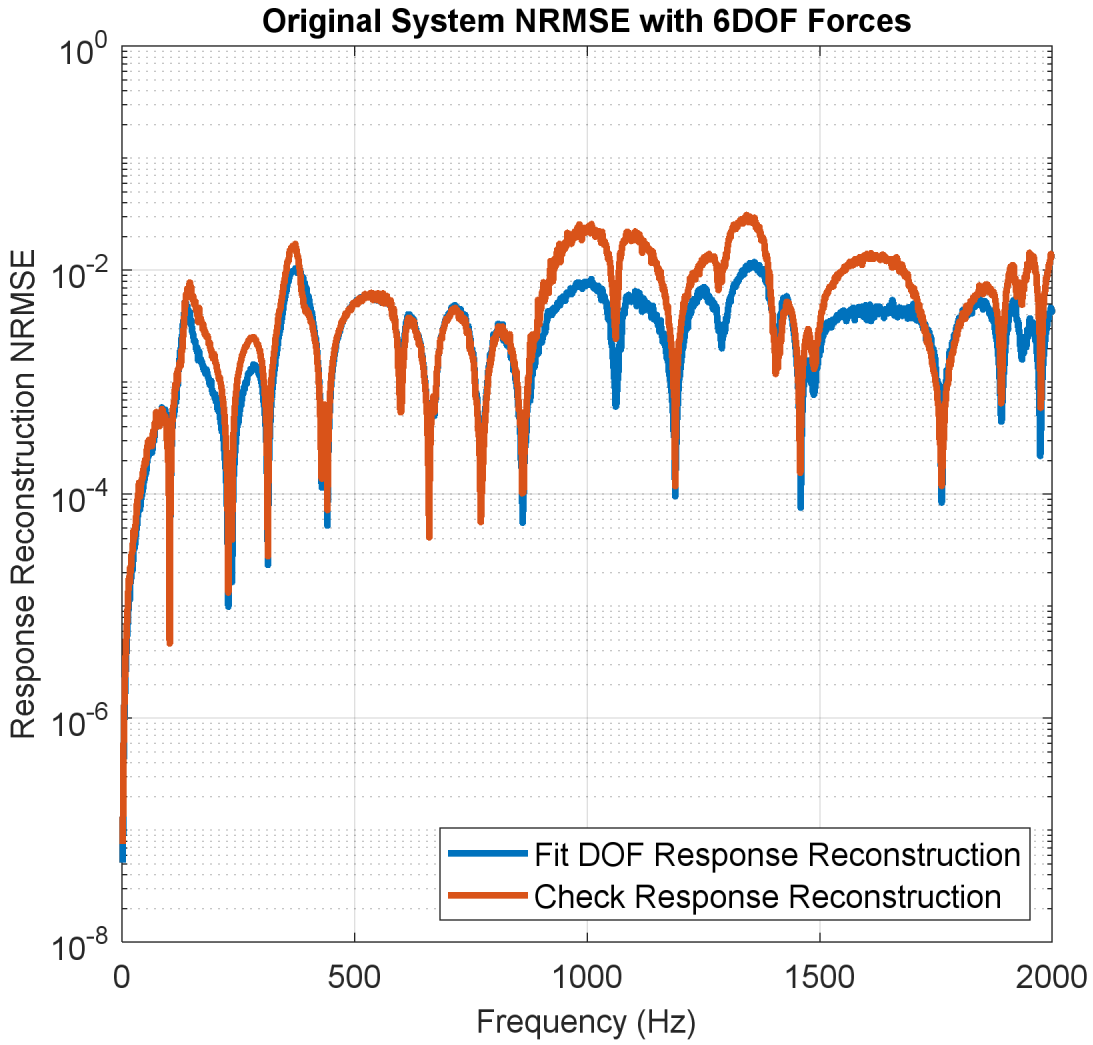


Different response DOFs were used to estimating the forces and perform the response reconstruction check

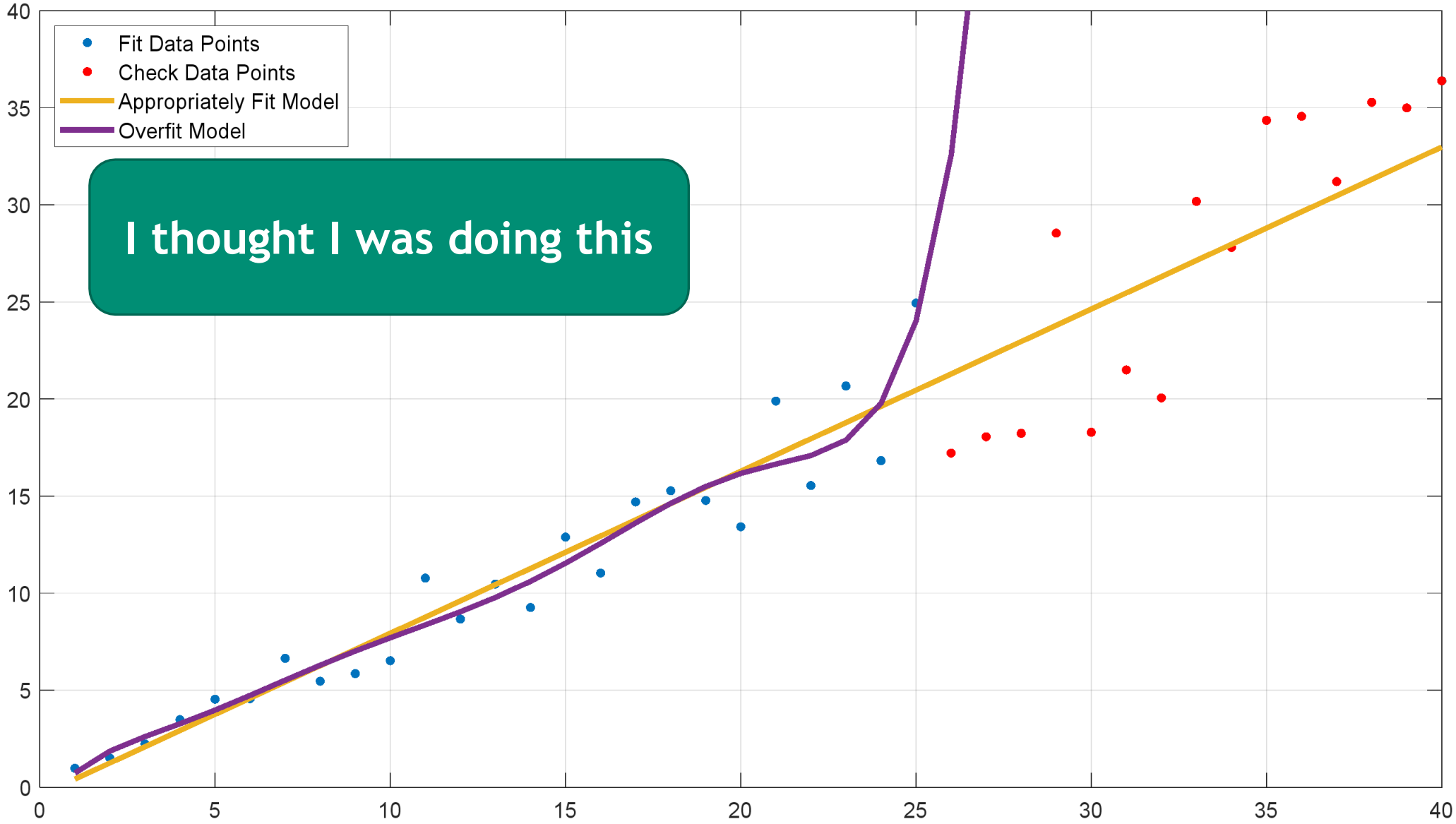
Testing for the Possibility of an Overfit Solution – Sample Splitting





There aren't differences in the NRMSE spectrums for the different DOF sets

Potential Issue with Sample Splitting – 2D Data Example



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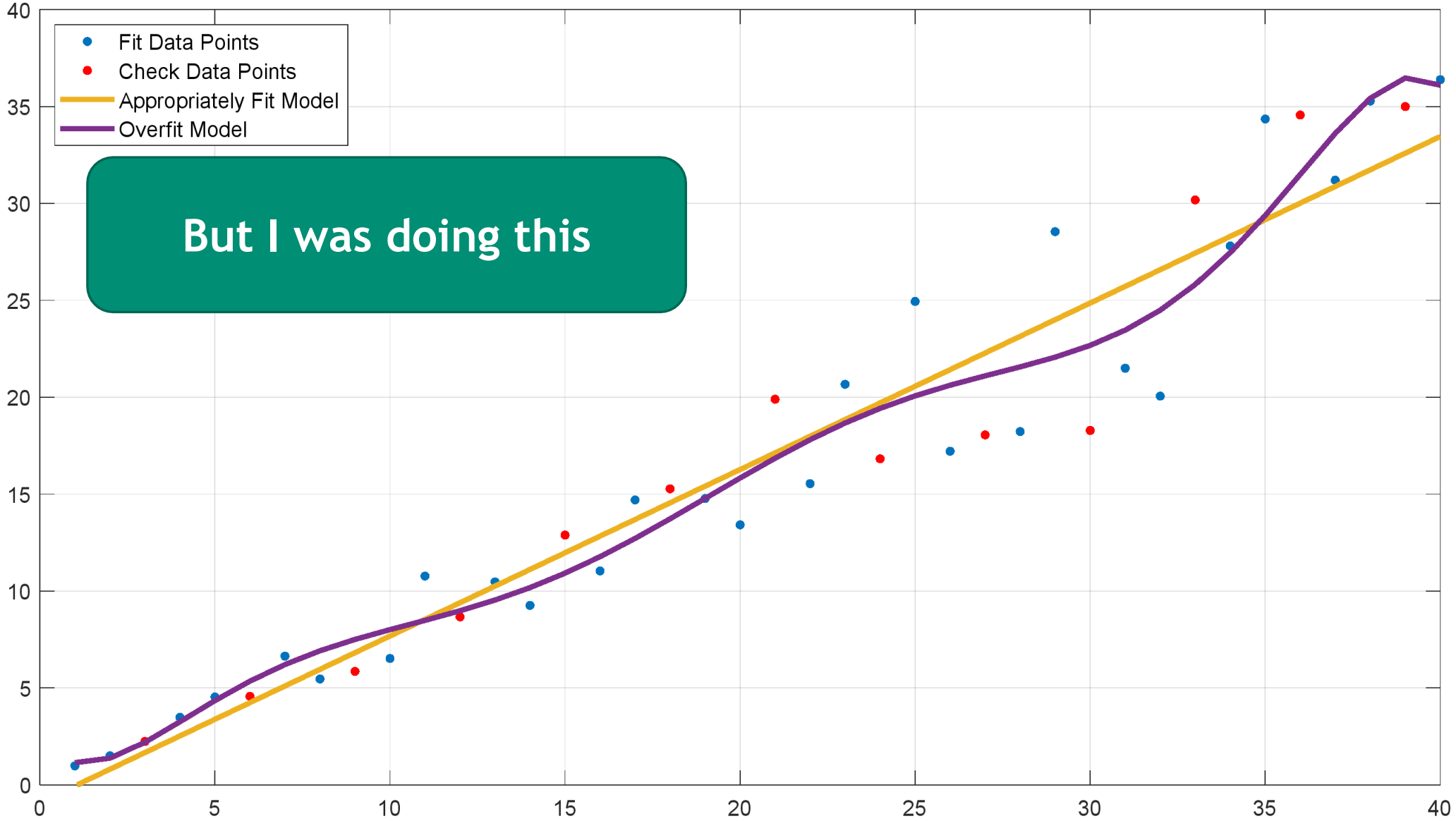

Key Findings and Conclusions

Response reconstruction error may be insufficient for validating force estimates

Need to be careful when choosing reference DOFs for inverse force estimation

Practitioners should consider two forms of error for inverse force estimation:

- Measurement error
- Model form error

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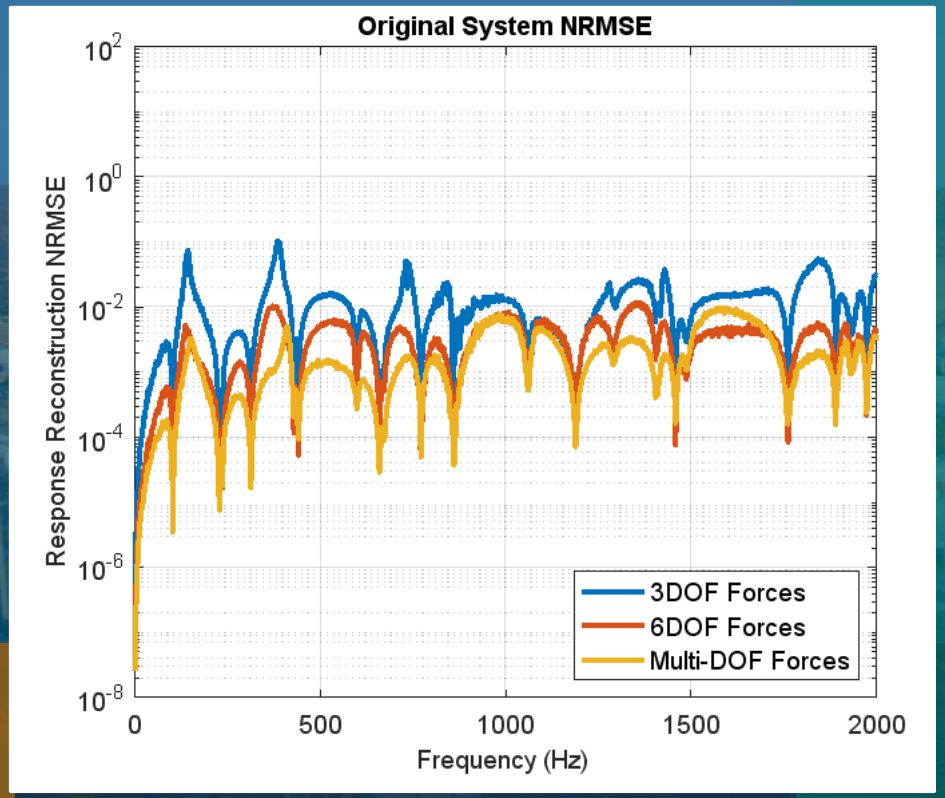
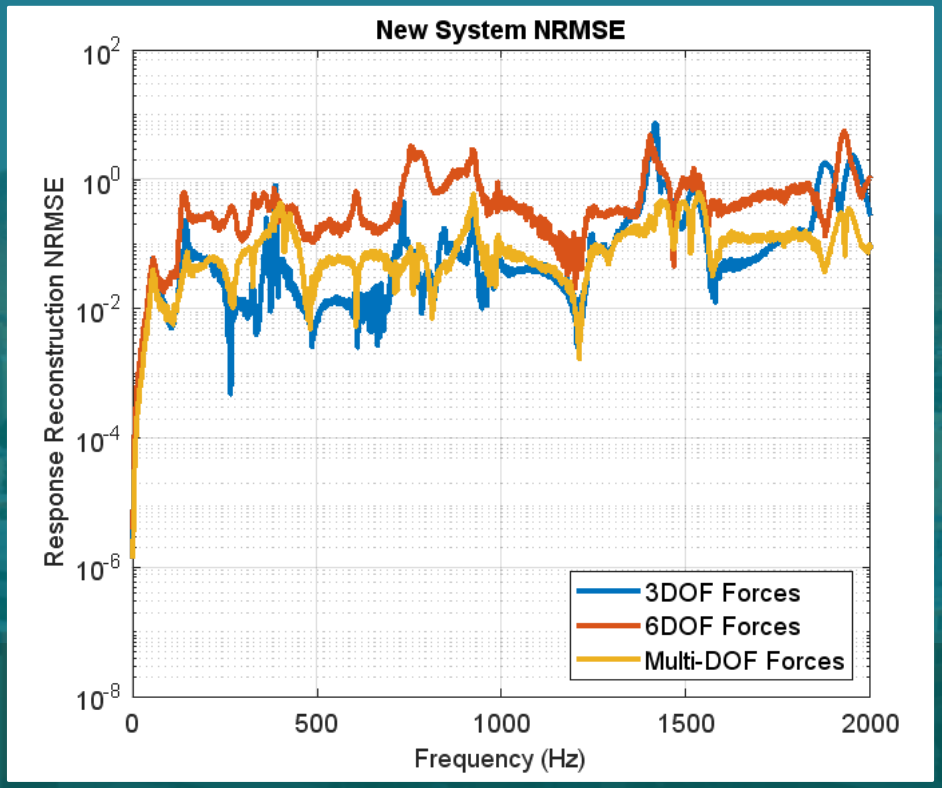
- **Measurement error**
- **Model form error**



Environment Translation

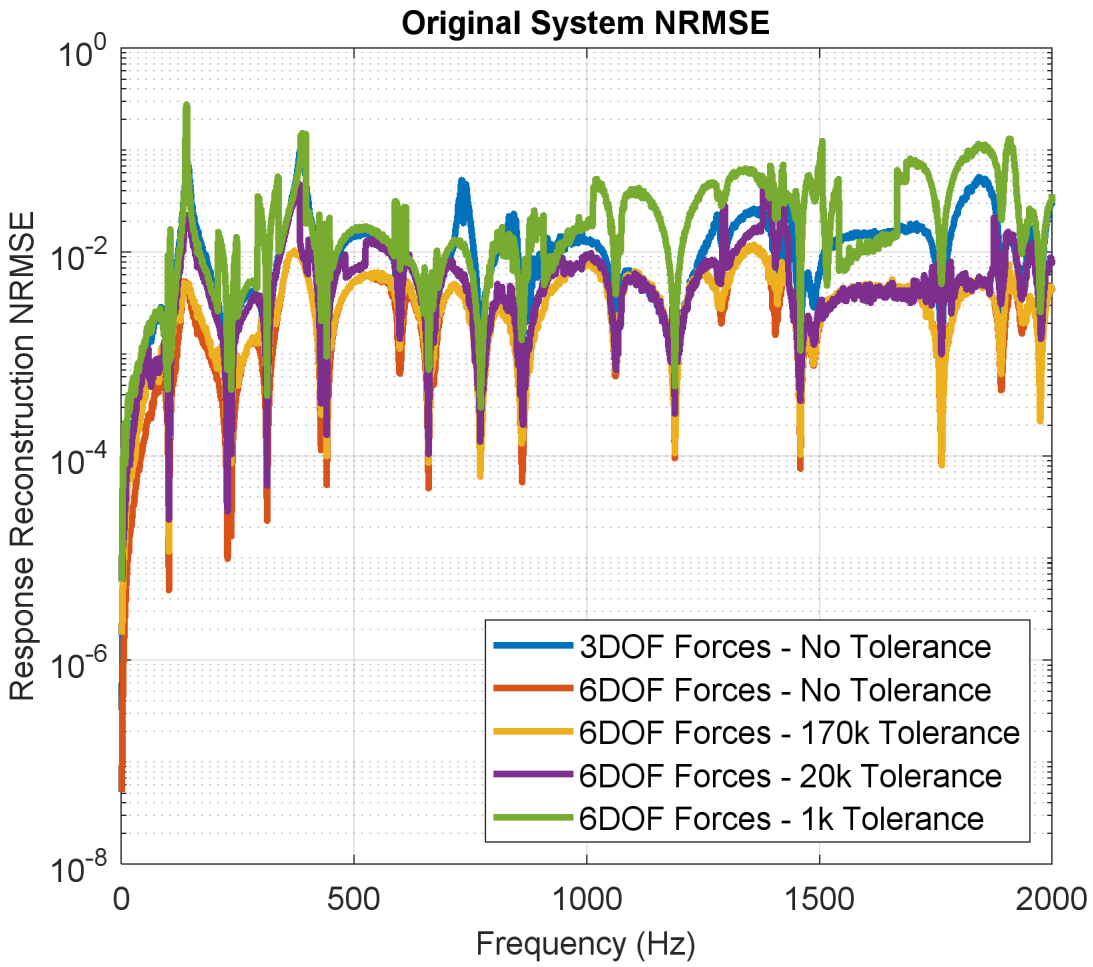


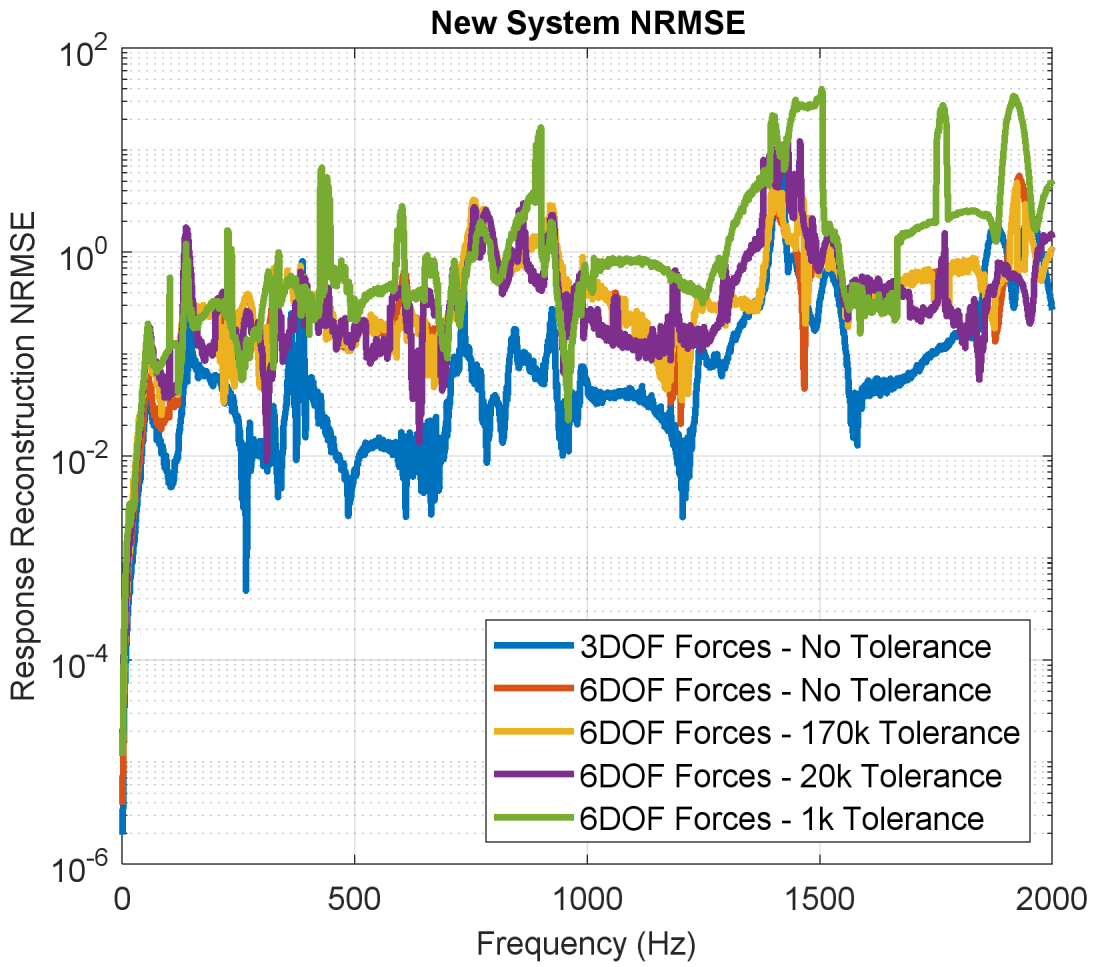
Thank You!

- *Response reconstruction error may be a misleading metric for the accuracy of estimated forces*
- *Unnecessary reference DOFs may lead to errors in inverse force estimation*

Back-up

Results – Singular Value Rejection





Results – Regularization