PRACTICAL CONSIDERATIONS USING WEIGHTED-ACCELERATION COMPENSATION TECHNIQUES FOR DYNAMIC FORCE MEASUREMENTS IN WIND TUNNELS

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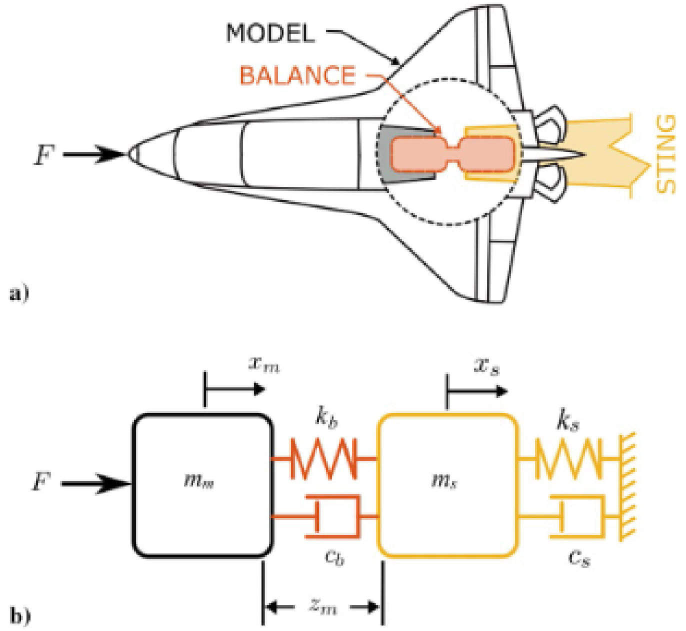
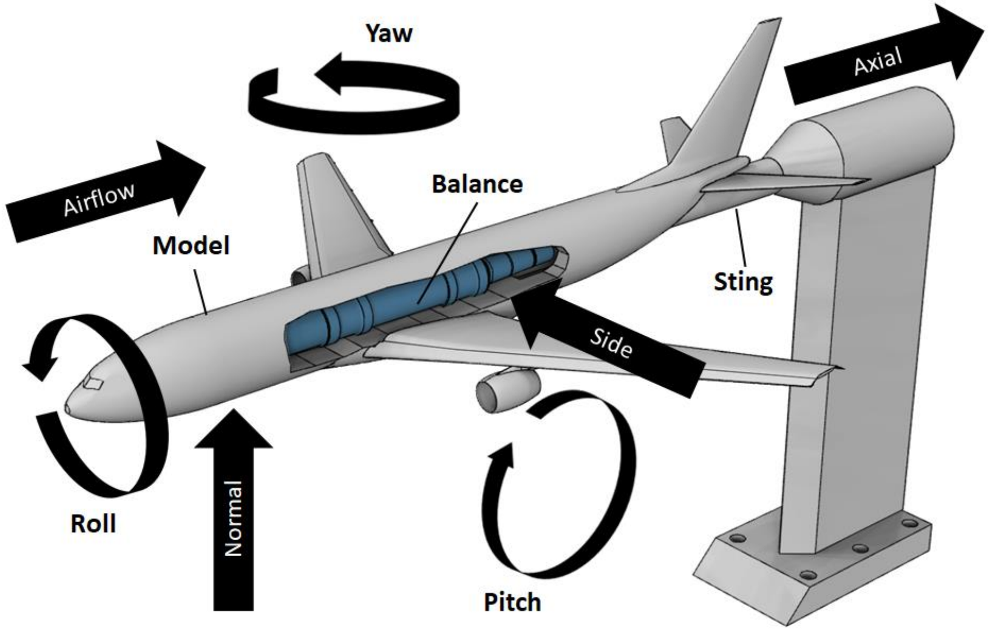
Introduction

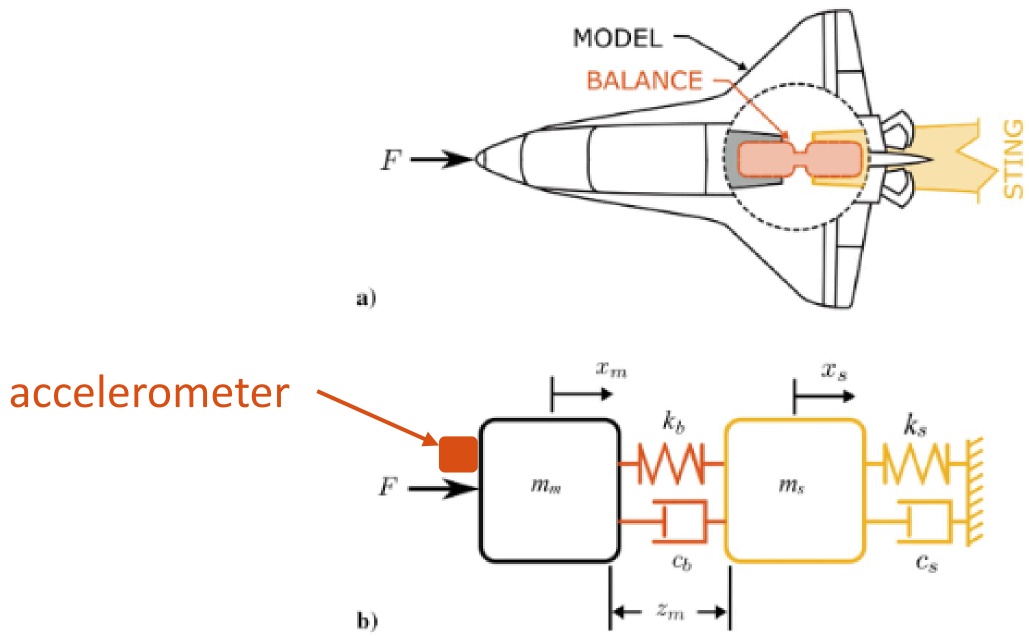
- Ground test facilities typically consist of a test article, wind tunnel balance to measure loads, and additional supporting structures.
- Wind tunnel measurement systems can be modelled as a collection of mass, spring, damper elements.
- This work is interested in measuring the externally applied loads F.

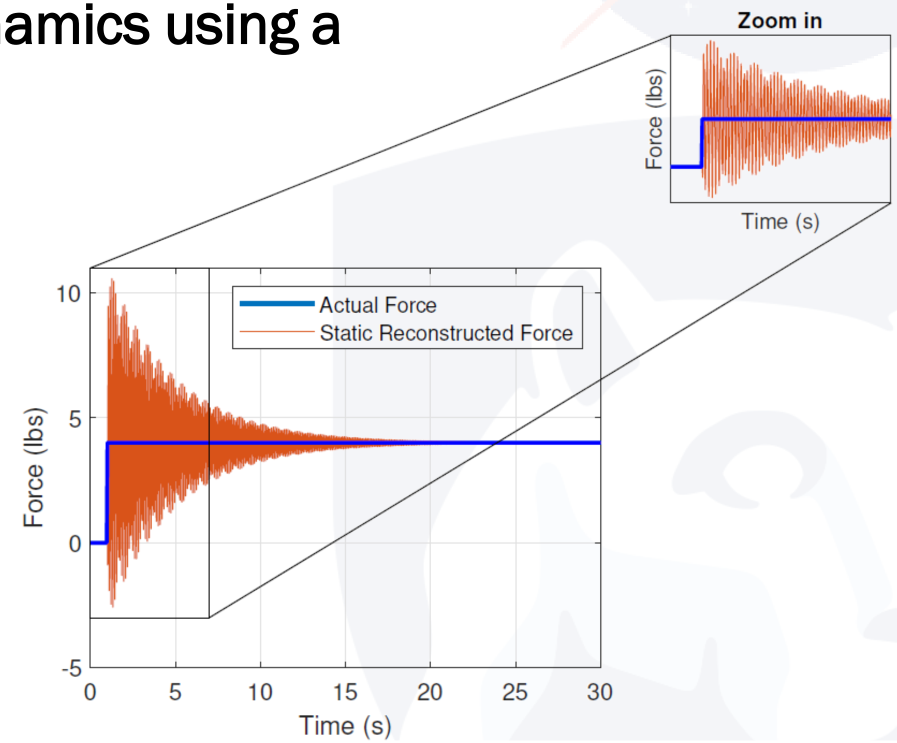




Motivation

- Dynamic forces are of interest to specific wind tunnel applications.
- This work explores augmenting traditionally measured data with accelerometers to compensate for the system dynamics using a weighted-accelerations technique [7].

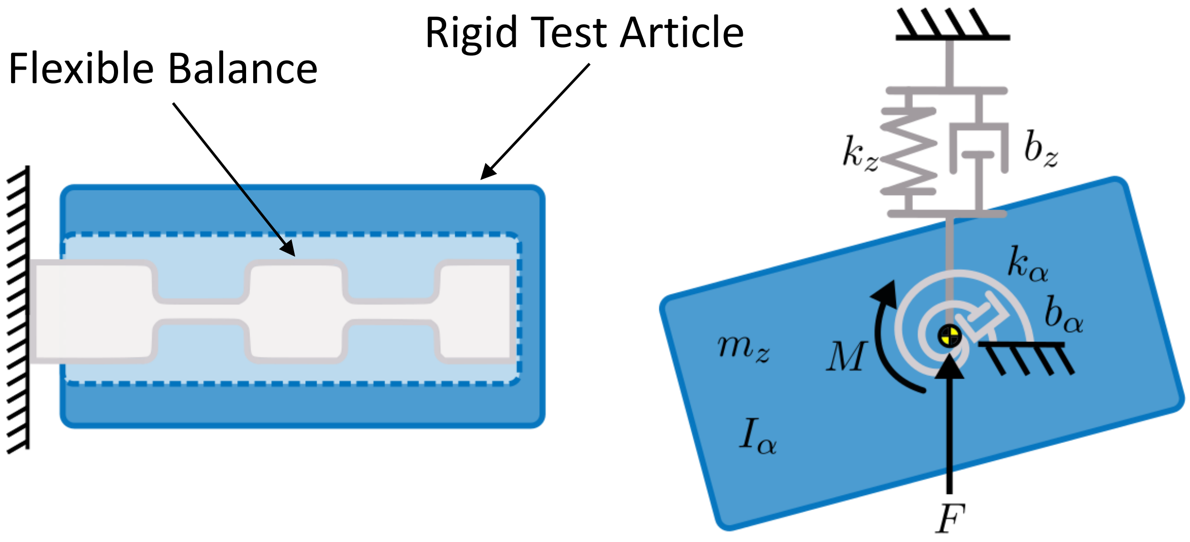




Reconstructing dynamic forces using traditional static methods can lead to unacceptably large errors due to the dynamics of the system.

Practical Considerations

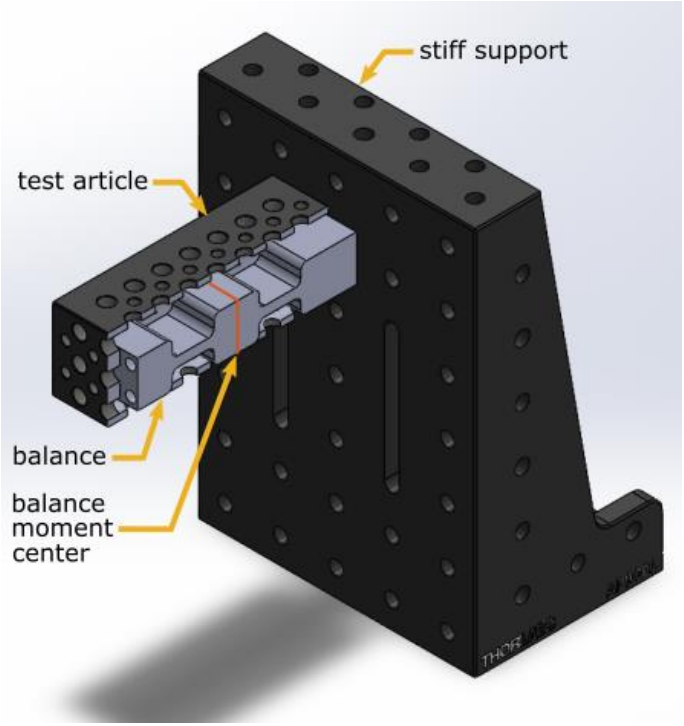
- Weighted-acceleration techniques work best when:
  - Test article is a rigid body
  - Balance is rigidly supported
- A reduced order model was developed to validate the technique.

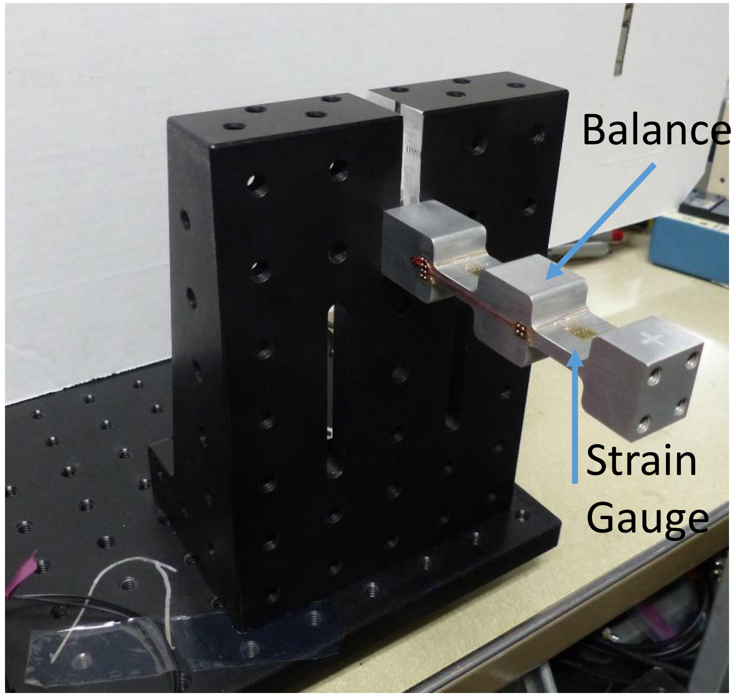


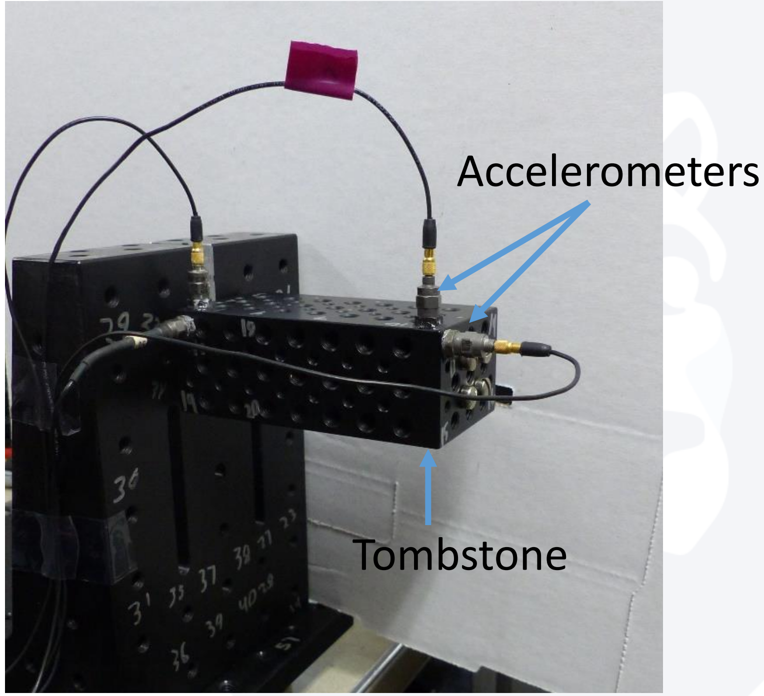
Reduced-order model of a normal force and pitch moment measurement system.

Tabletop Experimental Testbed

- Weighted-acceleration technique and practical considerations demonstrated on a tabletop experimental apparatus.
- Two component measurement system: normal force and pitch moment.
- System designed to be modular and have components that serve as a proxy to a wind tunnel measurement system.







Compensation Methodology

- Goal is to measure the dynamic forces acting on the balance using:

$$\boldsymbol{Q} = \overbrace{\boldsymbol{\epsilon C_0}}^{\text{Traditionally Measured}} + \overbrace{\boldsymbol{SC}}^{\text{Dynamic Correction}}$$

Force & Moment　Strain　Static Calibration　Accel. Data　Dynamic Calibration

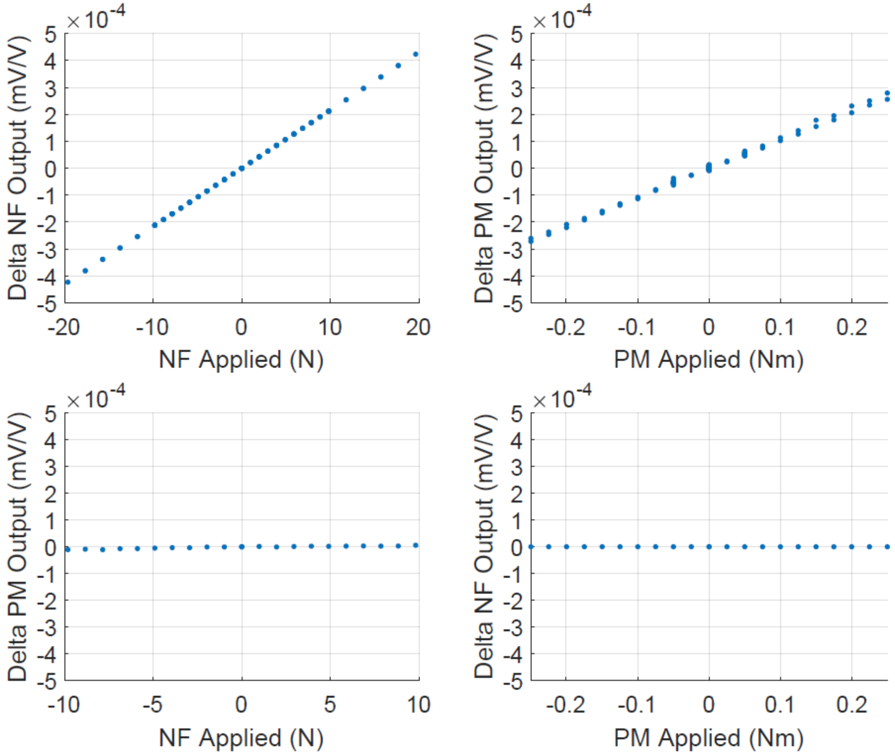
- Dynamic calibration matrix is found by applying known dynamic forces:

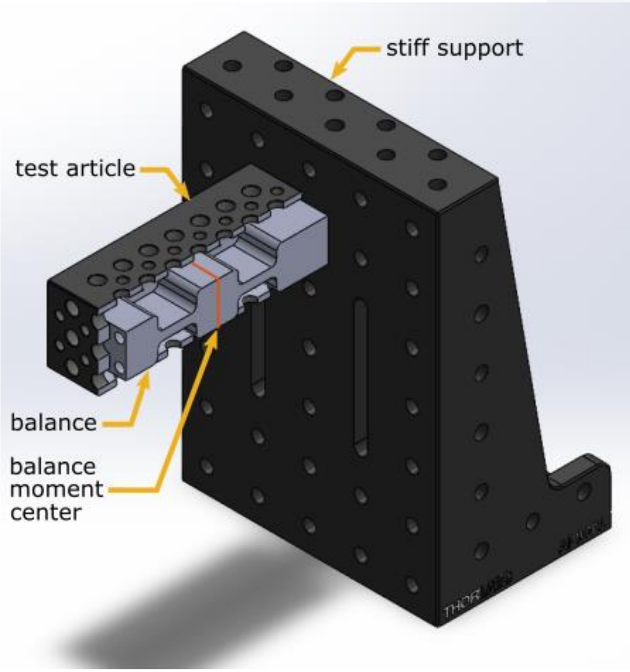
$$\boldsymbol{C} = \left(\boldsymbol{S^T S}\right)^{-1} \boldsymbol{S^T}\left(\boldsymbol{Q} - \boldsymbol{\epsilon C_0}\right)$$

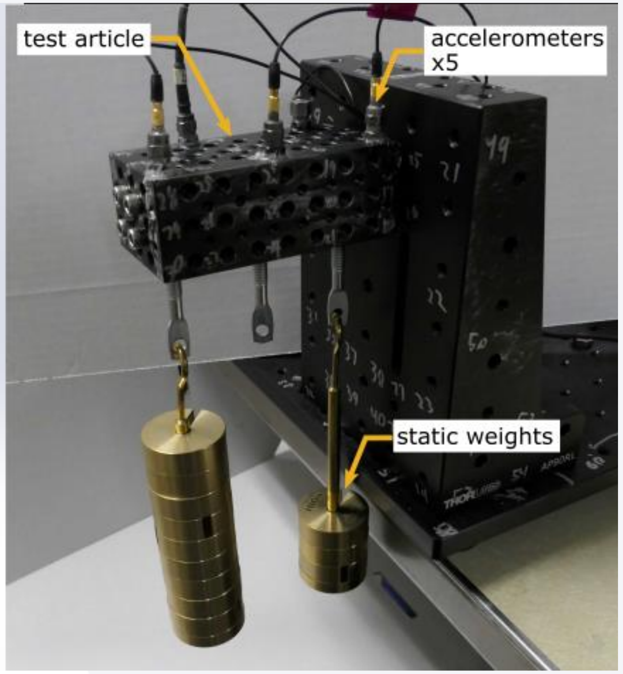
Accel. Data　Force & Moment　Strain　Static Calibration

Static Calibration Results

- Balance was statically calibrated using hanging weights.
- Applied normal force and pitching moments were only 44% and 10%, respectively, of full scale design.
- The normal force had a residual error as a percent of full scale applied of 0 – 0.1% while the pitching moment had a residual error of 0-1.6%.

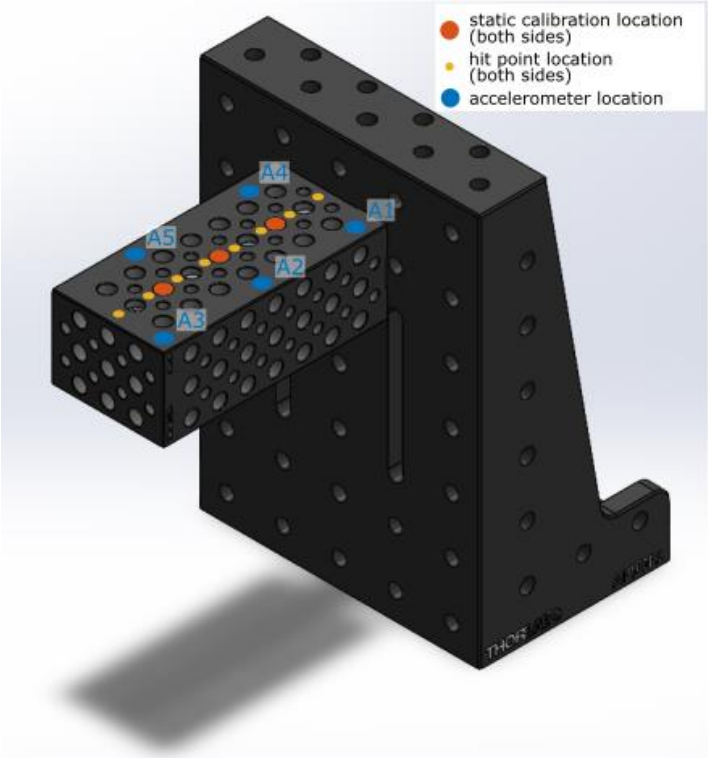


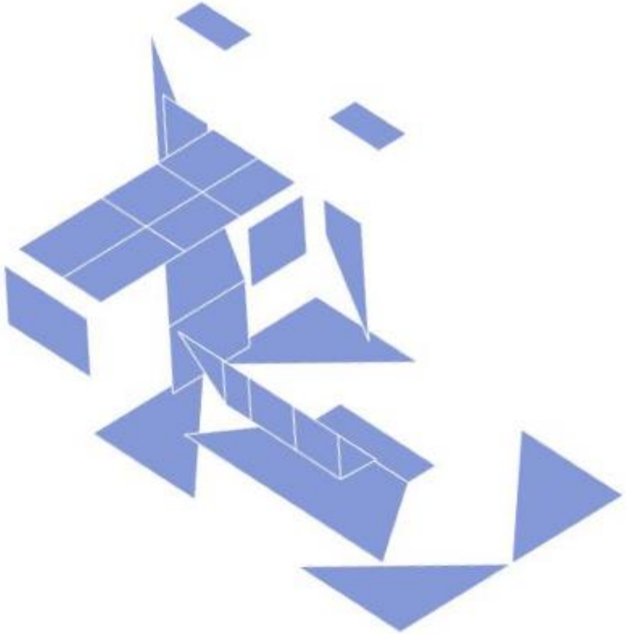




Dynamic Experimental Methodology

- A modal analysis was conducted to verify rigidity of test article.
- Five accelerometers were used in the dynamic reconstruction.
- The image on the right shows the mesh used for the computational modal analysis. Each corner represents an impact hammer tap location.

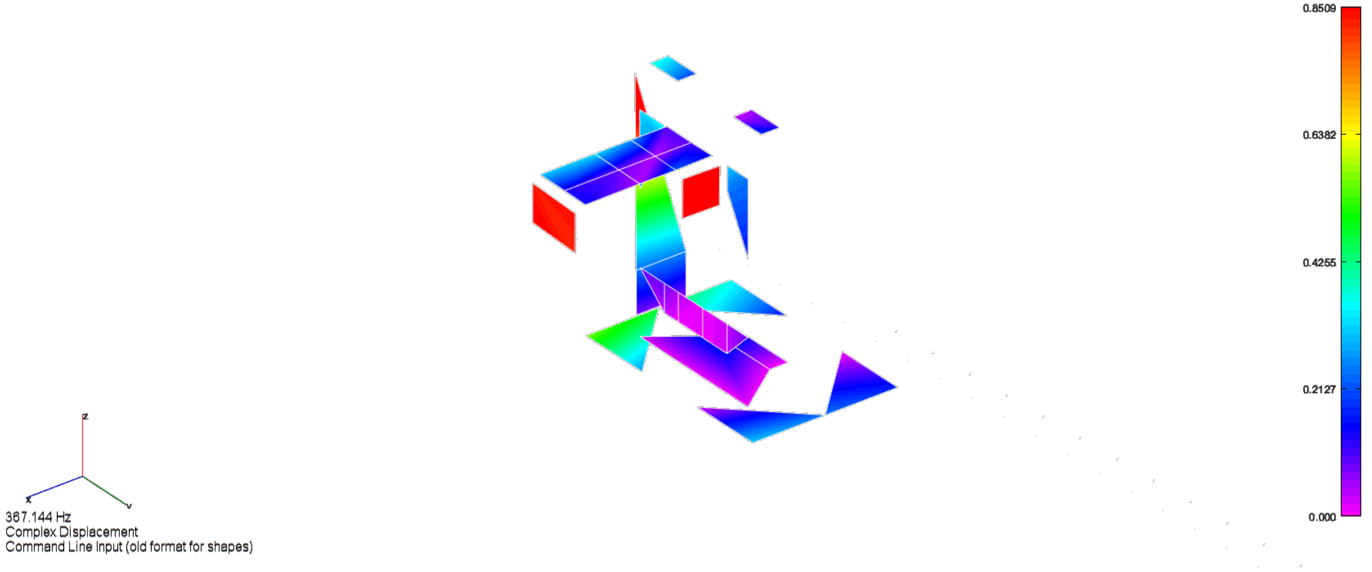


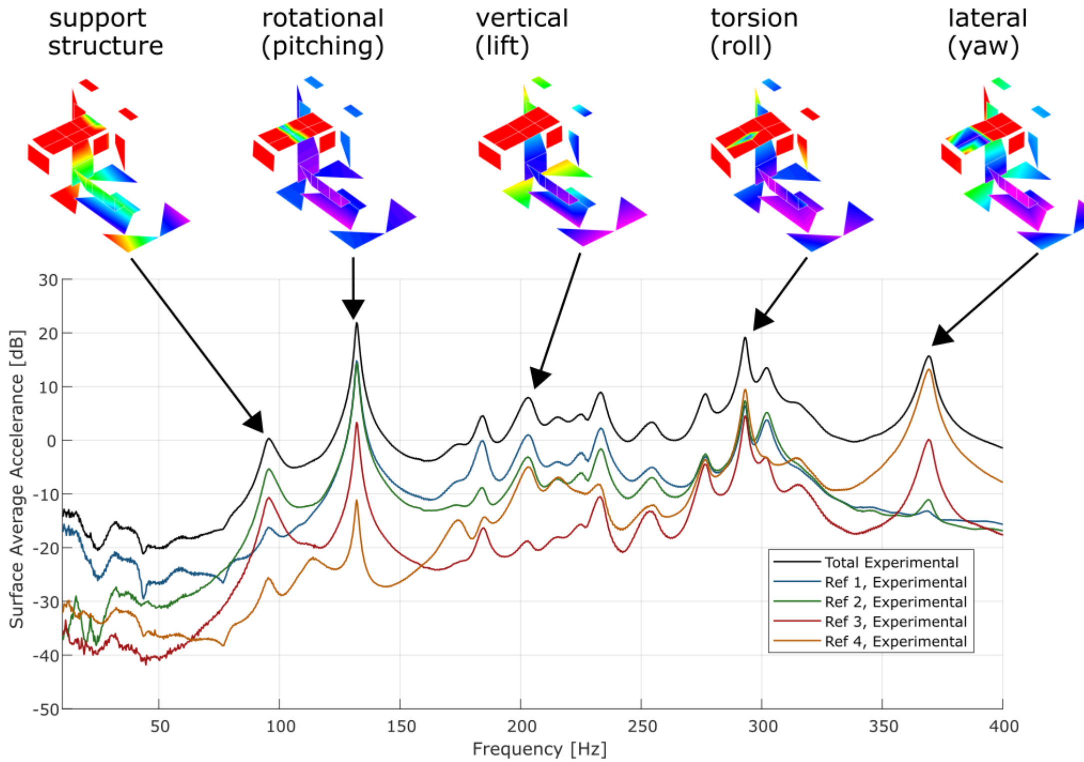


Experimental mesh

Modal Analysis

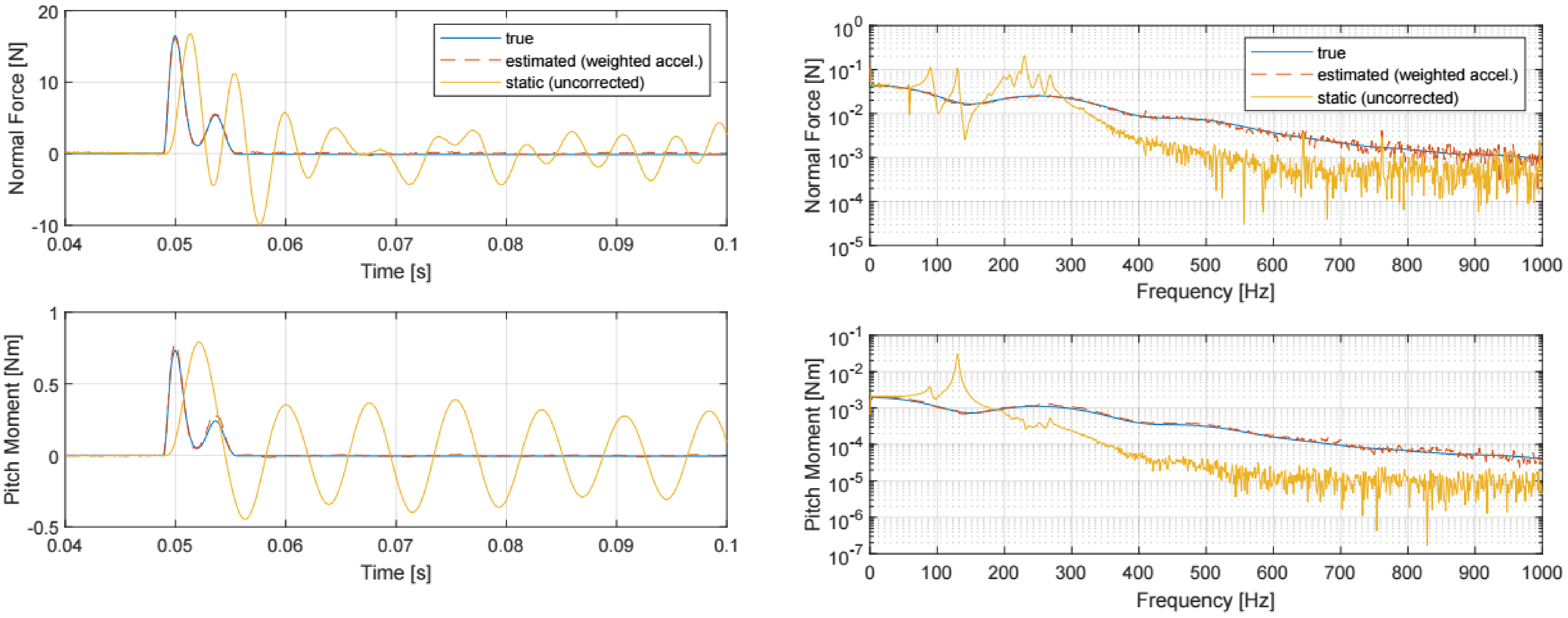
- Each individual component was tapped with an impact hammer.
- Modes occurred at 95 Hz. 132 Hz. 202 Hz. 293 Hz, and 367 Hz.





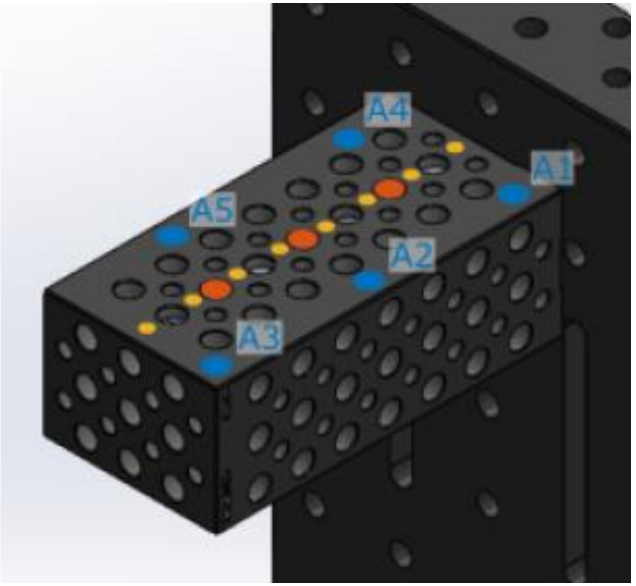
Dynamic Calibration Results

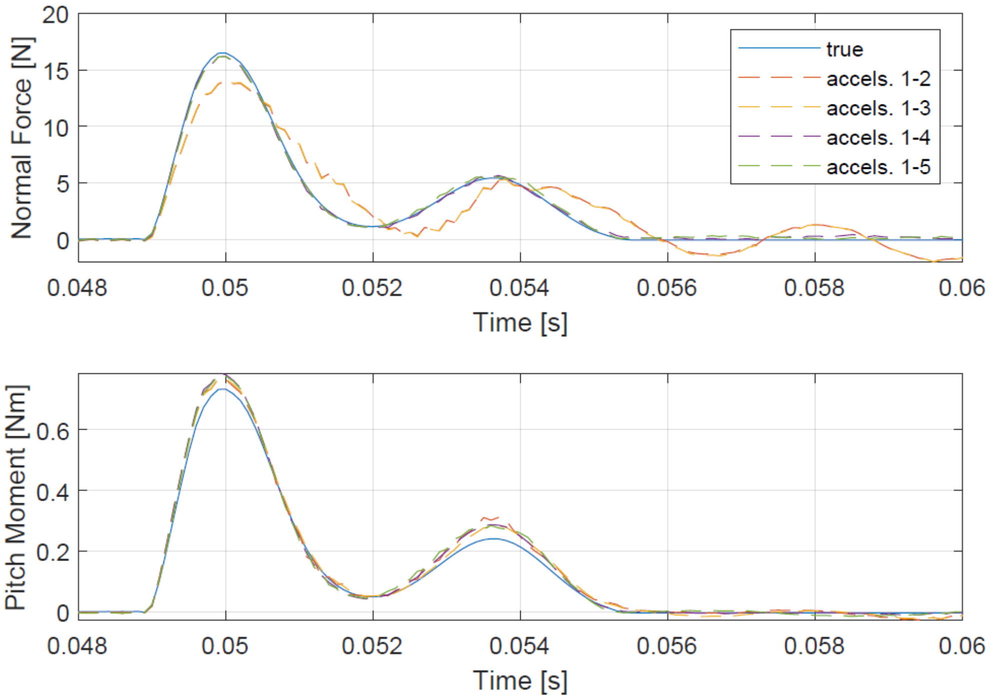
- Reconstruction of a pulse-like force using five accelerometers.
- Methodology was able to remove more modes than accelerometers.



Dynamic Calibration Results

- Experimental dynamic calibration saw increasing accuracy for an increasing number of accelerometers with the present model.
- Noticeable improvement in accuracy transitioning from 3 to 4 accelerometers.
- Additional accelerometers capture the torsional mode, which demonstrates the importance of accelerometer placement.



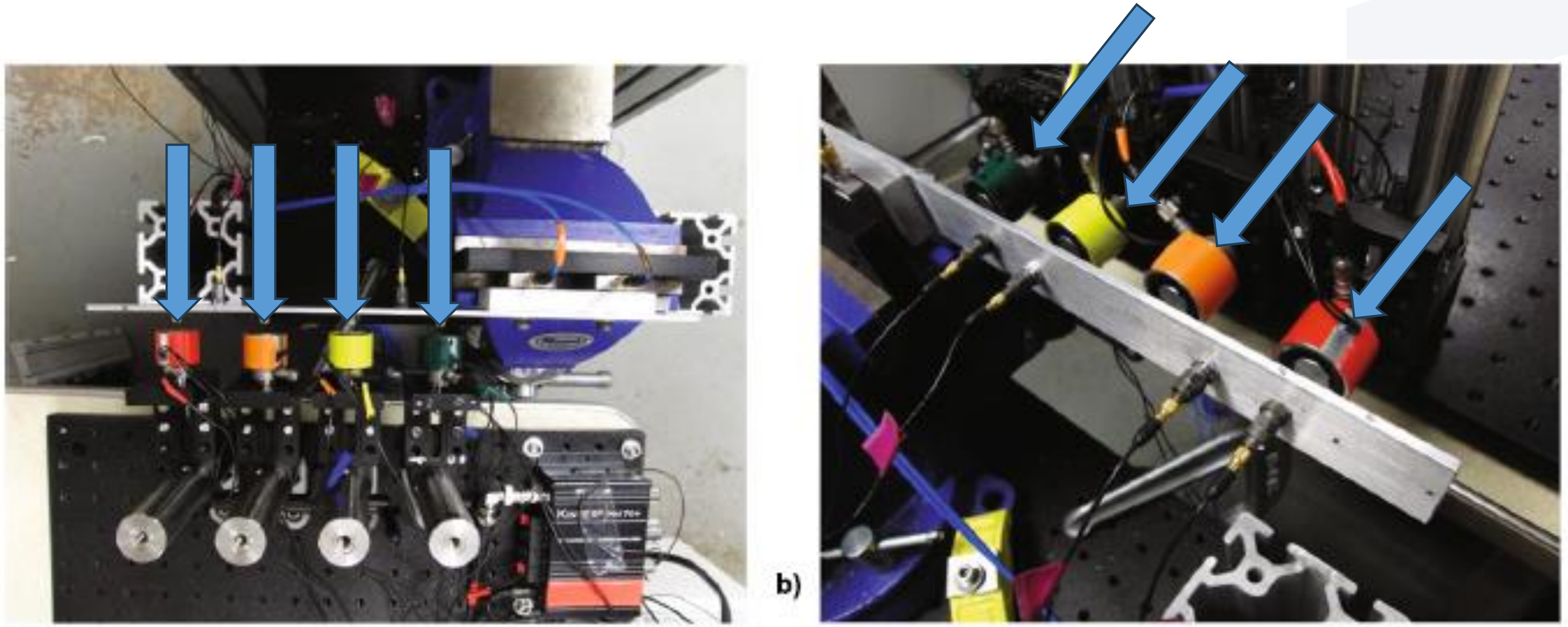


Conclusions

- Experiment was designed to meet the weighted acceleration technique assumptions and demonstrated good performance as a result (<5% of full scale).
- Number and placement of accelerometers plays a role in the quality of the reconstruction.
- There was no numerical regularization in this technique, but the problem was over-constrained using more accelerometers to reduce noise.

Future Work

- Distributed loads would be more representative of a wind tunnel configuration
- Distributed forces can be applied using electromagnets



a) b)

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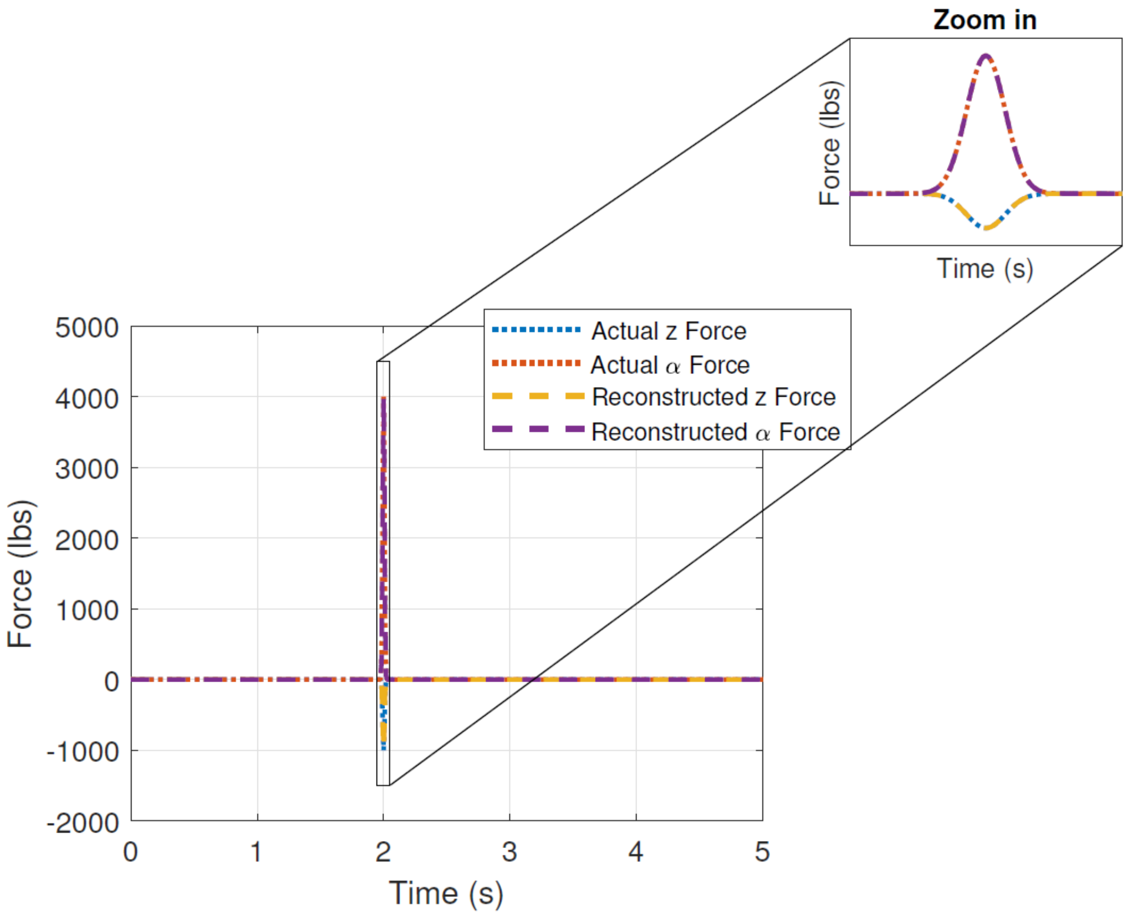
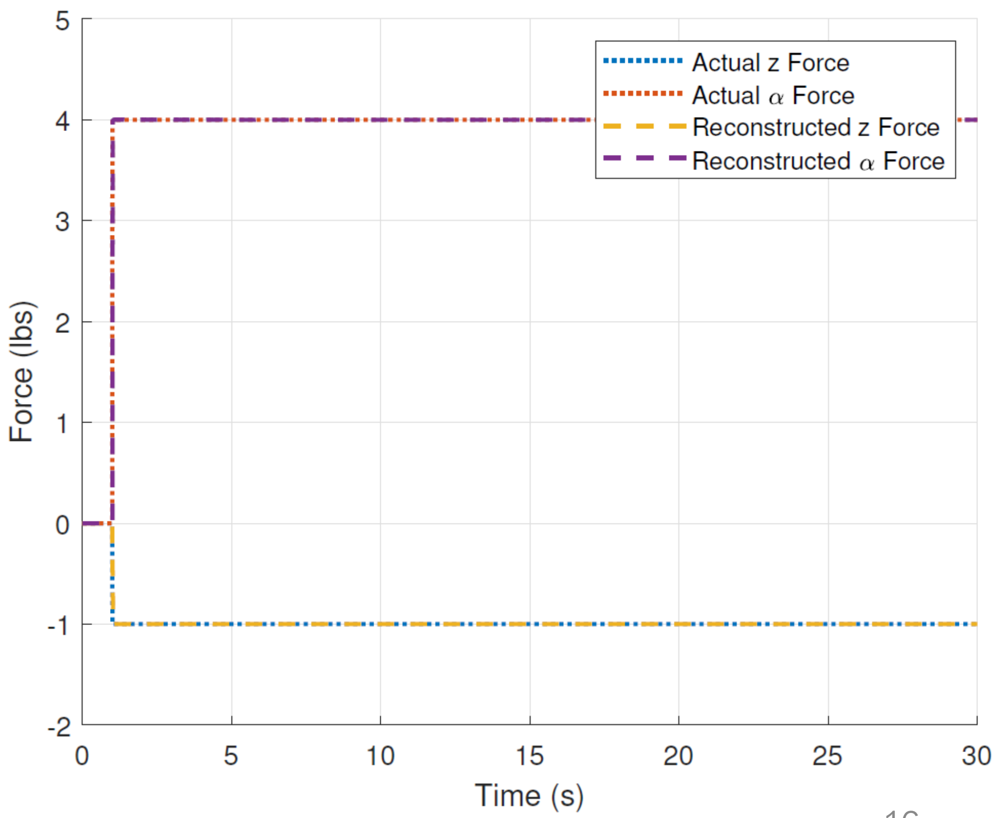
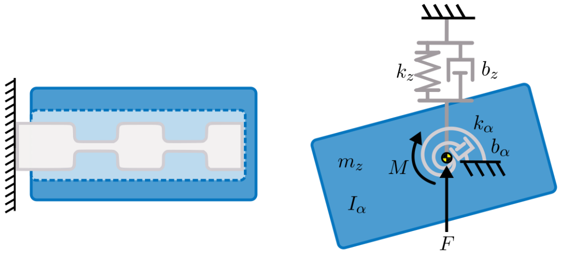
Method Validation using a Numerical Reduced Order Model





Force Reconstruction using Weighted-Accelerations

- A two degree-of-freedom system was used.
- $m_z\ddot{z} + b_z\dot{z} + k_z z = F$
- $I_\alpha\ddot{\alpha} + b_\alpha\dot{\alpha} + k_\alpha\alpha = M$



- The static component can be determined by applying a static force
- $C_0 = (\epsilon^T\epsilon)^{-1}\epsilon^T(Q)$
- The static force/moment can be subtracted out from the dynamic force/moment
- $C = (S^TS)^{-1}S^T(Q - \epsilon C_0)$
- This matrix can be used to reconstruct the dynamic force.