Nonlinear Computational Models for Dynamic Response Prediction of Long Slender Structures

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Outline

- Motivation and scope
- Development of high-fidelity nonlinear computational models
- Correlation of computational results with experimental datasets
- Conclusions

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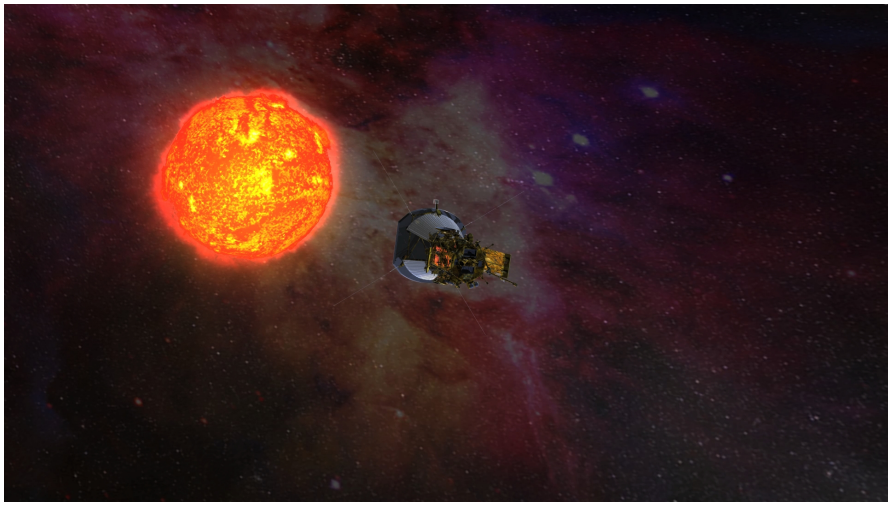
Background and Motivation

- The Solar Probe Plus (SPP) is a NASA mission to fly into the Sun's atmosphere
- It will come closer to the Sun than any previous spacecraft
- The scientific goal is to understand how the Sun's corona is heated and how the solar wind is accelerated

SPP Leaving Earth. *Image Credit: JHU/APL*.



SPP Observing the Sun. *Image Credit: JHU/APL.*

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Scope

- Investigate the dynamic behavior of a long slender whip antenna attached to the SPP
- Develop nonlinear finite element model of the whip antenna test setup including surrounding parts
- Simulate the model by subjecting the whip to an input sine sweep vibration
- Assess the viability of the developed model by correlating it with test configuration
- Upon validation, the nonlinear model can be used to optimize the design process of the whip antenna and its constraints

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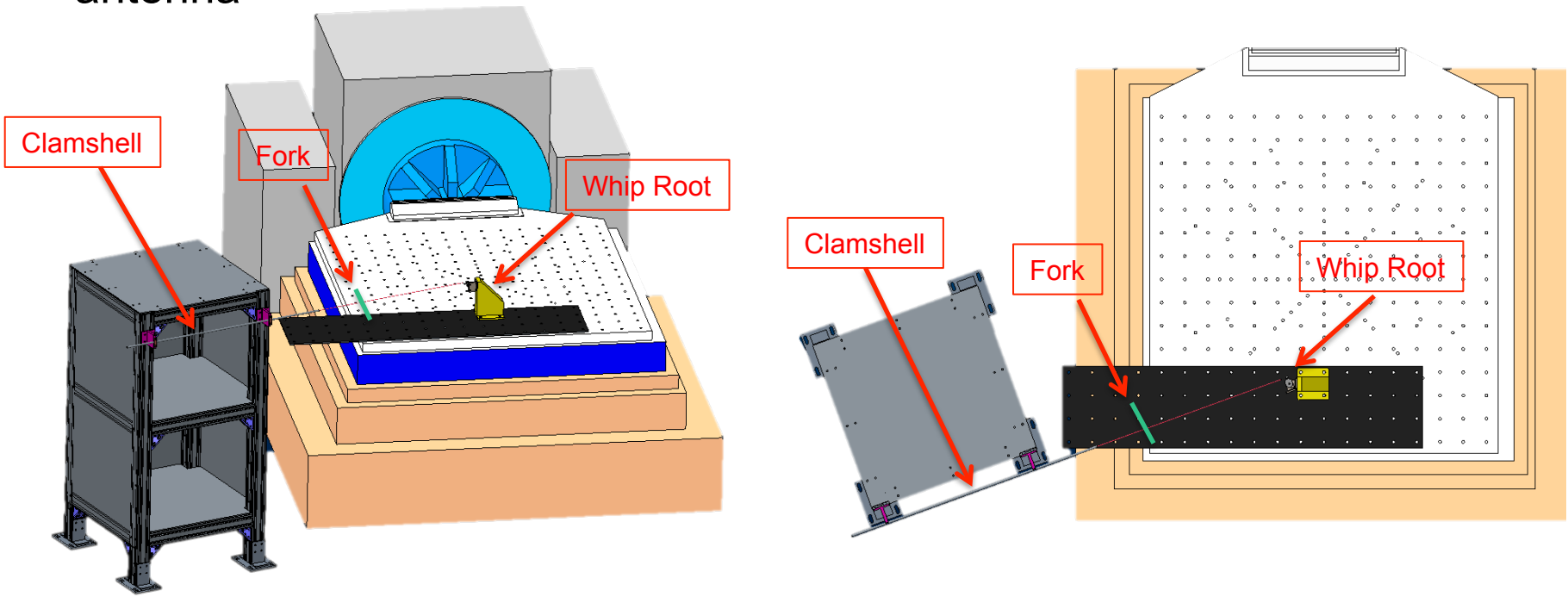
Test Configuration

- The Whip antenna was clamped at its root
- A fork was used to constrain the motion in the mid-span
- A Clamshell was used to constrain the motion at the free-end of the whip antenna



CAD Model of Test Fixture

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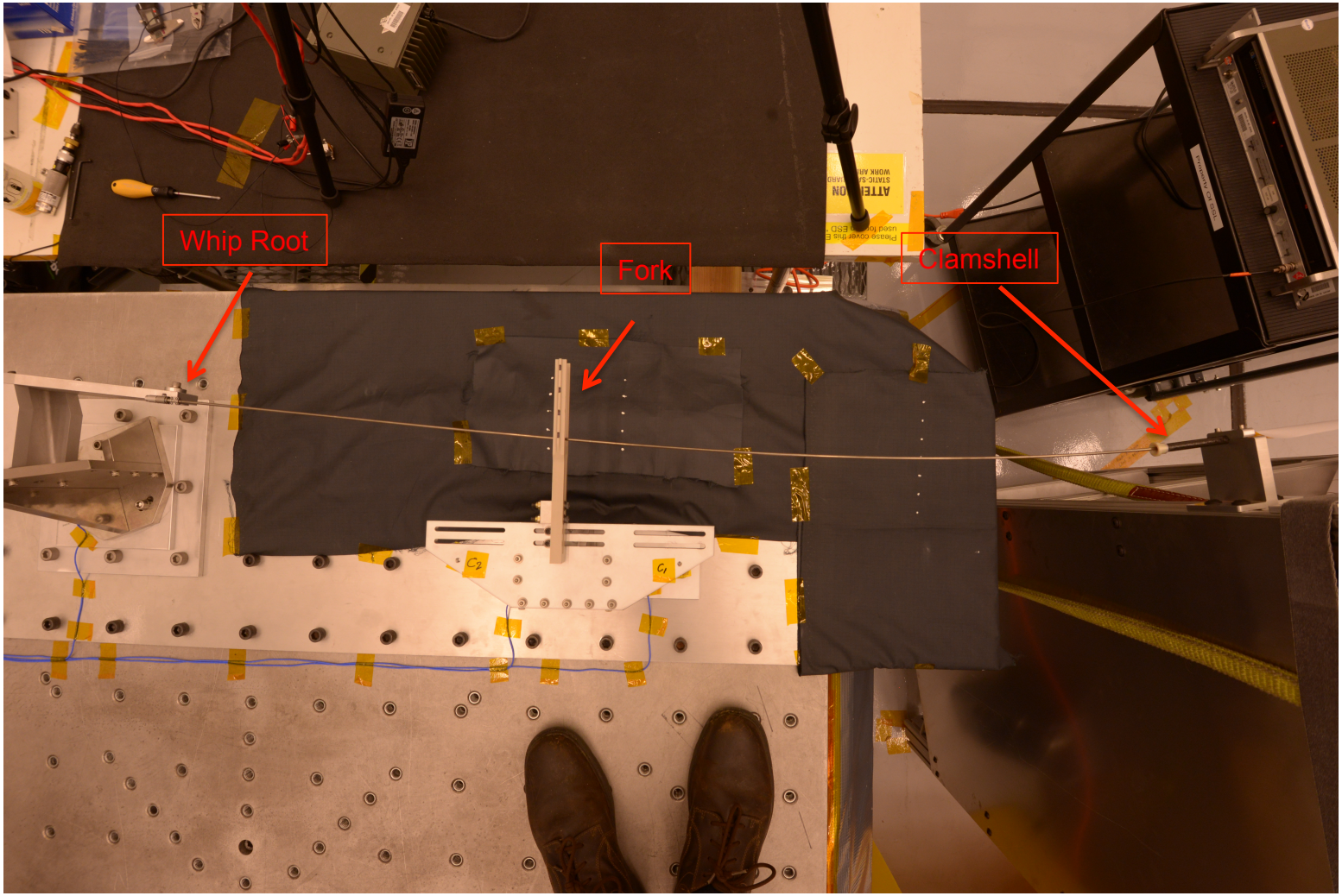
Test Configuration



A photo of Test Fixture – *Image Credit: JHU/APL.*

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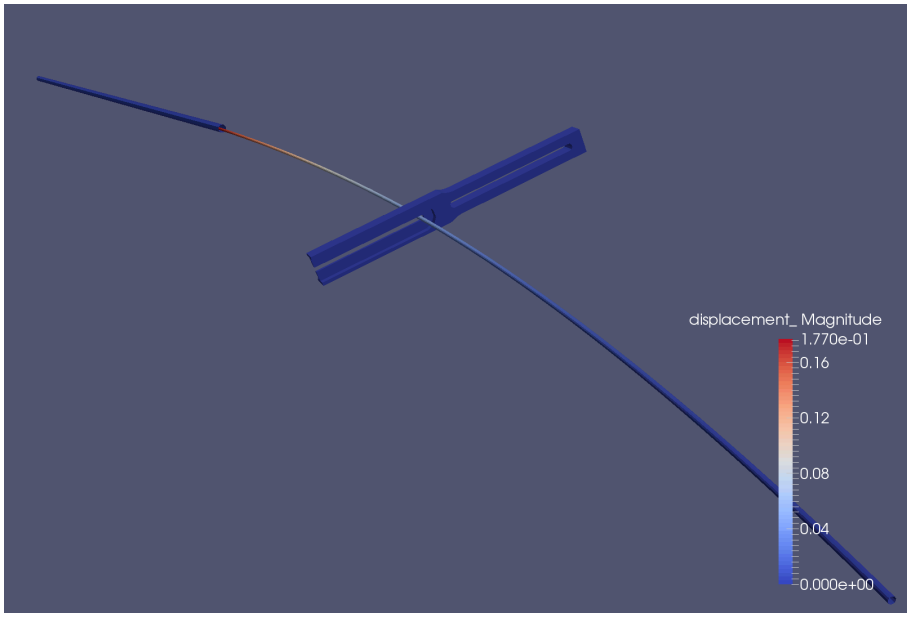
Development of Nonlinear Whip Model

- Whip Mesh Features:
  - Include only the Whip, Fork and Clamshell
  - Modified Whip and Clamshell CAD due to inconsistencies with test article
  - Whip is allowed to chatter within the Clamshell
  - Whip also impacts the inside of the fork



- Simulation included the following steps:
  - Implicit solver for Pre-Contact (Static) phase. Explicit solver for Contact (Static) and Vibration (Dynamic) phases

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Computational Tools Used for this Study

- **Sierra/Solid Mechanics** (Solver)
  - High performance computing platform for solid mechanics, dynamics and multi-physics
  - Exploit hundreds or thousands of processors
  - Interface with JPL imuQ tools for parameter studies and uncertainty quantification

- Key Model Elements
  - Nonlinear geometric effects
    - Large angle bending of the whip
    - Preload and prestressing of the whip
  - Nonlinear contact and friction
    - Impact and sliding of the whip on the fork
    - Impact and sliding of the whip within the clamshell
  - Two step simulation
    - Quasi-static preload stage
    - Dynamic contact and vibration stage

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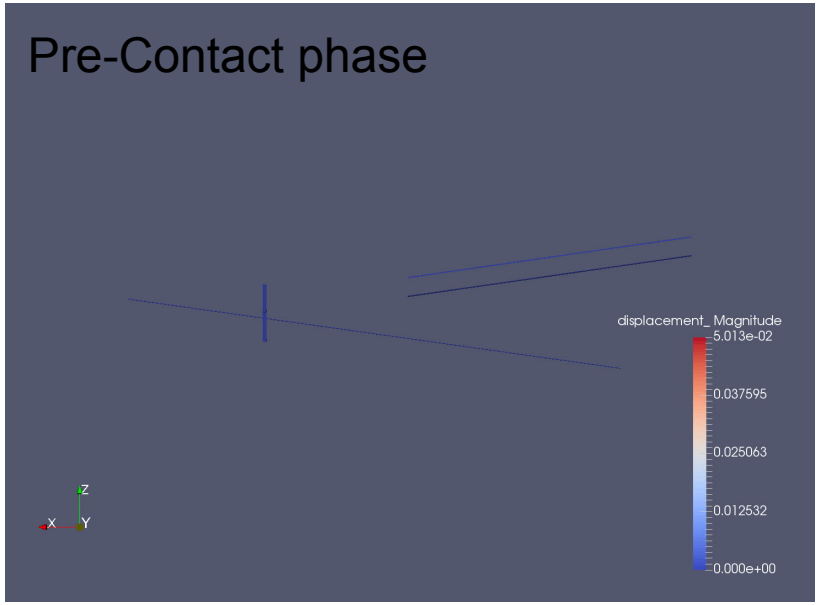
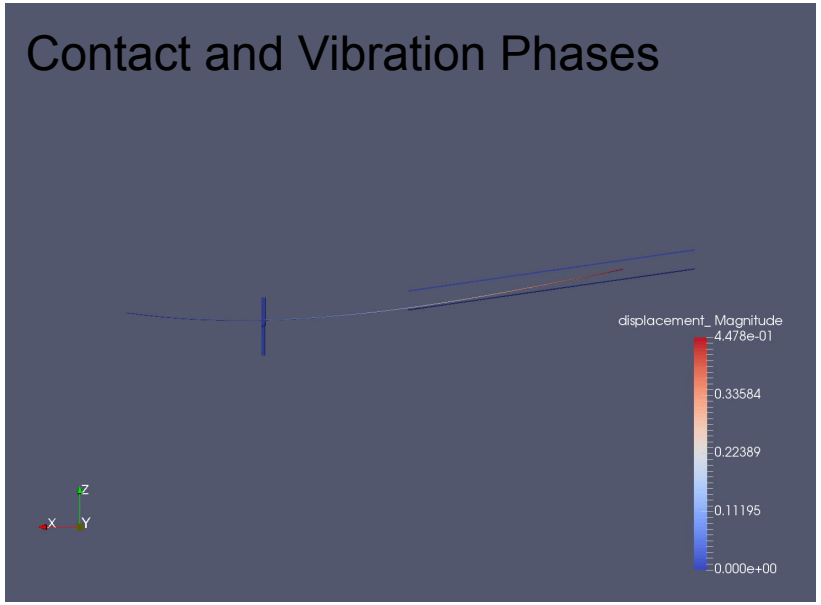
Simulation Stages

- Whip meshed with shell elements
- Three-Stage Simulation
  - Pre-Contact (Static)
    - Moves whip above Fork and Clamshell with contact off
  - Contact (Static)
    - Relaxes whip into contact with the Fork and the Clamshell
  - Vibration (Dynamic)
    - Input Sine Sweep data provided by APL





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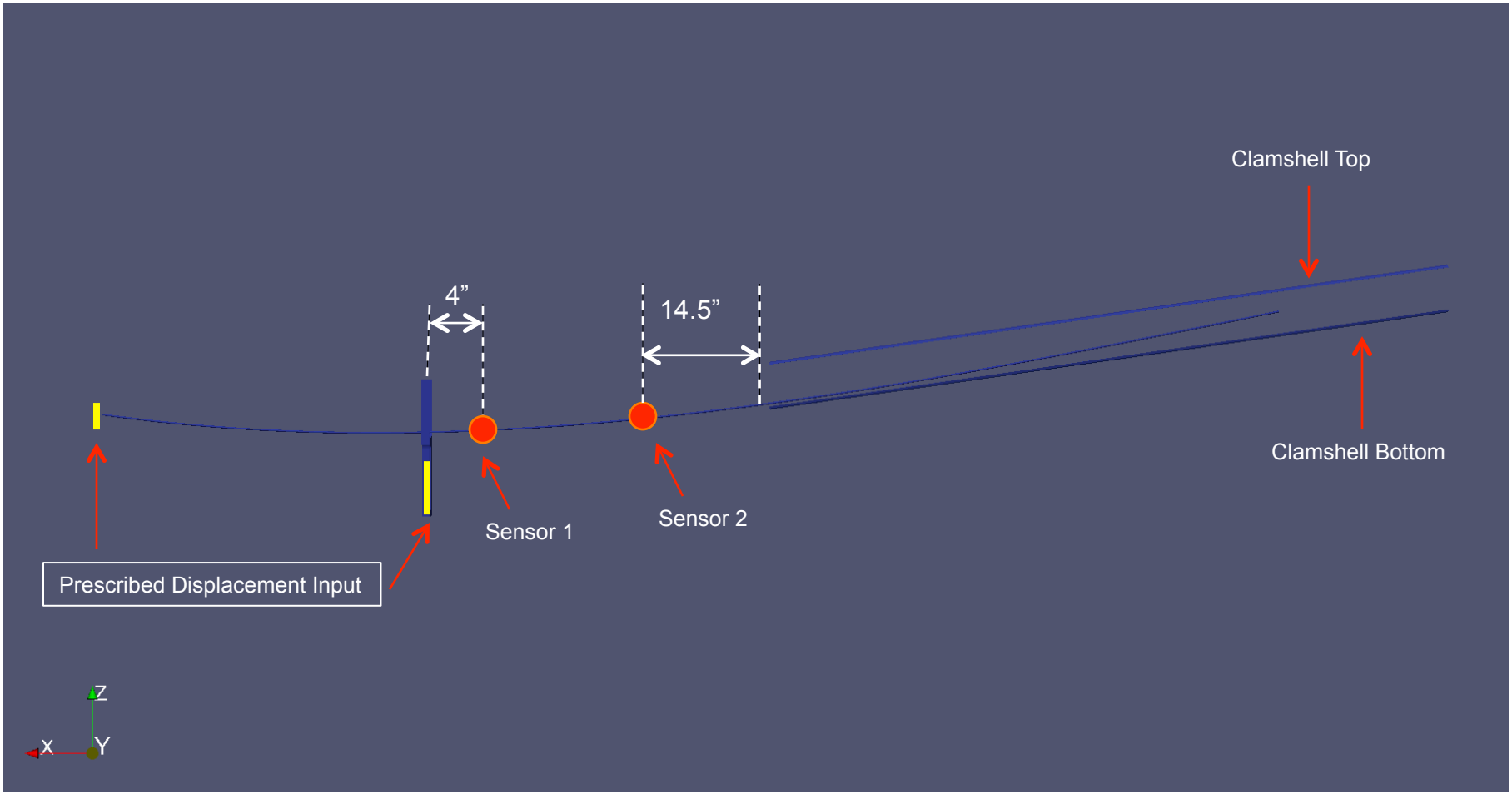
Boundary Conditions and Sensor Locations



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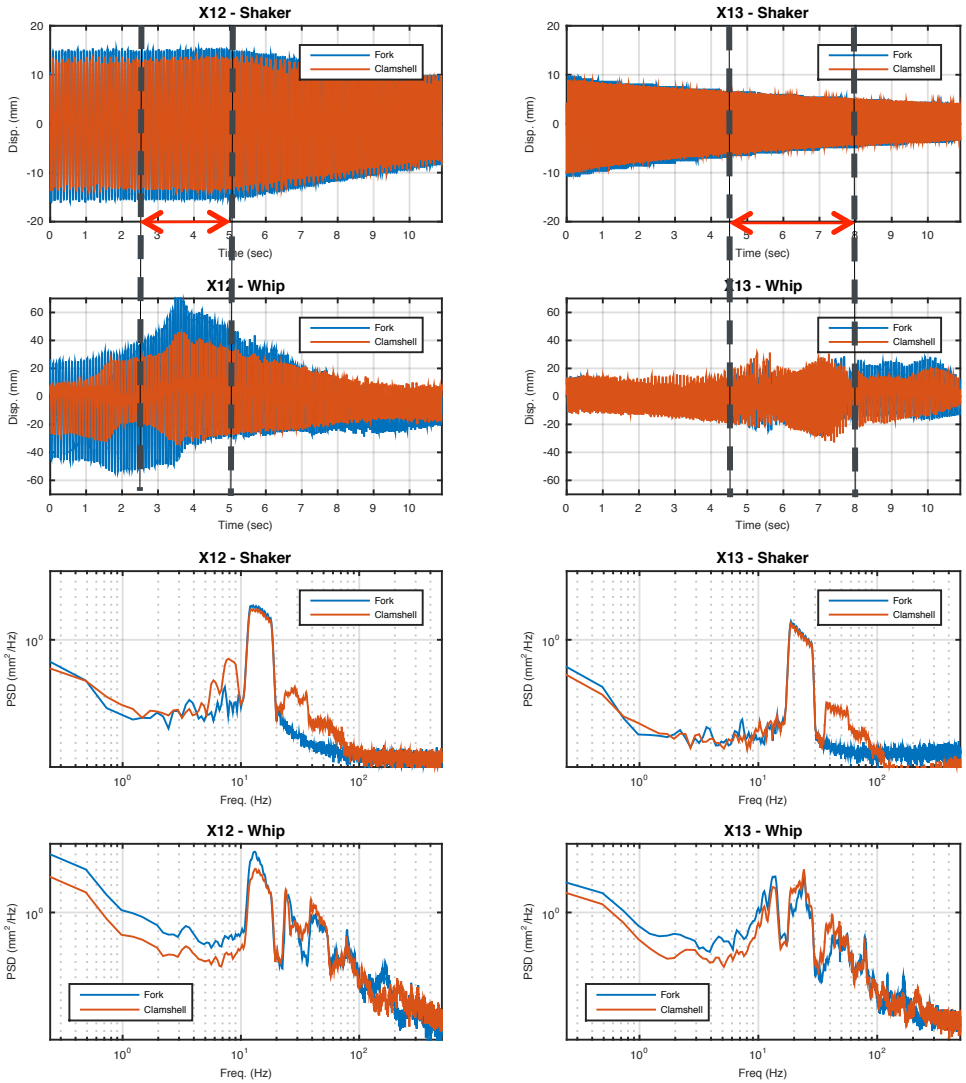
Initial Evaluation of Vibration Data from Tests Performed at APL



- Two datasets were provided by APL:
  - X12 and X13 datasets are from the same test configuration
  - Each dataset represents part of the overall sine sweep test
- Two time history segments selected as input for the nonlinear analysis:
  - X12 shaker data
  - X13 shaker data
  - Segments used for the analysis are highlighted in black vertical dashed lines
- X12 input was band pass filtered [12-17] Hz
- X13 input was band pass filtered [19-28] Hz

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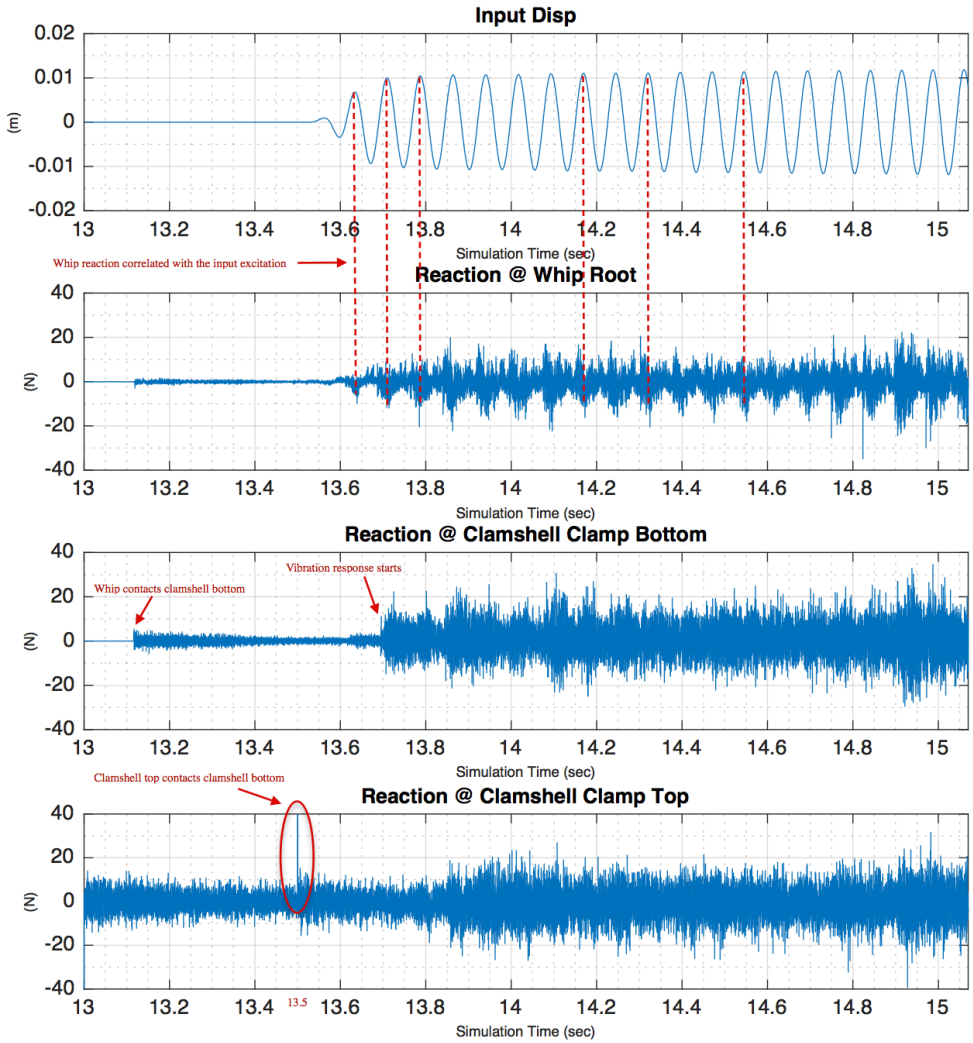
Preliminary Results from X12 Simulation: Reaction Time History



- Observations:
  - Reaction at the whip root correlates reasonably well with the input displacement. Positive peaks in displacement correspond to negative peaks in the reaction (as expected)
  - Clamshell Clamp Bottom: the start of the contact between whip and clamshell bottom is depicted. The response to the vibration input is also depicted
  - Clamshell Clamp Top: A large force at 13.5 sec. Corresponds to the instance when the clamshell top and bottom contact each other

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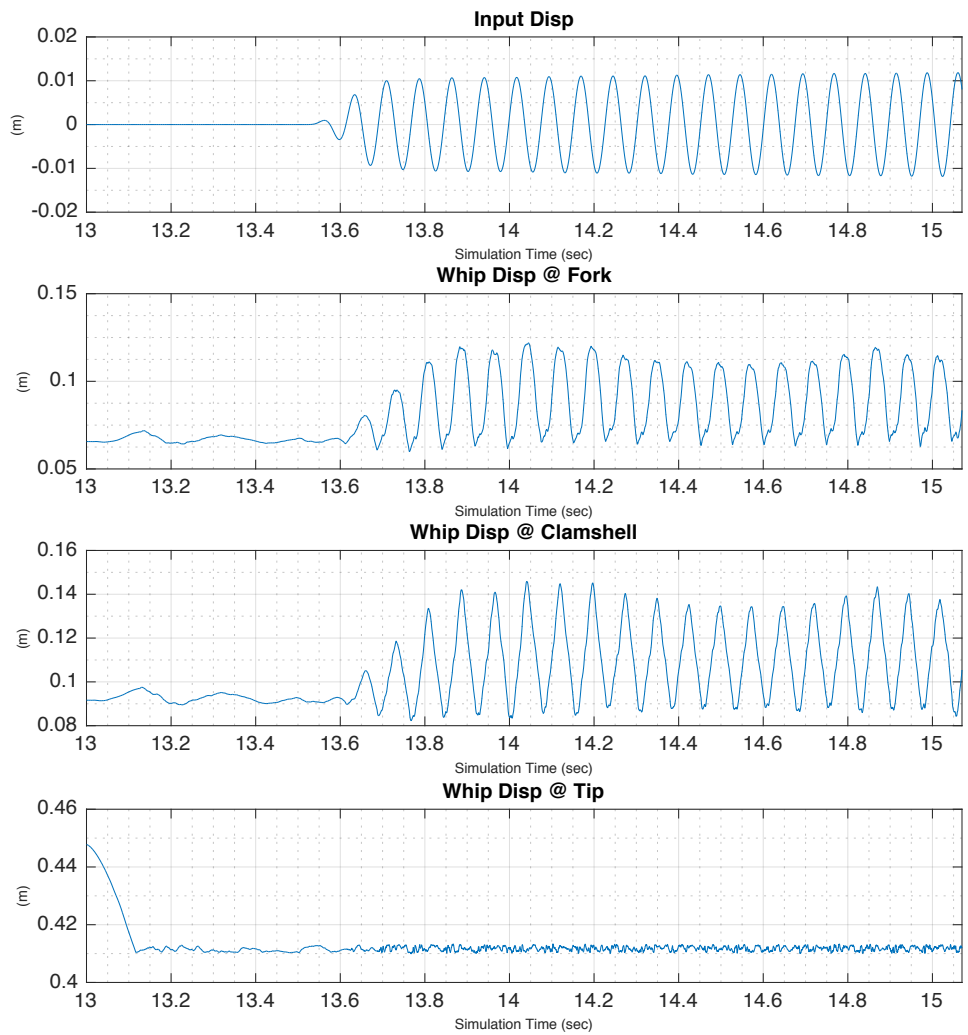
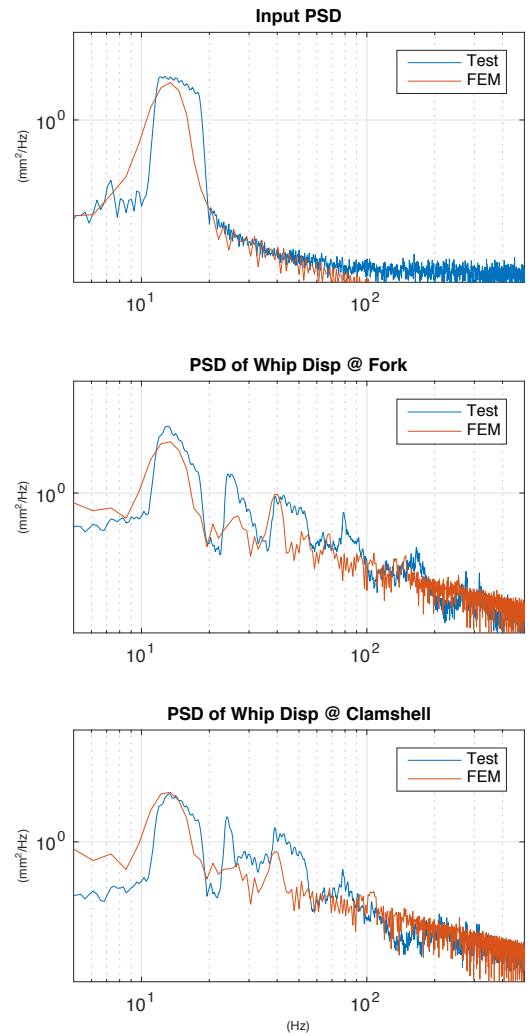
Preliminary Results from X12 Simulation: Displacement Correlation with Test Data





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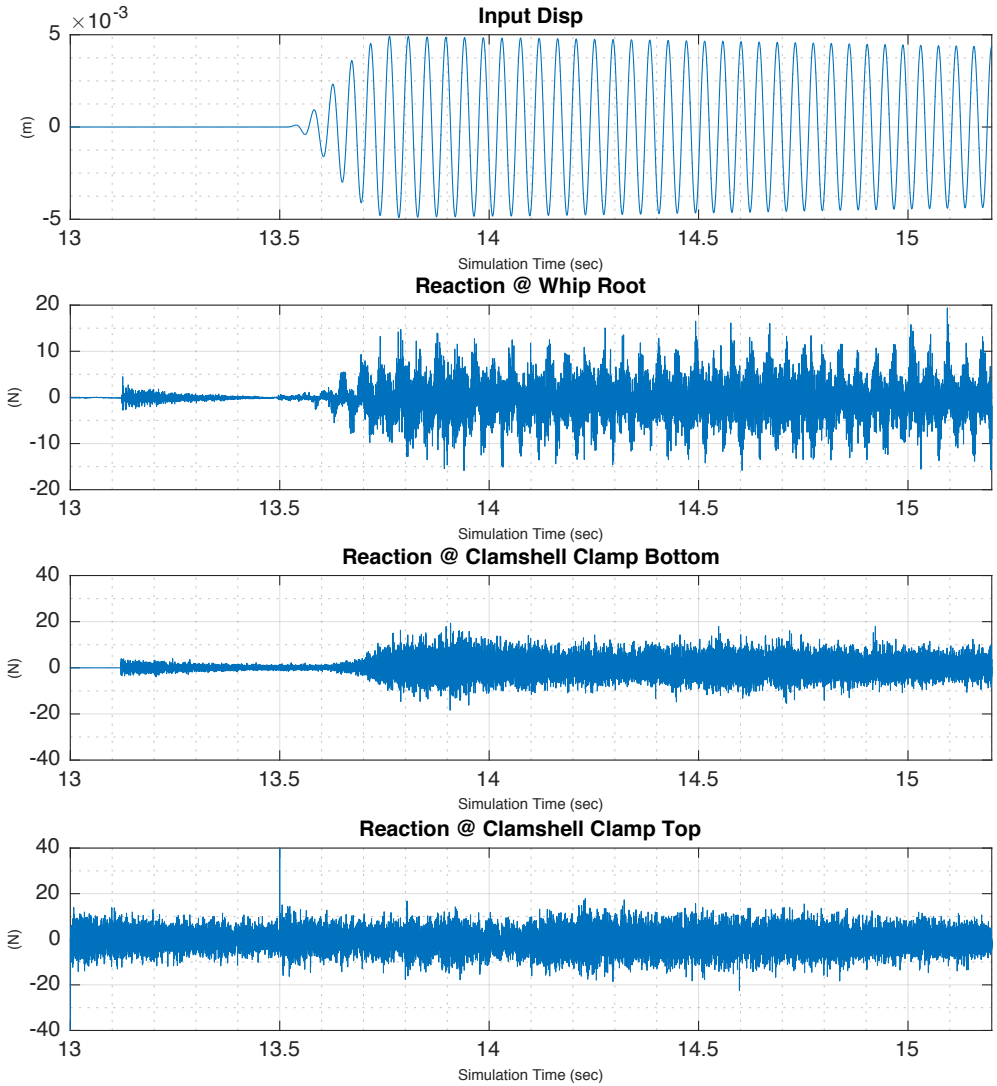
Preliminary Results from X13 Simulation: Reaction Time History



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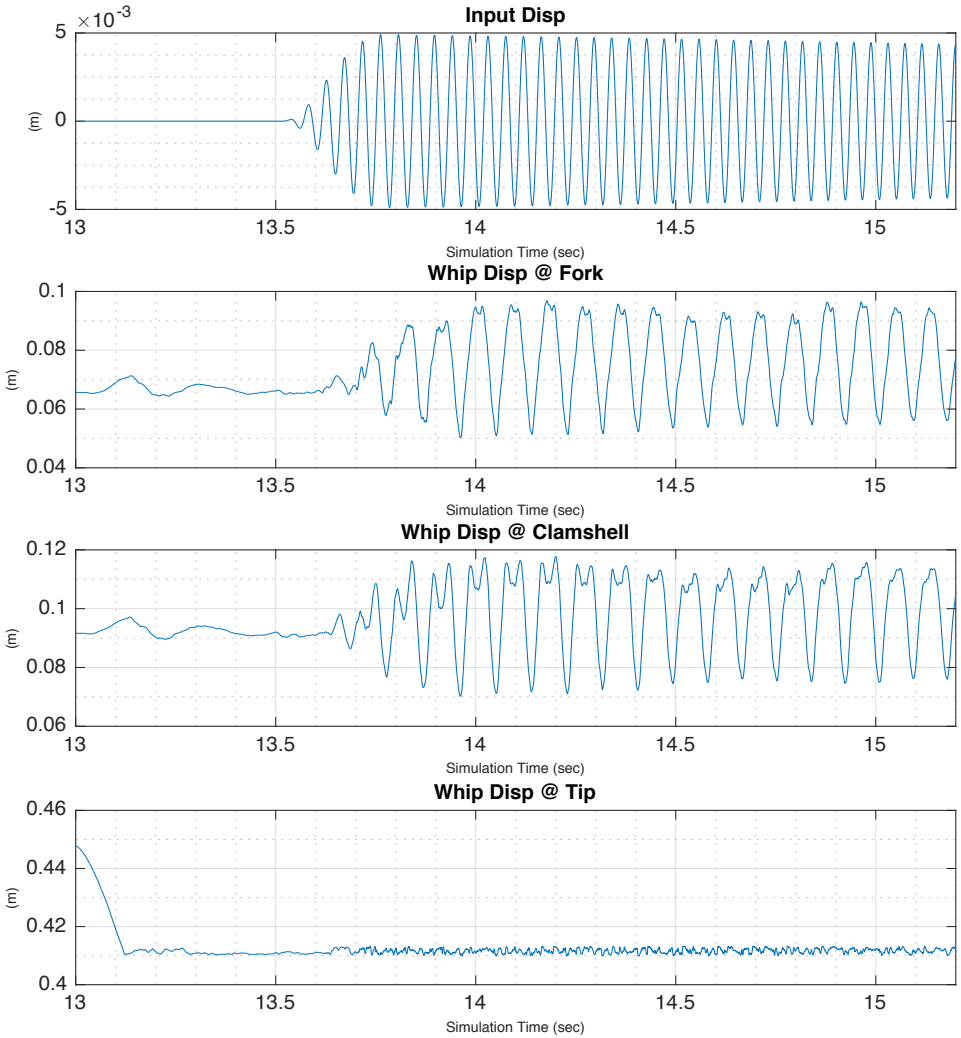
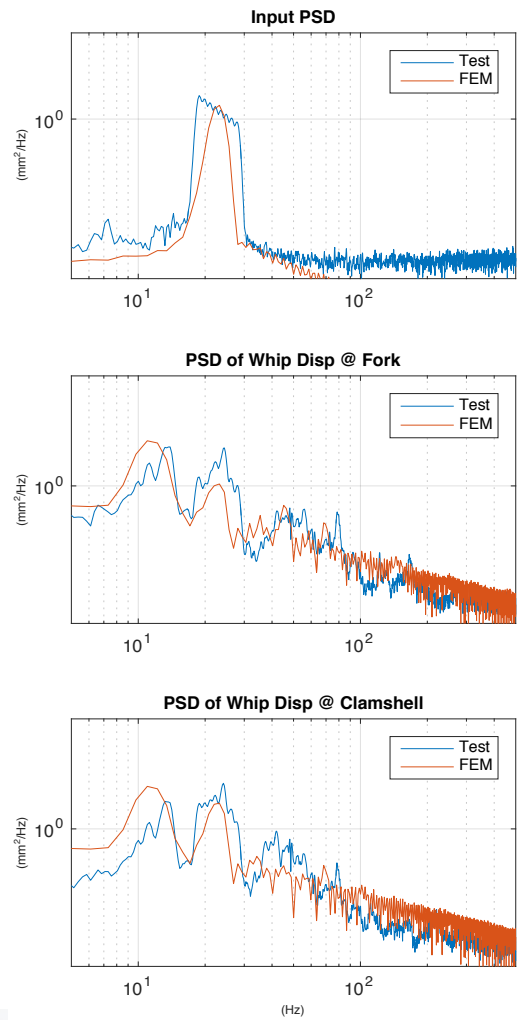
Preliminary Results from X13 Simulation: Displacement Correlation with Test Data





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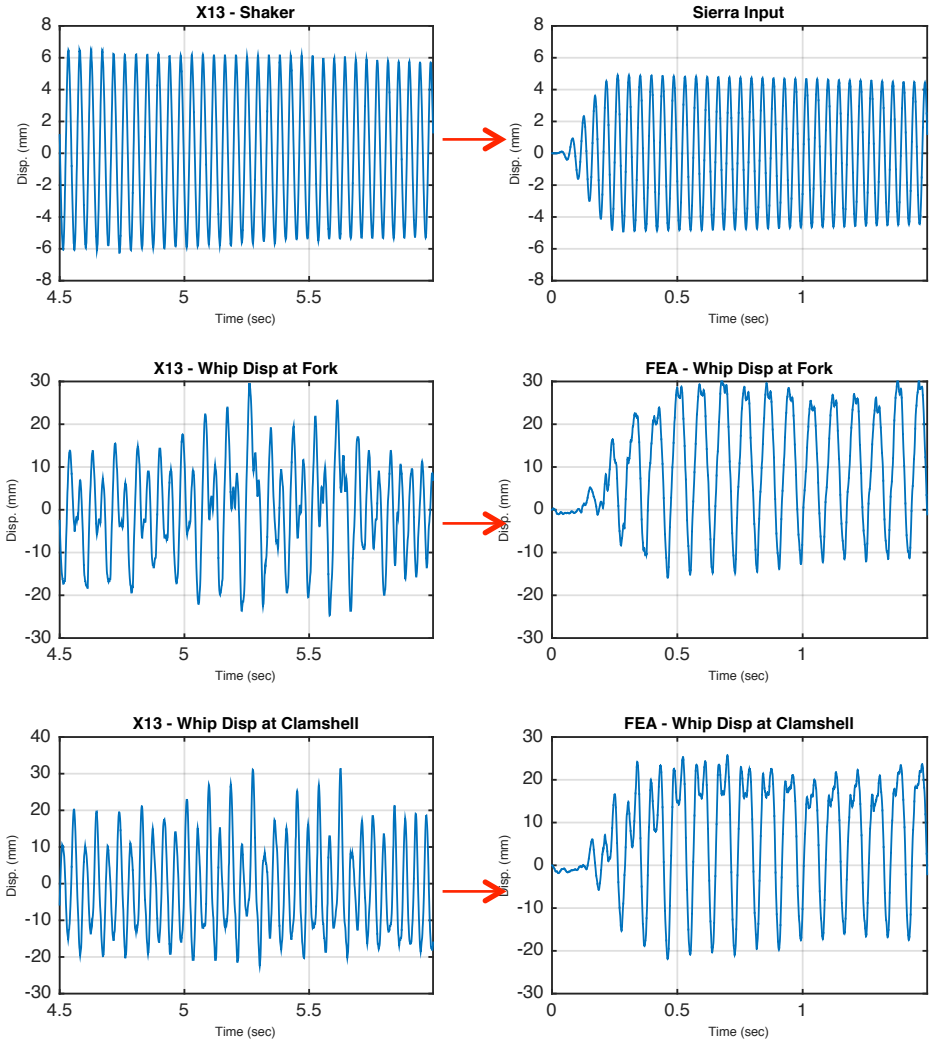
Preliminary Results from X13 Simulation: Whip Displacement Correlation with Test Data



- The left column shows the test data
- The right column shows the FEA displacement results. Magnified view of Sierra results from the vibration phase
- The displacement amplitudes from the FEA qualitatively match the displacement amplitude range from the test

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Summary

- A nonlinear model was developed
  - Captures nonlinear friction contact between whip & fork and whip & clamshell
- Preliminary results show reasonable correlation between the test data and the Sierra results
  - Displacement magnitudes were compared in time domain and frequency domain
- The developed model can potentially be used to guide and optimize the design process of the whip constraints on the SPP
- As in other numerical tools, it is crucial to validate the modeling assumptions and the corresponding simulation results with experimental test datasets

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Future Work

- Refine the FE model by including more parts (as needed), and improve the estimates of certain parameters, such as the damping ratio
- Utilize the FE model within the imuQ framework at JPL to perform parametric studies at frequency ranges of interest
- Use the FE model to assess the feasibility of various test configurations (e.g., adding multiple forks along the span of the whip, etc.)
- Incorporate inputs from the larger spacecraft model into the nonlinear FE model of the whip, to perform system level analysis

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