MSC.ADAMS Mode Verification for Spinning Spacecraft with Wire Booms

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MSC SOFTWARE
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ABSTRACT

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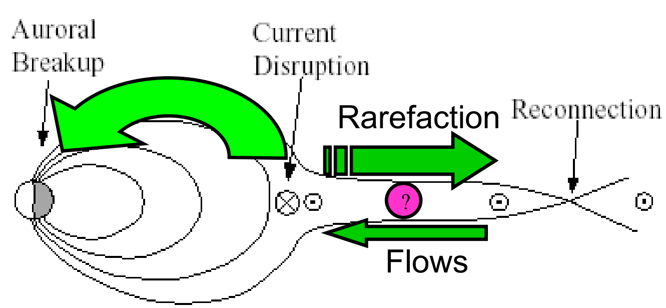
Linear modes for a spinning wire boom configuration with tip masses are computed from Lagrangian equations of motions and compared with results from Simulink Simulations and ADAMS/Linear. The spacecraft is modeled in ADAMS/View using rigid bodies. Appendages are attached like pendula to a central hub in the spin plane using two degree of freedom universal joints. Thruster firings simulated using user-defined functions induce in-plane and out-of-plane boom oscillations for comparison with analytical predictions. Simulated modes are extracted via Fast Fourier Transforms. Quantitative agreement is found for some modes. In addition, ADAMS/Linear predicted additional modes due to in-plane/out-of-plane coupling not present in the simplified analytical model. Mode visualization using MSC.ADAMS animation has proven particularly effective in this ongoing investigation. The results of this work will be used to identify thruster firing frequency and spin rate operational constraints for the THEMIS spacecraft.

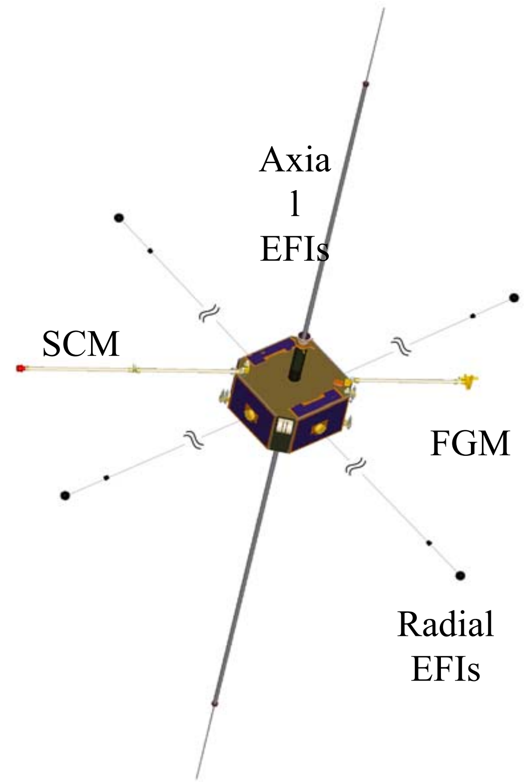
INTRODUCTION (Mission)

Time History of Events and Macroscopic Interactions during Substorms (THEMIS)

- NASA Medium-Class Explorer mission
  - Principle investigator & instruments: U.C. Berkeley
  - Probe/spacecraft bus: Swales Aerospace
  - Auroral science



- Spinning spacecraft
  - Axial and radial electric field instrument booms
  - Axial and side thrusters



INTRODUCTION (Deployments)

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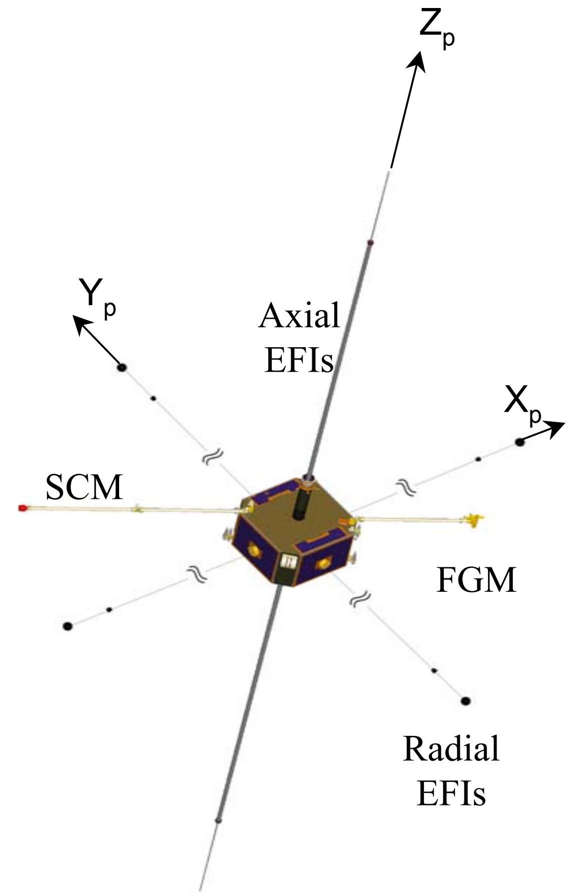
Magnetometer boom deployment, spin

Wire boom deployment (strawman)

- 25% WB±X, 25% WB±Y, 50% WB±X, 50% WB±Y, Spin-up
- 60% WB±X, 60% WB±Y, Spin-up
- 70% WB±X, 70% WB±Y, Spin-up
- 80% WB±X, 80% WB±Y, Spin-up
- 90% WB±X, 90% WB±Y, Spin-up
- 100% WB±X, 100% WB±Y, Spin-up

Axial boom deployment



PROBLEM DEFINITION

THEMIS Probes are coupled multi-body systems

Spin rate and deployment state (e.g, boom lengths) alter the resonant modes

Thruster pulsing can also excite resonant modes

Identify operational constraints to avoid interaction of thruster pulsing and spin rate with resonant frequencies

- Use simulations to verify analytical calculations of modes
- Analytical calculations provide efficient estimates of operational constraints to support mission planning

ANALYSIS (Simulation)

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Simulation

- MSC.ADAMS & Simulink Models
  - Up to 9 bodies
    - One 6DOF rigid bus
    - Four wire boom (point tip masses) with universal joint (2DOF) at bus interface
    - Two axial boom (point tip masses) with universal joint (2DOF) and torsional spring at bus interface
    - Two slosh pendulums (point masses) with universal joint (2DOF) at pivot
  - 2 axial force (SFORCE: Single_Component_Force)
  - 2 side force (SFORCE: Single_Component_Force)
- Output processing (Matlab)
  - Power spectrum peaks of boom deflections ⇒ natural frequency
  - FFT phase at peaks in power spectrum ⇒ mode shape

MSC.ADAMS/PostProcessor (FFT)

MSC.ADAMS/Linear (mode frequencies & mode animations)

ANALYSIS (Simulation – Model)

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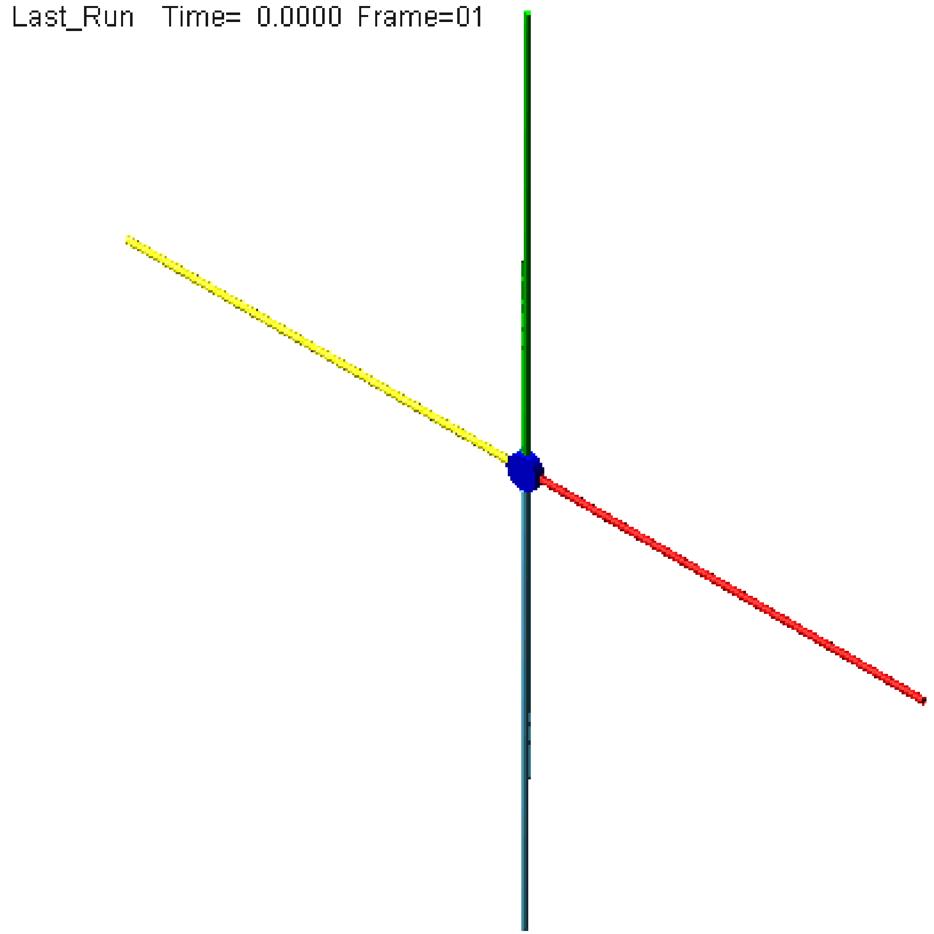
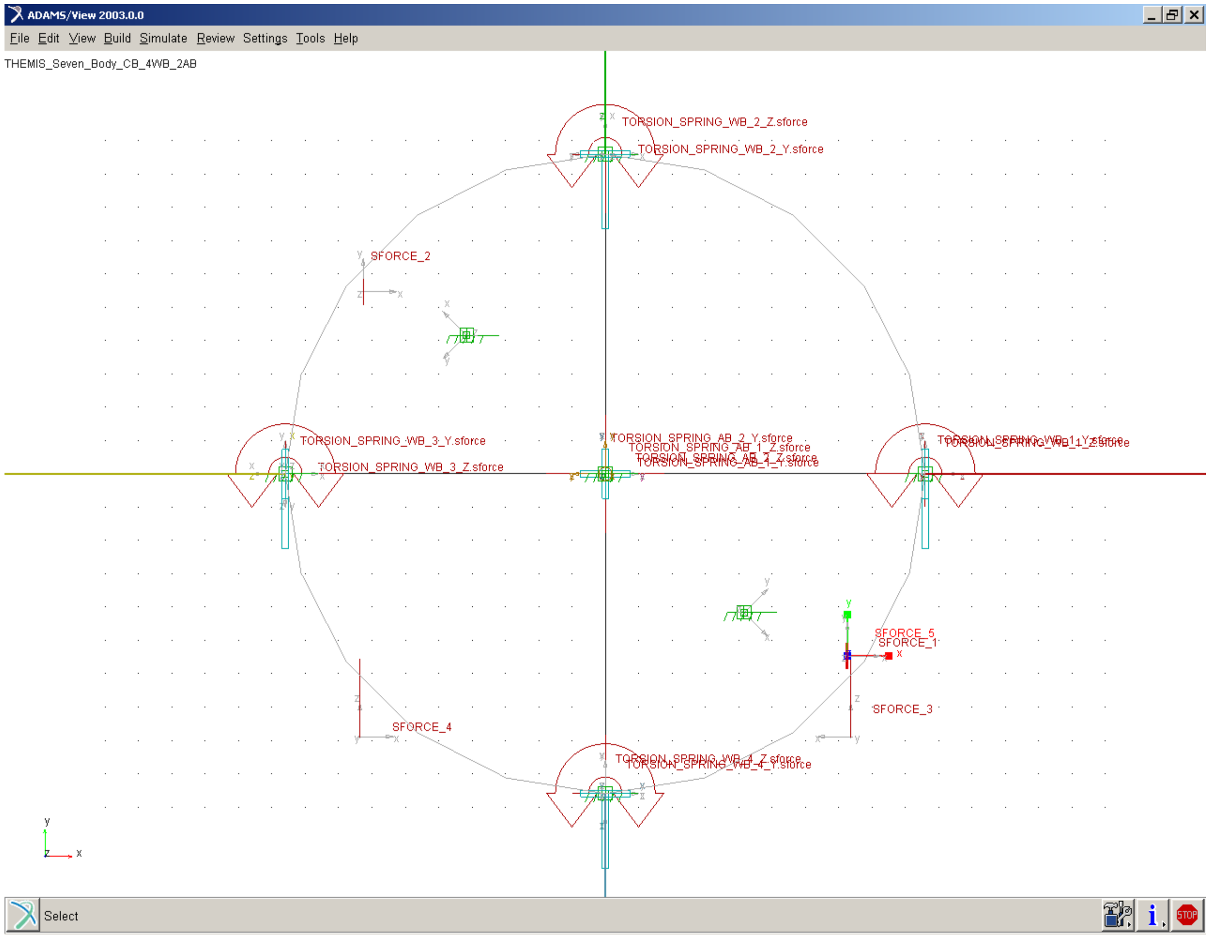
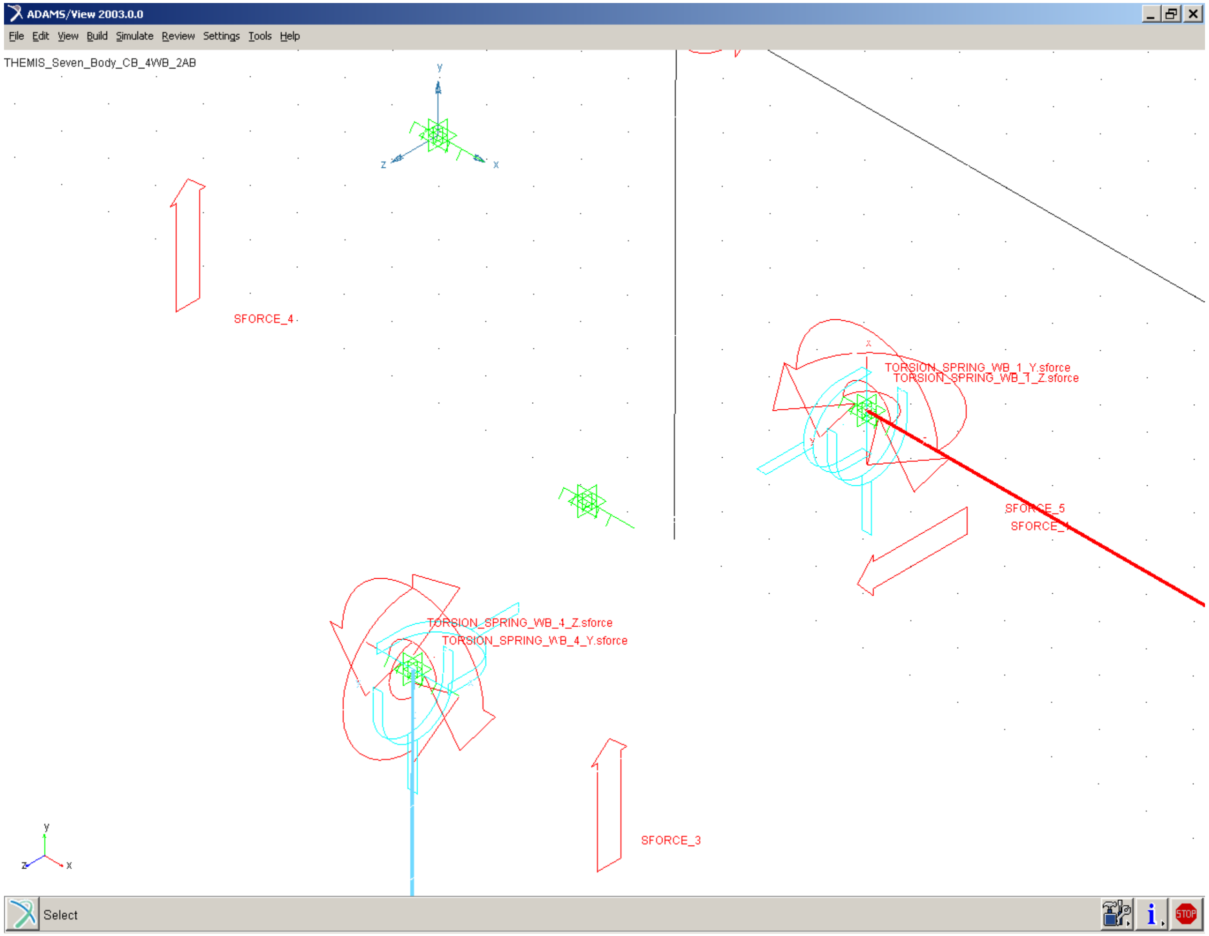


ANALYSIS (Simulation – Model)



ANALYSIS (Simulation – Model)



ANALYSIS (Simulation Output)

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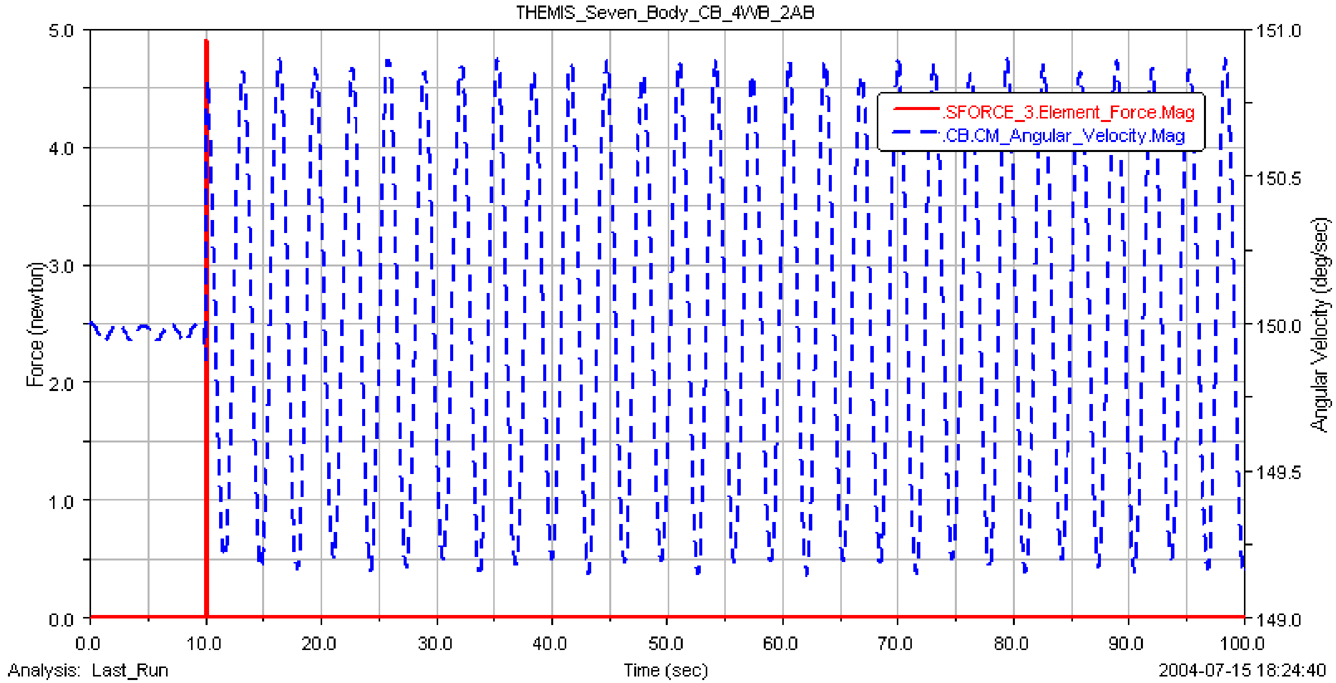
Case: Thrust for Probe Spin Up

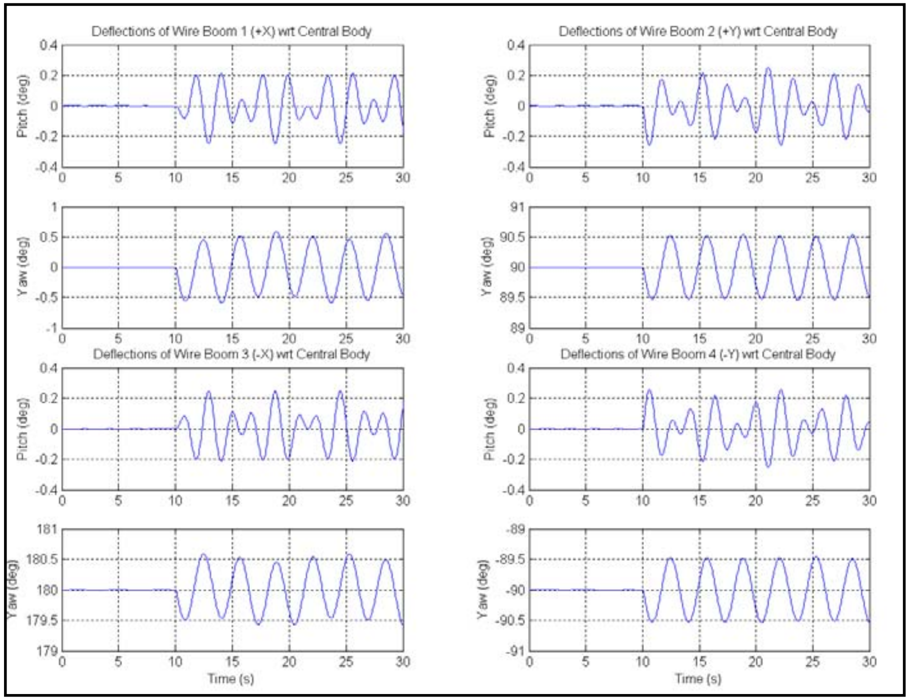
- Force & Central Body Angular Velocity

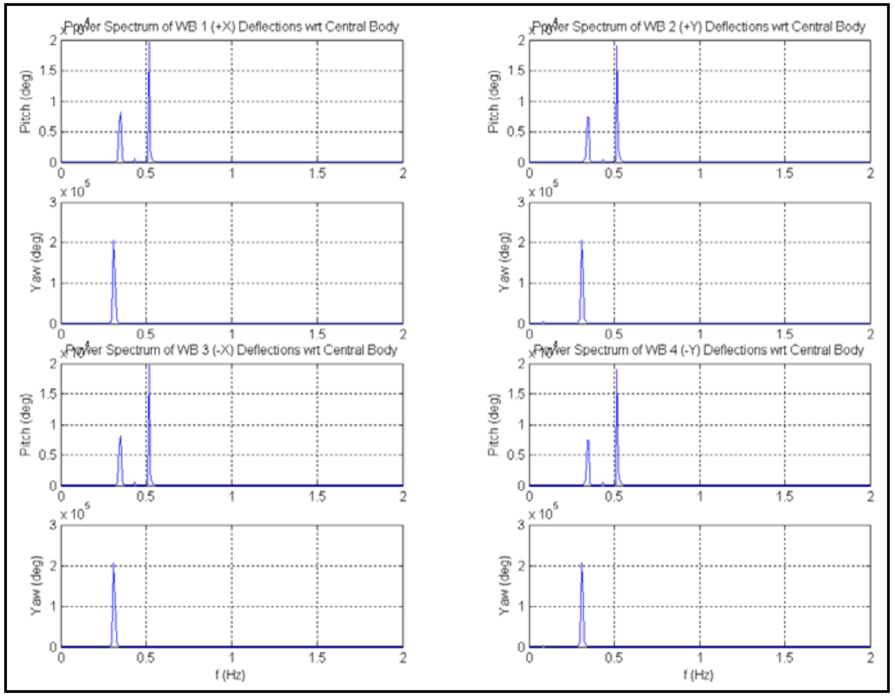


ANALYSIS (Simulation Output)

Case: Thrust for Probe Spin Up

- Radial wire boom deflections (yaw is in-plane, pitch is out-of-plane)





ANALYSIS (Analytical)

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Analytical

- Linearized Lagrangian equations of motion*
  - In-plane
  - Out-of-plane
- Processing (Matlab function eig)
  - Eigenvalues $\Rightarrow$ frequency
  - Eigenvectors $\Rightarrow$ mode shape

$$\widetilde{M}\ddot{\widetilde{\alpha}} + \widetilde{C}_\theta \dot{\widetilde{\alpha}} + \widetilde{K}_\theta \widetilde{\alpha} = 0$$

$$\Rightarrow \dot{\widetilde{x}} = \begin{bmatrix} -\left[\widetilde{M}\right]^{-1} \widetilde{C}_\theta & -\left[\widetilde{M}\right]^{-1} \widetilde{K}_\theta \\ \widetilde{I}_{n_\alpha \times n_\alpha} & \widetilde{0}_{n_\alpha \times n_\alpha} \end{bmatrix} \widetilde{x}$$

$$\text{where } \widetilde{x} = \begin{bmatrix} \dot{\widetilde{\alpha}} \\ \widetilde{\alpha} \end{bmatrix}$$

* Lai, S. T. and Bhavnani, K. H., "Dynamics of Satellite Wire-Boom Systems," AFCRL-TR-75-0220, 1975.

ANALYSIS (In-Plane Modes)

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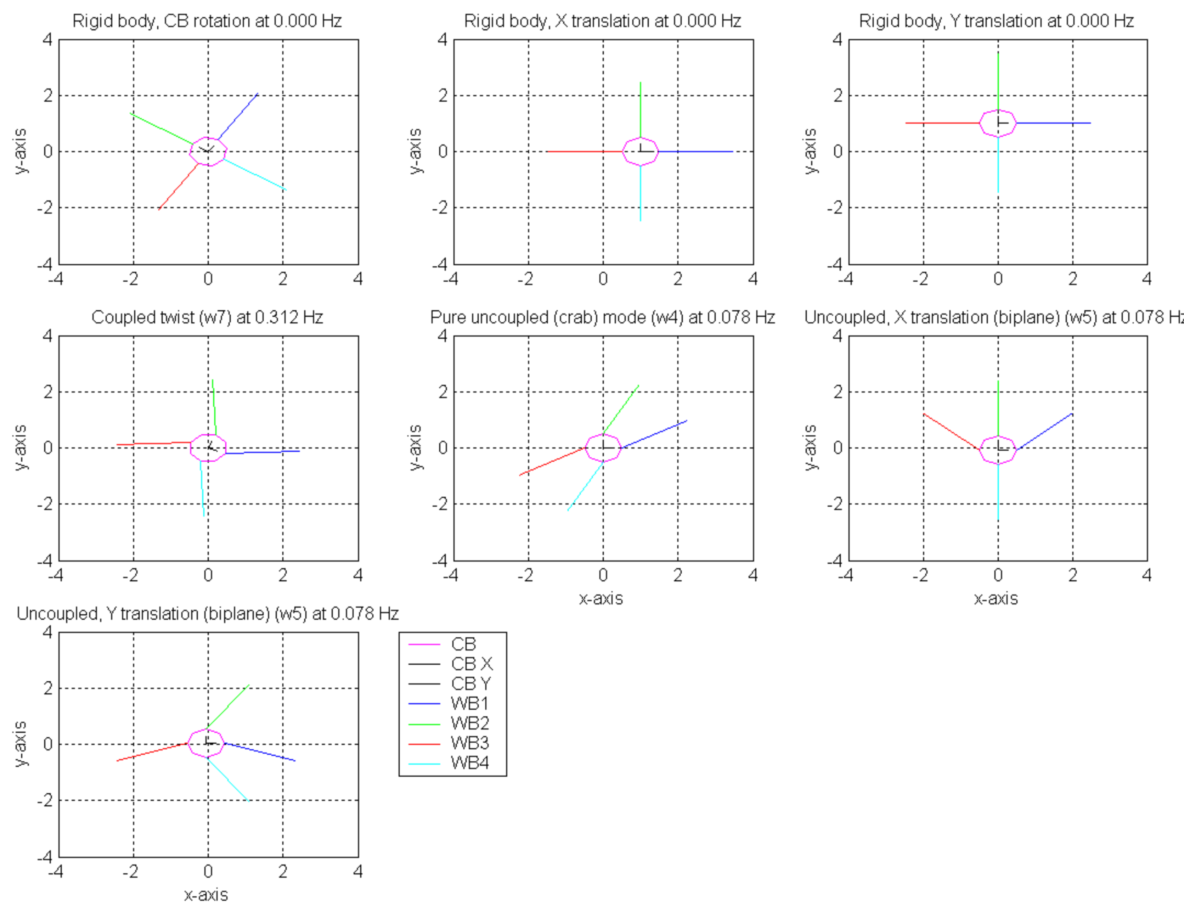
$$\tilde{\alpha} = \begin{bmatrix} \phi_1 \\ \vdots \\ \phi_n \\ \theta \\ X \\ Y \end{bmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{WB deflection} \\ \left.\begin{matrix} \\ \end{matrix}\right\} \text{CB rotation} \\ \left.\begin{matrix} \\ \\ \end{matrix}\right\} \text{CB translation} \end{matrix}$$



WB = Wire Boom
CB = Central Body

ANALYSIS (Out-of-Plane Modes)

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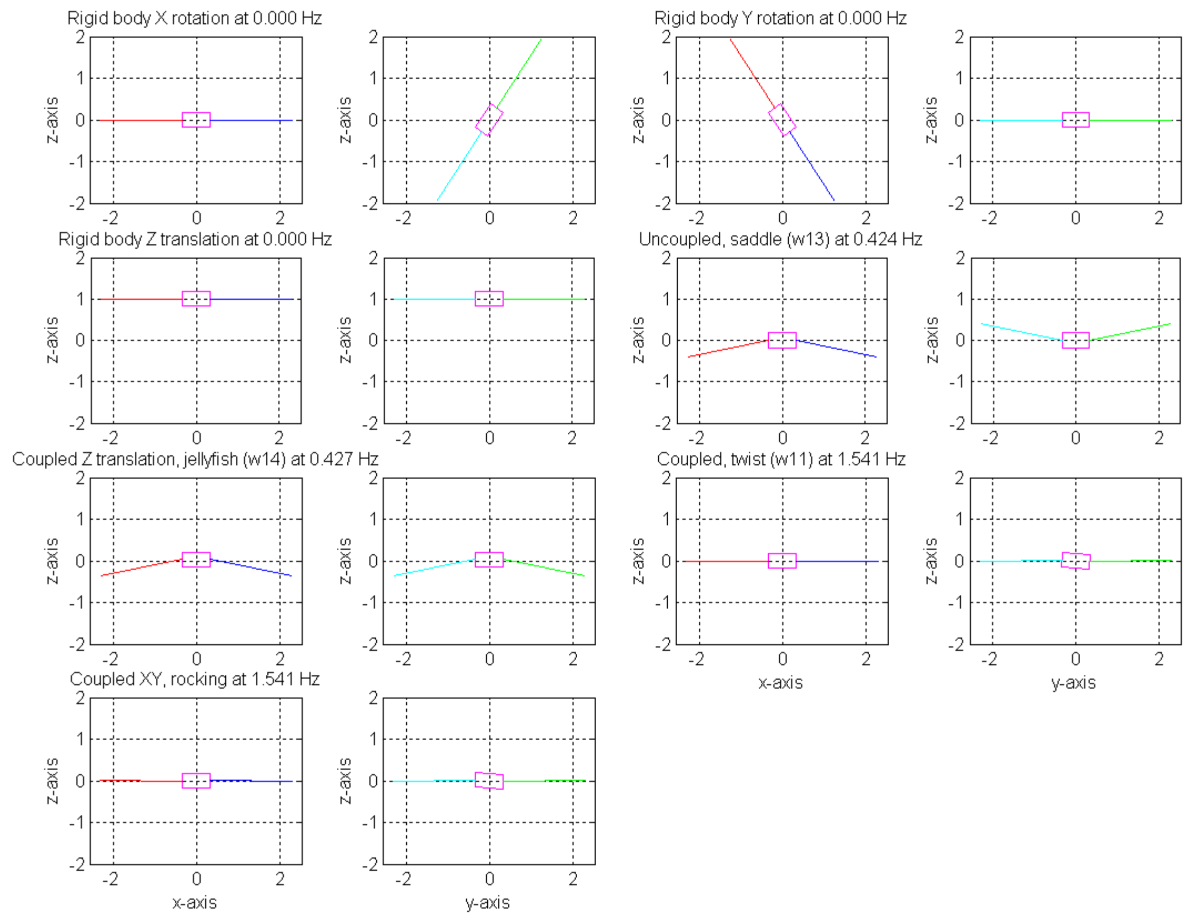
$$\tilde{\alpha} = \begin{bmatrix} \psi_1 \\ \vdots \\ \psi_n \\ \theta_1 \\ \theta_2 \\ Z \end{bmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \text{WB deflection} \\ \left.\begin{matrix} \\ \\ \end{matrix}\right\} \text{CB rotation} \\ \left.\begin{matrix} \\ \end{matrix}\right\} \text{CB translation} \end{matrix}$$



WB = Wire Boom
CB = Central Body

ADAMS/Linear

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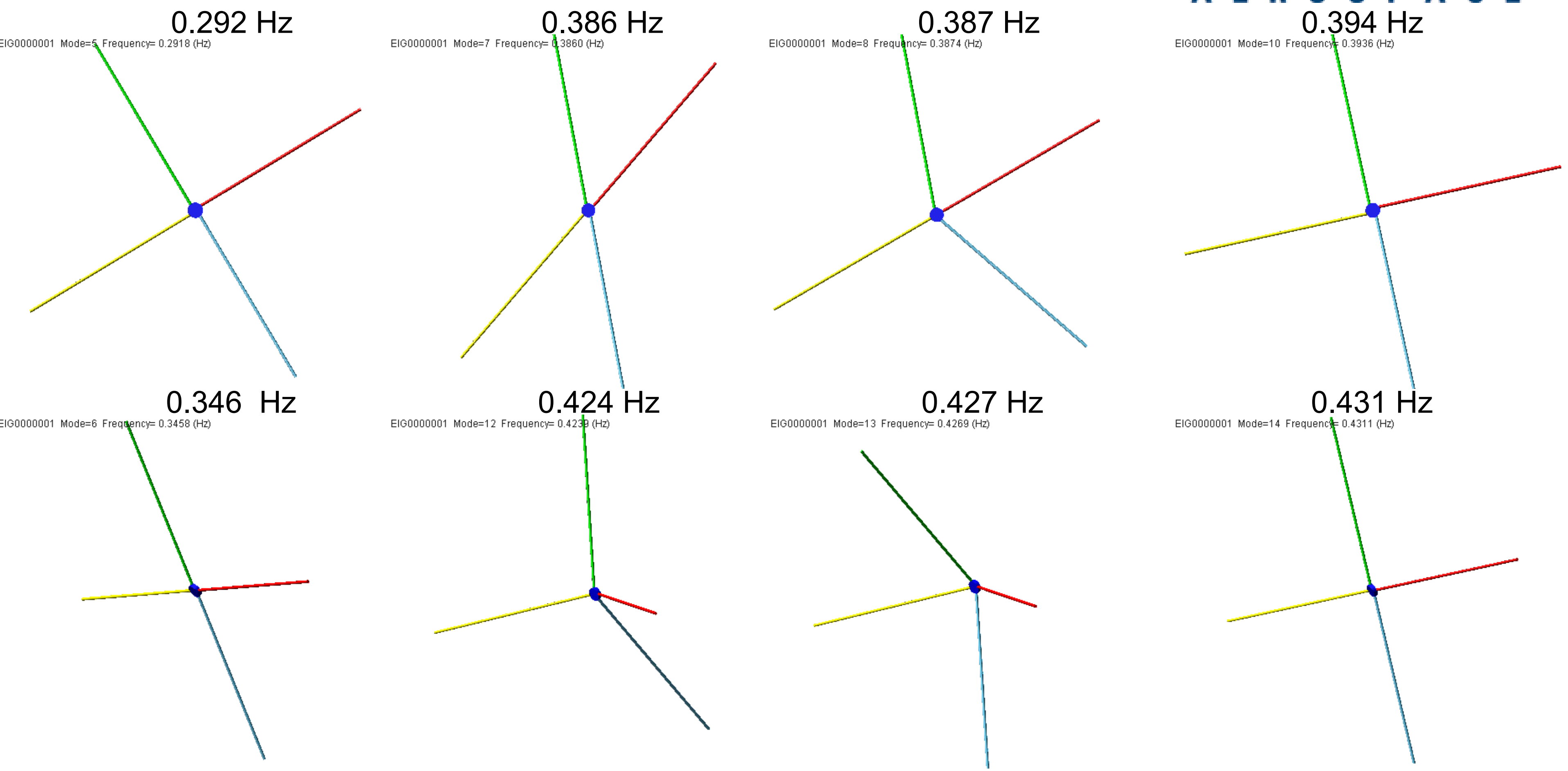

DISCUSSION (Modes)

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Analytical vs. Simulink Simulation vs. ADAMS Linear Modes

Natural Frequency Source	Phases				Analytical Frequency (Hz)	Simulation Frequency (Hz)	ADAMS Linear Modes (Hz)
	WB1	WB2	WB3	WB4			
IP, pure uncoupled (crab) mode (w4)	1	-1	1	-1	0.078	0.080	Not Found*
IP, uncoupled mode with Y translation (biplane) (w5)	1	1	-1	-1	0.078	0.080	Not Found*
IP, uncoupled mode with translation (plane) (w6)	1	0	-1	0	0.078	0.080	Not Found*
IP, coupled mode (twist) (w7)	1	1	1	1	0.312	0.310	0.292/0.394
Spin Rate	N/A	N/A	N/A	N/A	0.417	0.417	0.417
OOP, uncoupled saddle mode (w13)	1	-1	1	-1	0.424	0.420	0.424
OOP, jellyfish (w14)	1	1	1	1	0.427	0.430	0.427
OOP, coupled mode (w11)	0	1	0	-1	1.541	Not Found+	Not Found+
OOP, coupled mode (w12)	1	0	-1	0	1.541	Not Found+	Not Found+

***FFT of ADAMS/Solver results agreed with Analytical modes**
+FFT of ADAMS/Solver results and Simulink simulation agreed

DISCUSSION (Ops Constraints)

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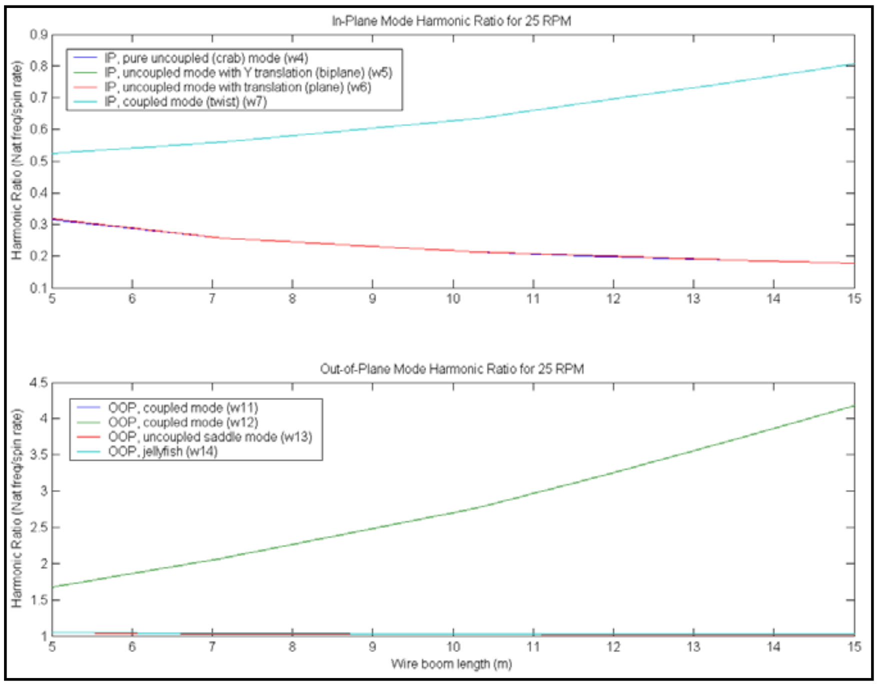
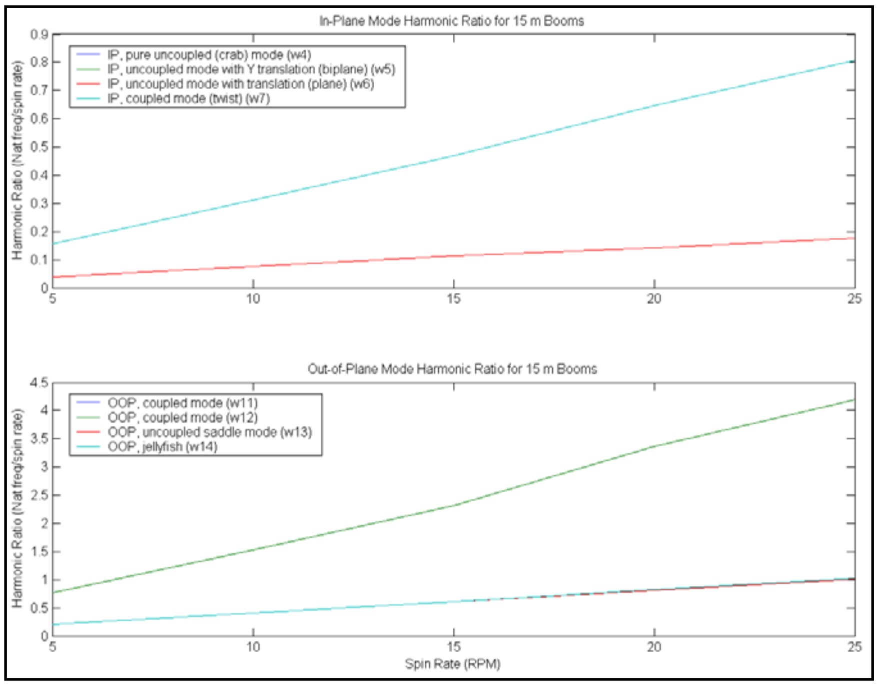
Harmonic Ratio: Natural Frequency/Spin Rate

Versus Boom Length



Versus Spin Rate



CONCLUSIONS

Significance

- Mutual verification of ADAMS simulation and analytical formulation for some modes
- Mission operations constraints can be determined
  - Thruster pulse frequency
  - Spin rate
  - Deployments

Benefits to MSC.Software users

- Modes extraction and animation for coupled multi-body spinning spacecraft using ADAMS/Linear

ROI

- Leveraged MSC.ADAMS software via software token license
- Confidence in method for determining mission operations constraints
- Visualization aids interpretation of results