Dynamic Analyses of the Proposed Habitable Exoplanet Astrophysics Facility

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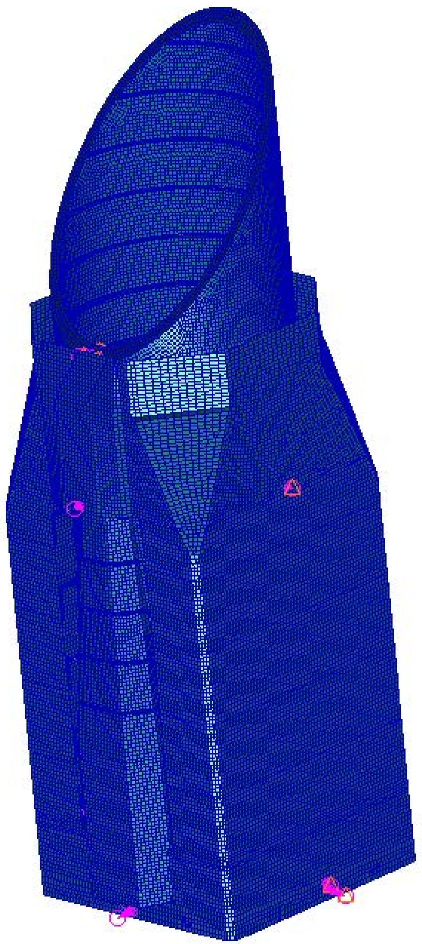
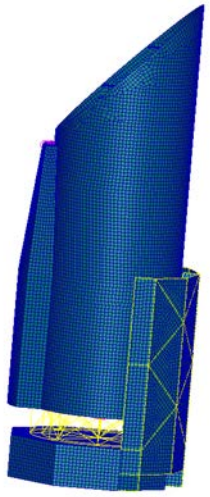
HabEx

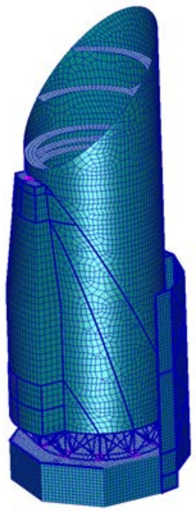
- HabEx is one of 4 large astrophysics facilities being considered by the 2020 decadal
  - It is intended to, among other things, directly image planetary systems around sun-like stars
  - Its main goal is to directly image earth like exoplanets and characterize their atmospheric content
- The current design is on the order of 17.2X5.25 m and the Primary Mirror (PM) is 4 m in diameter
- Performance requirements include an extremely stable system

Line of Sight Stability (Jitter)	< 0.5 milli-arc-seconds per axis
Wavefront Error Stability	1 to 250 pm depending on coronagraph and spatial frequency

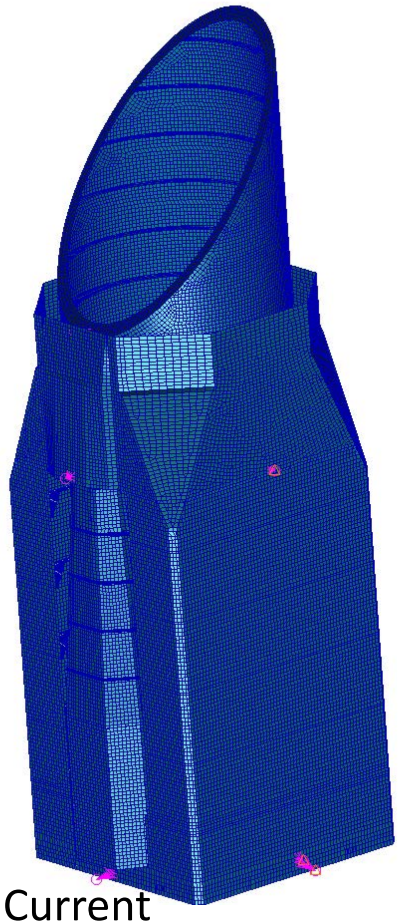


Objective


2016

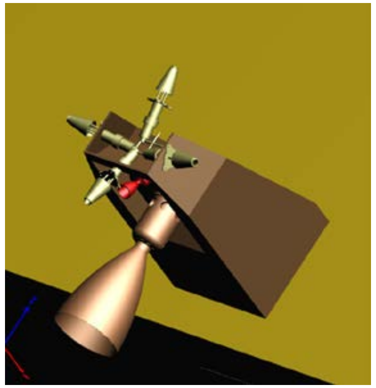

2017

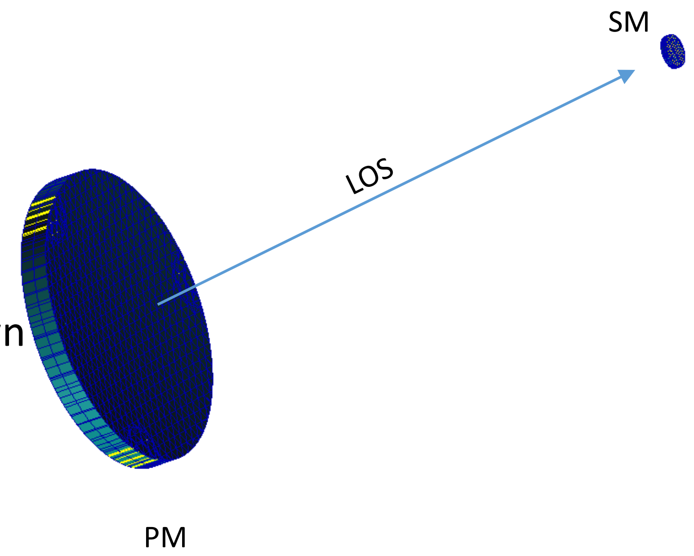
- As part of the HabEx Pre-Phase A (feasibility) study, structural dynamic analyses have been performed to provide Systems Engineers (SE) with order of magnitude estimates of dynamic responses
  - Results are consistent with feasibility studies and are based on first cut requirements, assumptions, and simplified inputs
  - These results are rolled into system level performance predictions
  - The objective of this presentation is to describe the models used, simulations performed, and results


Current

Jitter

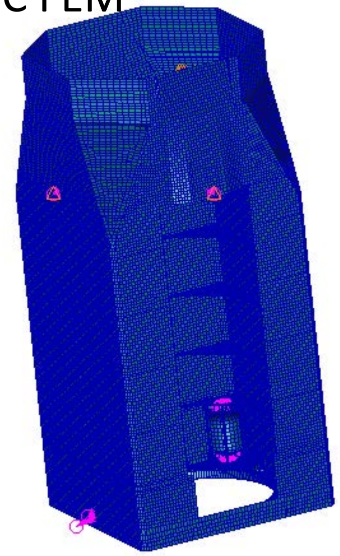
- Line Of Sight (LOS) jitter < 0.5 mas per axis
  - Equates to low Nanolevel allowable linear and rotational jitter motion
- Dynamic analyses were performed to predict jitter due to Attitude Control System (ACS) dynamic inputs
  - **Ring Down** - Transient ring down associated with turning the system
    - ACS thrusters will start turning the system then fire again to stop that motion
    - How long does it take for transient jitter to subside?
  - **Jitter** while pointing at a target and collecting data
    - Micro-Thrusters (MT) will be used to maintain orientation
    - Thrust level is expected to change, ramp up/down, very slowly
      - Considered to have no frequency content
    - The MT have a continuous noise level up to 10 Hz and then it ramps down
    - The MT noise is the only identified dynamic disturbance during science windows



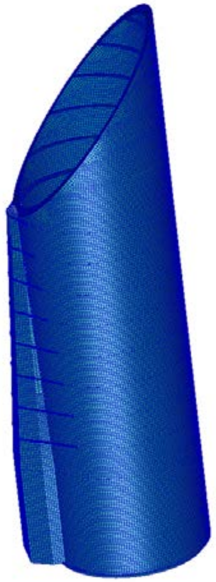


Model

- The analyses was performed via the Finite Element (FE) method
- MSC/NASTRAN was used as the solver and MSC/PATRAN was the pre/post processor
- The two primary systems are the Spacecraft (SC) and the telescope
  - SC
    - Modeled by JPL personnel
  - Telescope
    - Modeled by MSFC personnel



SC FEM



Telescope FEM

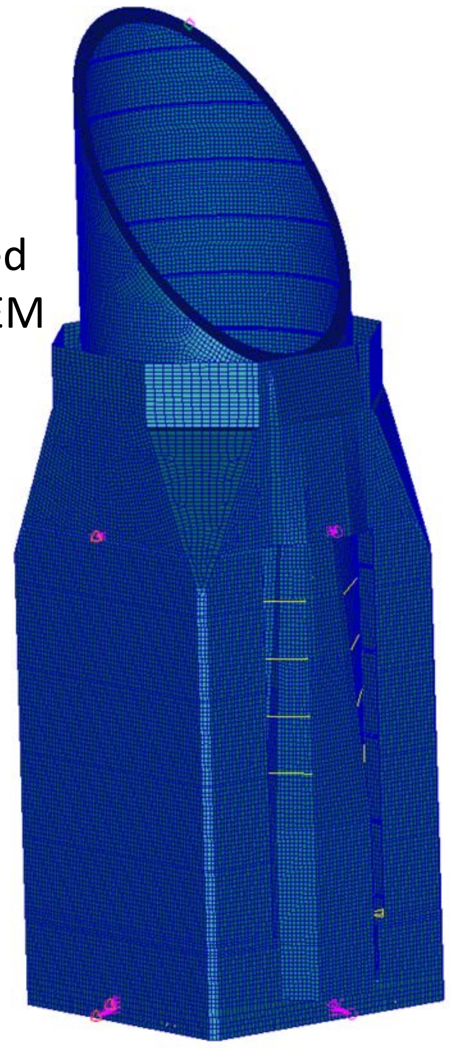
Model

- The SC and Telescope FEMs were integrated by JPL personnel
- FEM details

Grid	106381
Linear Elements	7382
Planar Elements	109023
Solid Elements	128
Point Elements	9596
RBE2 Elements	302
RBE3 Elements	53
MPC's	12

Approximately 636K DOF

Integrated HabEx FEM



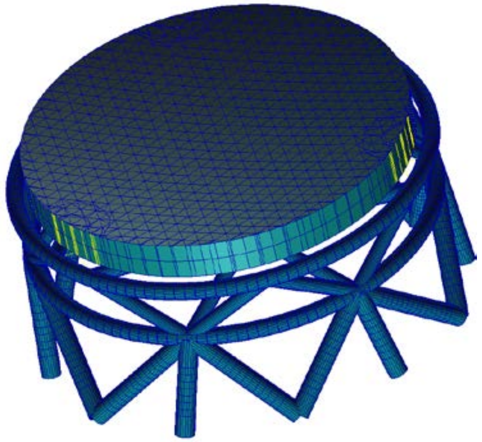
- FEM mass properties

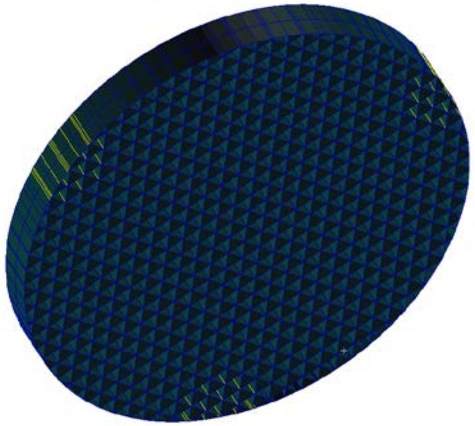
Mass, Kg	10,687
CGx, m	0.00
CGy, m	-.25
CGz, m	2.04

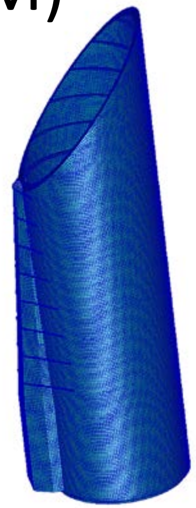
Model

Mirror Models

- Primary Mirror (PM)



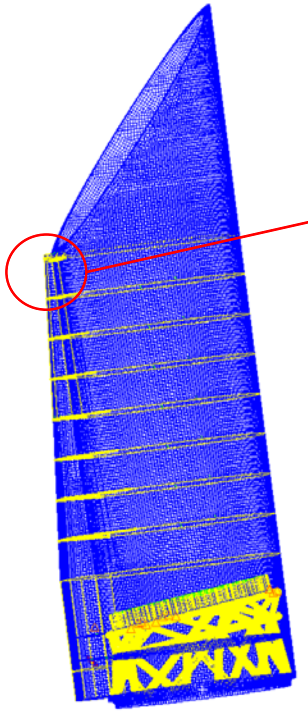


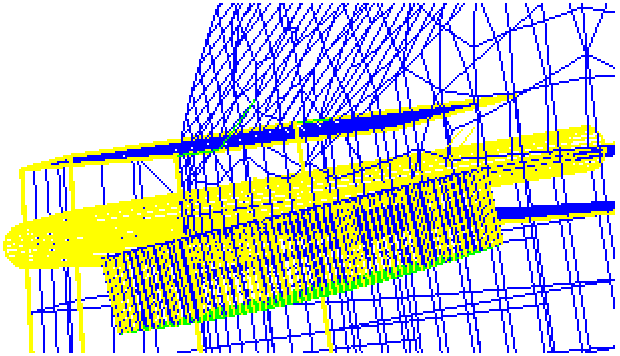


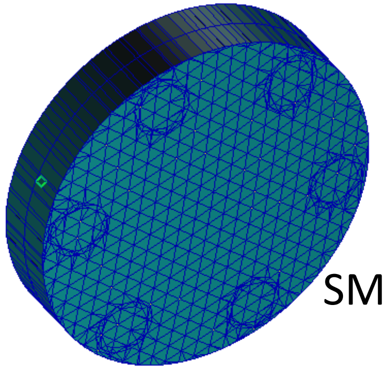
PM FEM created using
The Arnold Mirror Modeler

PM has ≈ 14K DOF

- Secondary Mirror (SM)



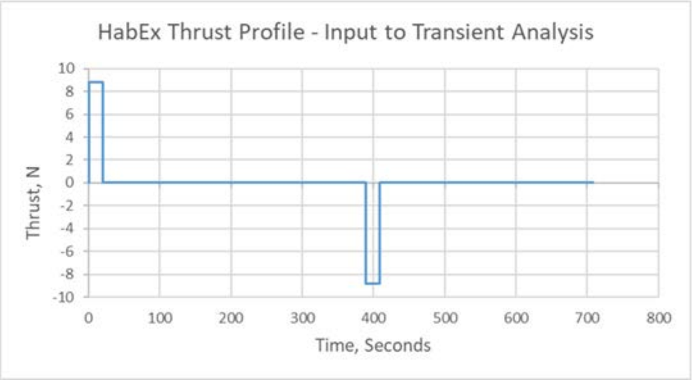


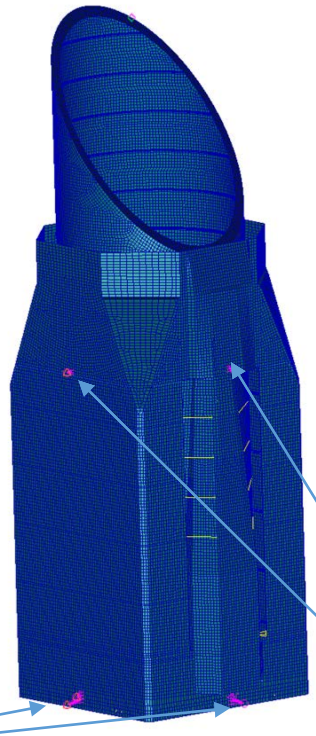


SM has ≈ 10K DOF

Analysis Input Loads and Locations

- Ring Down
  - JPL provided thrust loads associated with a simple maneuver
  - Step function applied at 2 of the 4 ACS thruster locations – Y axis selected
  - 8.8N for 20.5 s, drift 368 s, -8.8N for 20.5 s





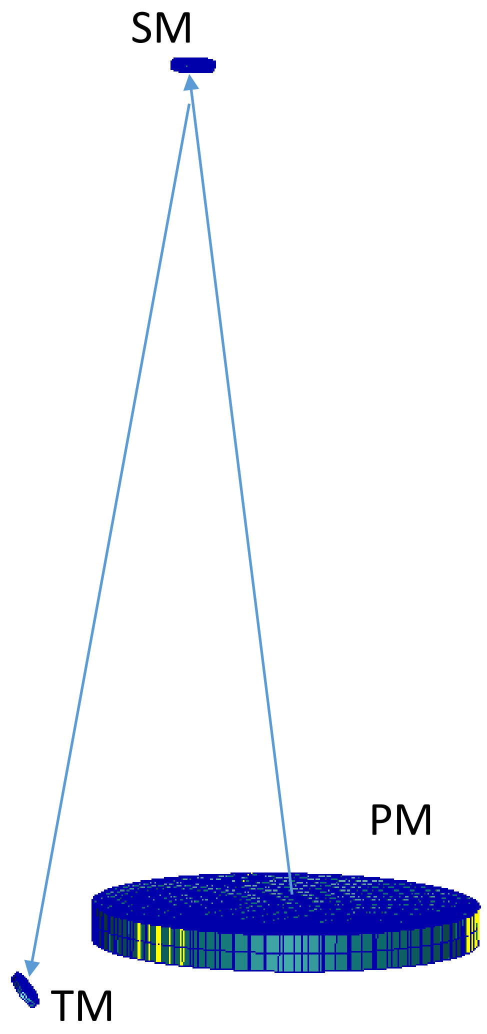
4 ACS thruster locations and 4 large MT pod locations 90°apart

4 small MT pod locations 90°apart

- Jitter
  - MT noise is the disturbance during science windows
  - Noise input at all 8 MT locations
  - Large MT pods
    - F=0.8 μN, .1<f<10 Hz (spec)
    - F=0.8 μN, .1<f<20 Hz (applied)
  - Small MT pods
    - F=0.4 μN, .1<f<10 Hz (spec)
    - F=0.4 μN, .1<f<20 Hz (applied)

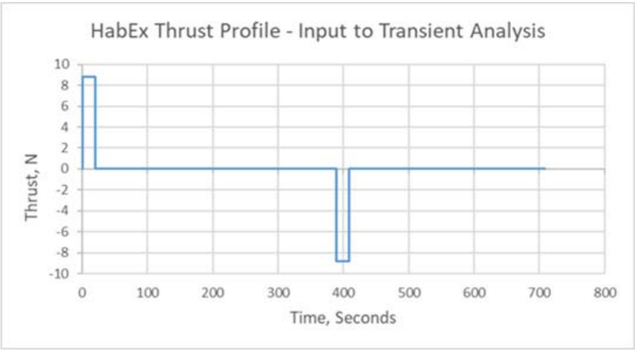
Analysis Output/Results

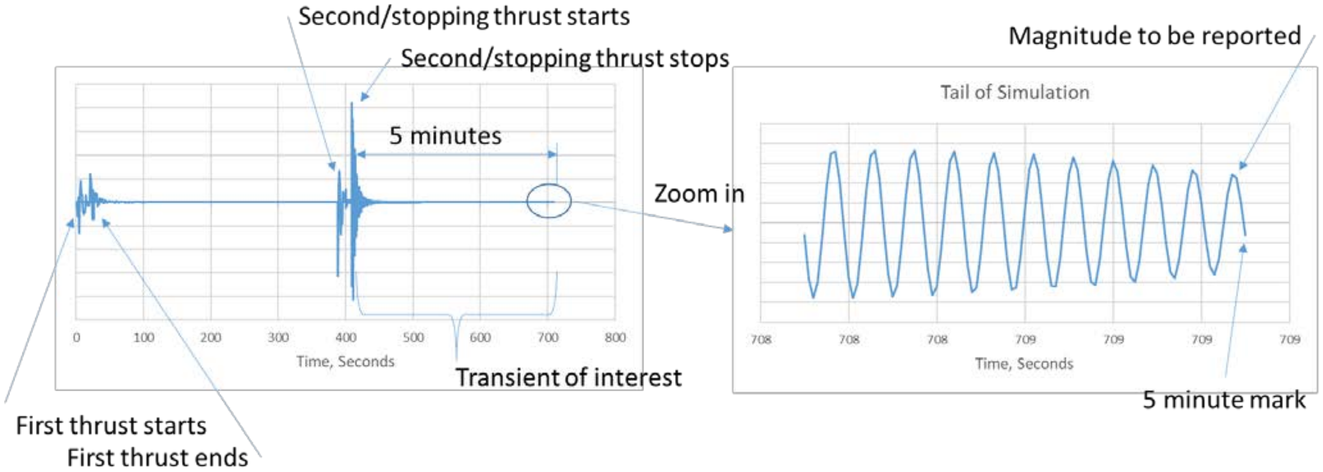
- NASTRAN Multi-Point Constrain (MPC) equations were incorporated to calculate Relative Motions (RM) within the solution sequence
- Per HabEx SE request, MPCs were written to calculate RM's between the PM/SM, the PM and Tertiary Mirror (TM), and the SM/TM



Ring Down Analysis

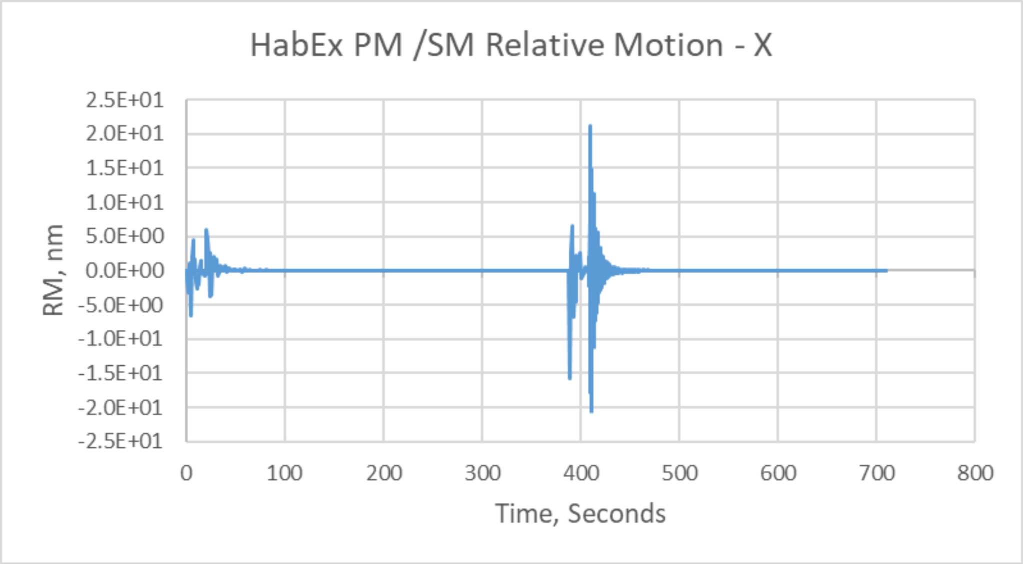
- Physically, ring down is a transient event
- To assess the design to estimate the ring down time a NASTRAN transient (time domain) dynamic analysis (Solution 112) was performed
  - Required damping of .05% was used
  - No ring down time requirement has been determined in this feasibility study
    - In the absence of a requirement, the simulation was run 5 minutes past the “stopping thrust”
    - PM/SM RM for each DOF was output
    - The max RM 5 minutes after the last thrust was reported

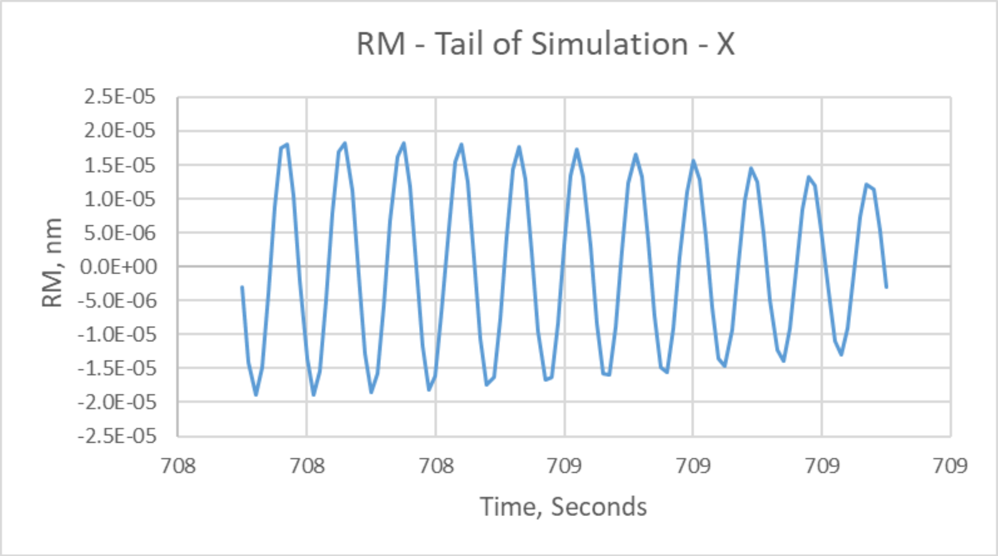




Ring Down Results

- PM to SM Relative Motion was the selected metric
- X Direction

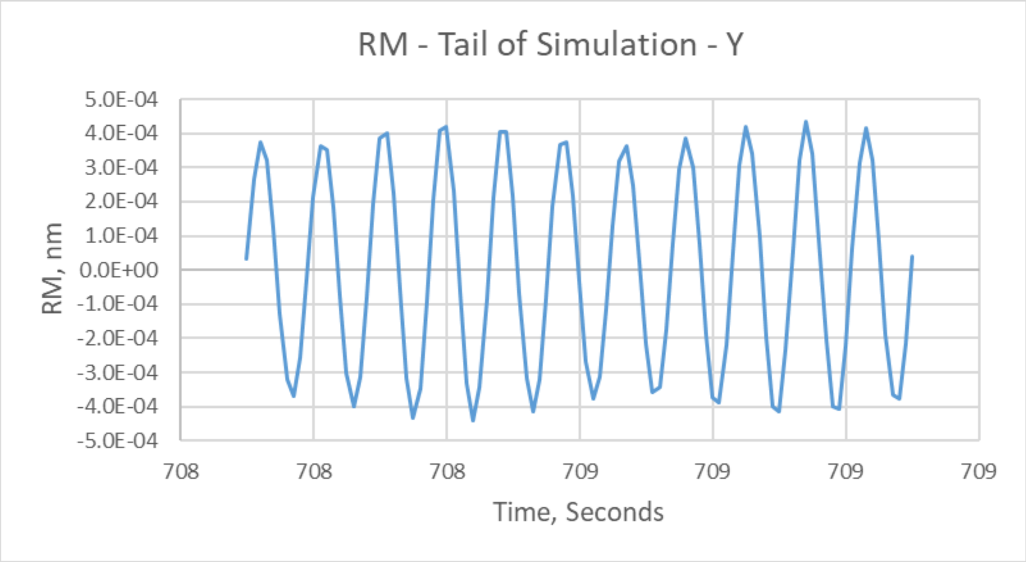


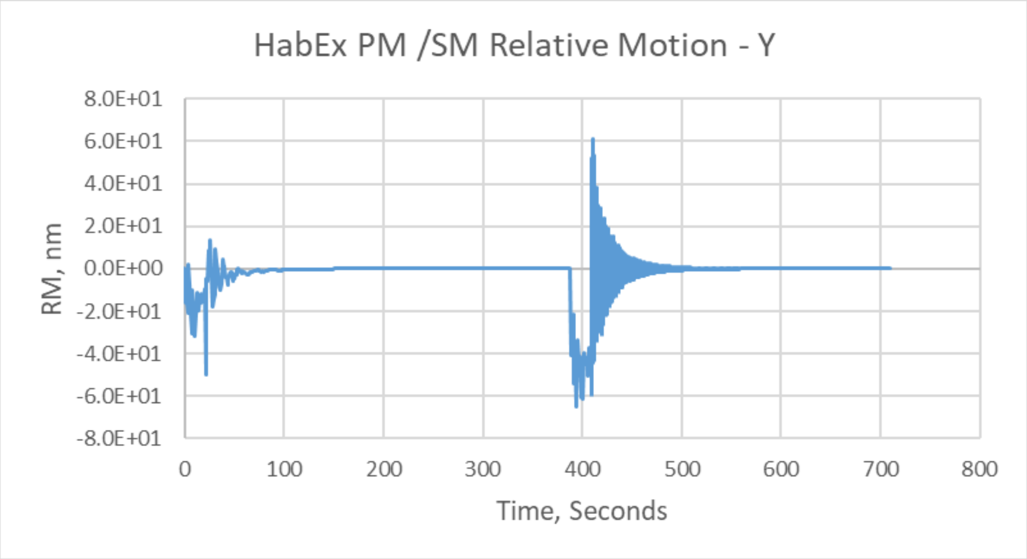


Peak after 5 minutes = 1.2E-4 pm

Ring Down Results

- PM to SM Relative Motion
- Y Direction

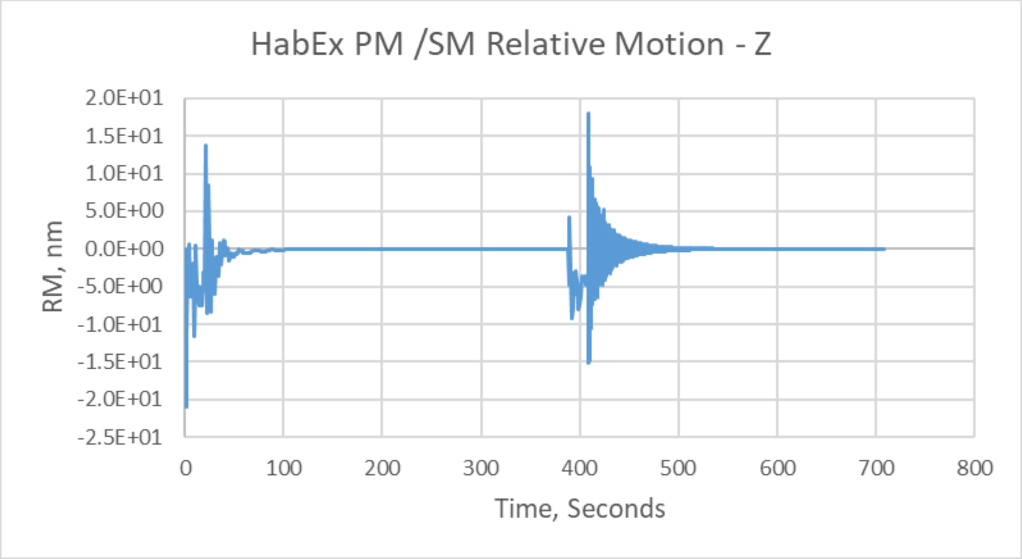


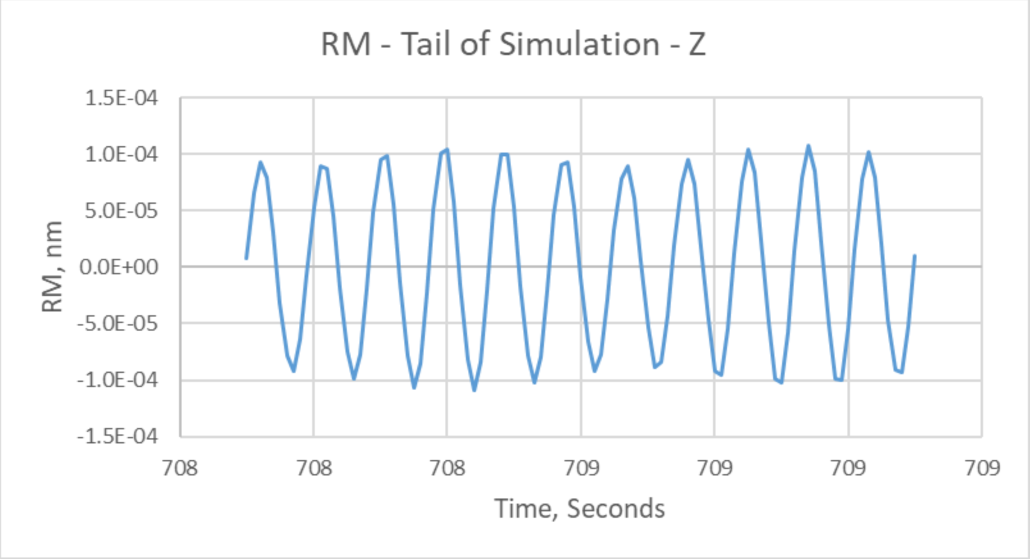


Peak after 5 minutes = 4.1E-4 pm

Ring Down Results

- PM to SM Relative Motion
- Z Direction

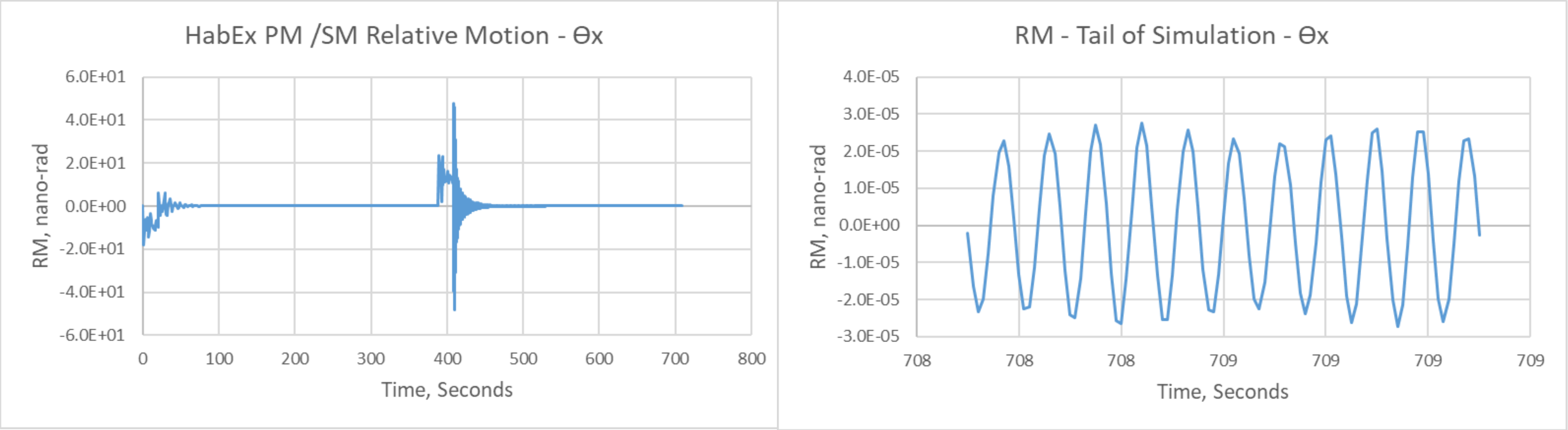




Peak after 5 minutes = 1.0E-4 pm

Ring Down Results

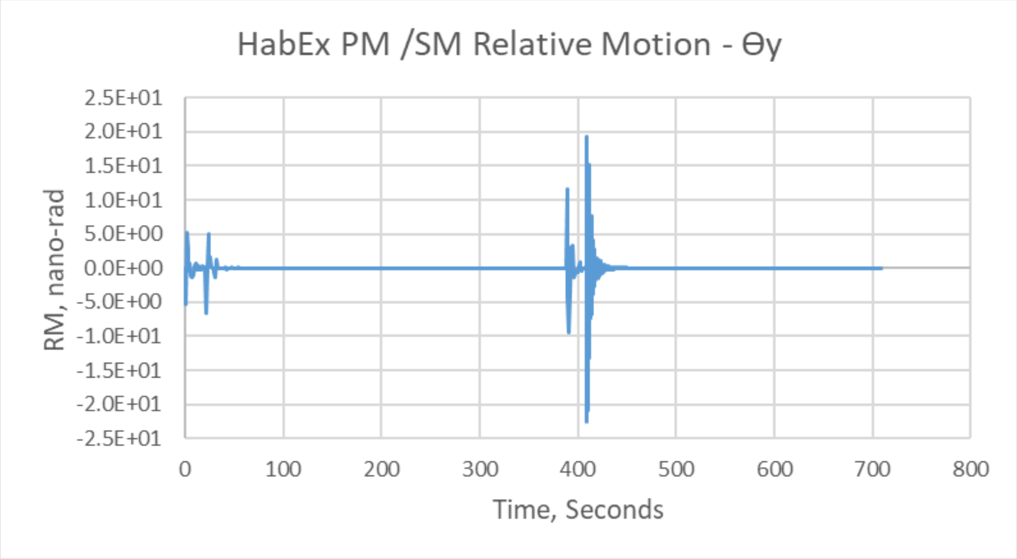
- PM to SM Relative Motion
- Ɵx Direction

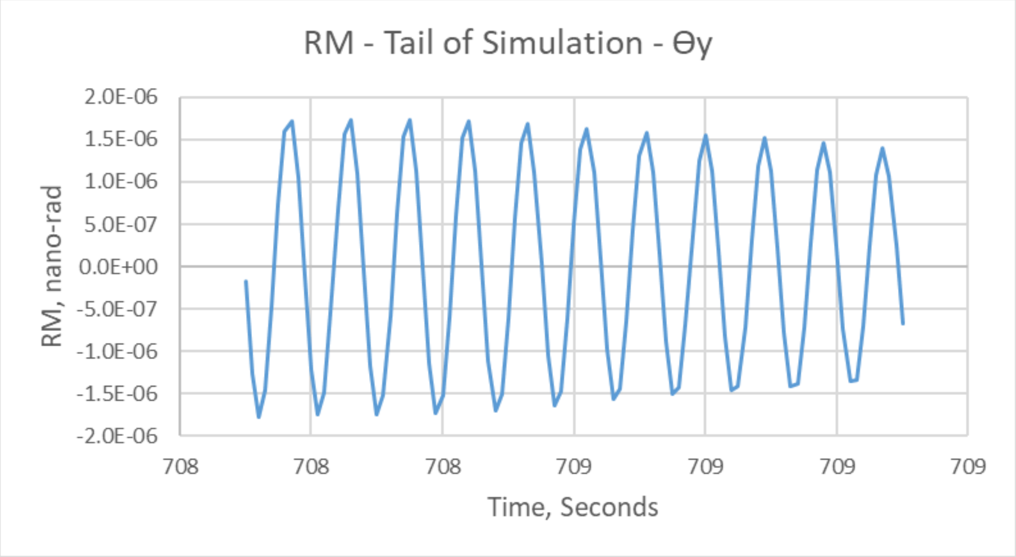


Peak after 5 minutes = 2.3E-5 pico-radians

Ring Down Results

- PM to SM Relative Motion
- Ɵy Direction

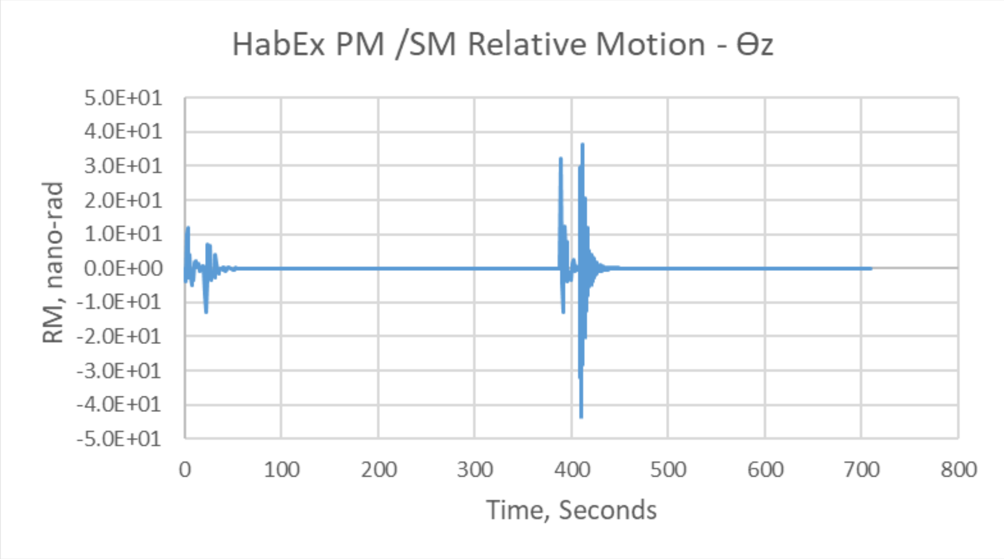


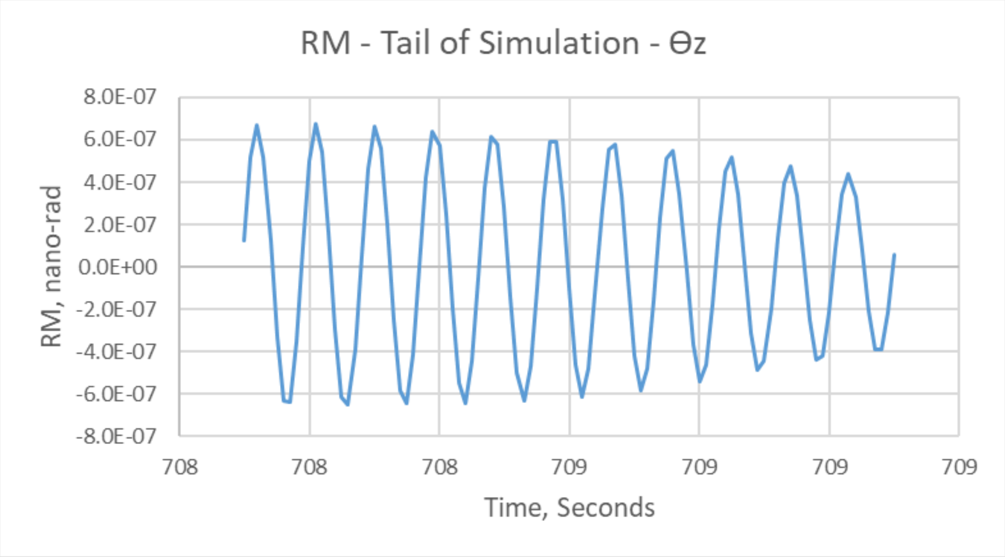


Peak after 5 minutes = 1.4E-6 pico-radians

Ring Down Results

- PM to SM Relative Motion
- Ɵz Direction





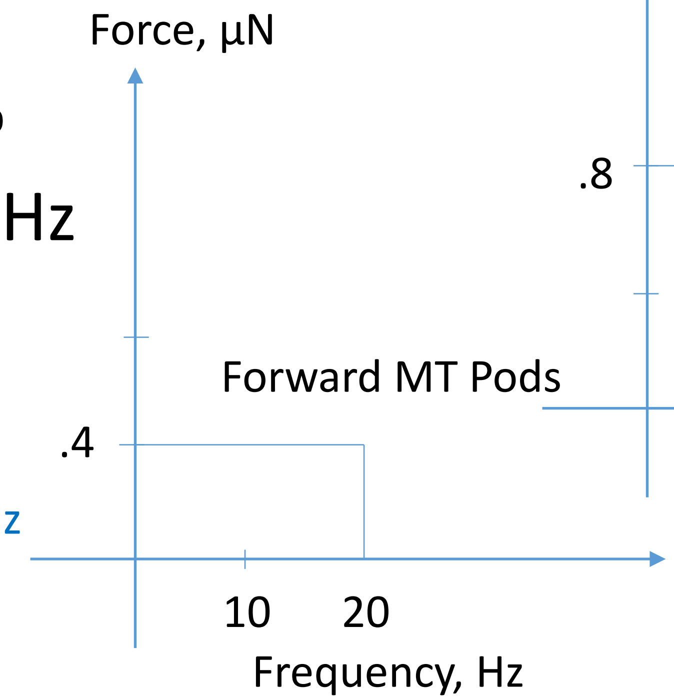
Peak after 5 minutes = 4.4E-7 pico-radians

Ring down Conclusion

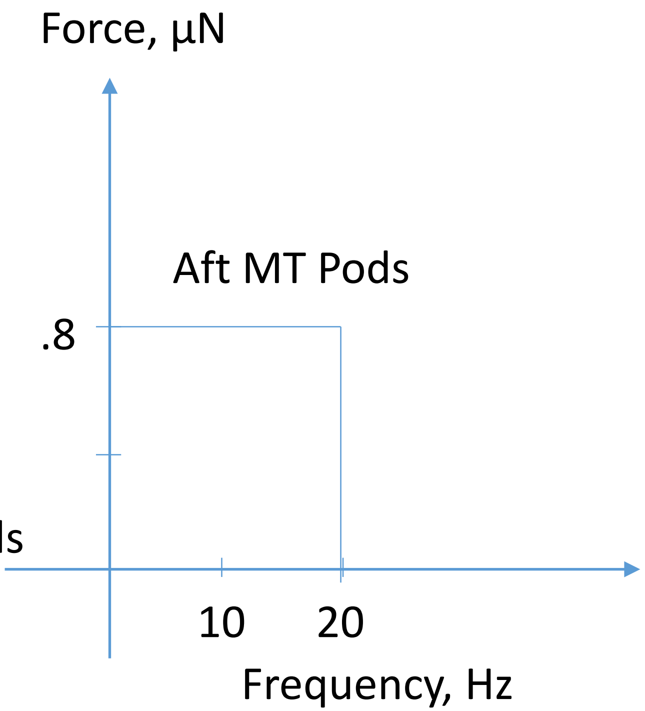
- No required time to regain stability after thruster induced transients has been determined
- The maximum linear RM is on the order of 10-4 pm after 5 minutes of settling time
- The maximum rotational RM is on the order of 10-5 p-rad after 5 minutes of settling time
- The LOS stability requirements are in the nm range
- Therefore, with small fractions of pm range motion predicted, 5 minutes of settling time is a conservative number to use in this early study

Jitter Analysis

- Jitter is a continuous event that occurs as long as the source vibration is in operation
- It is well suited for a frequency response or harmonic dynamic analysis
- Damping was required to be .05%
- Results were predicted up to 350 Hz

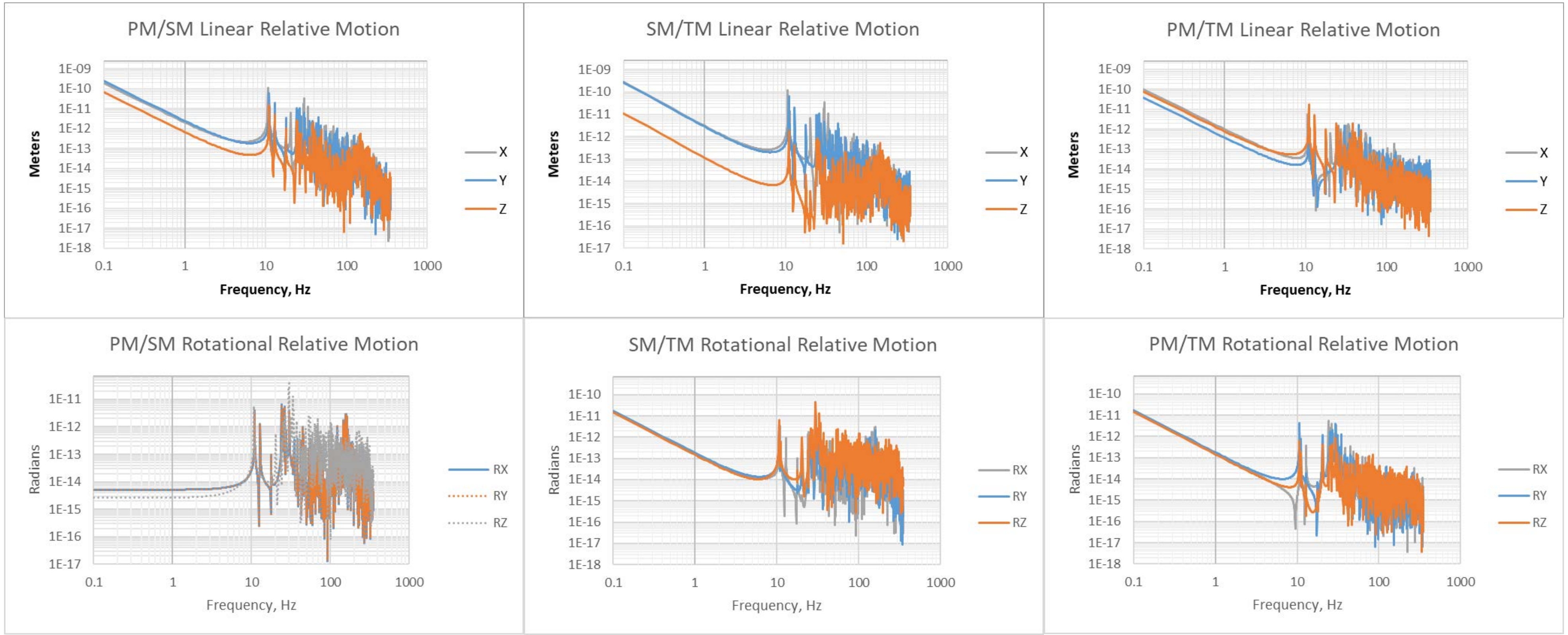


Noise specified to 10 Hz
Conservatively applied out to 20 Hz



Jitter Results

- Results up to 300 Hz were provided to the HabEx SE team and were rolled into system level performance assessments



Final Comments

- Feasibility fidelity dynamic analyses have been performed for the HabEx Pre-Phase A engineering effort
- Based on the provided FEM and required inputs, no show stoppers were identified