Dynamic Analyses of the Proposed Habitable Exoplanet Astrophysics Facility

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ABSTRACT

The proposed Habitable Exoplanet (HabEx) astrophysics facility is one of four large such facilities being proposed to the 2020 decadal. It is a large telescope that is sensitive to ultraviolet, optical, and near-infrared photons. The proposed design's overall length is on the order of 17.2 m and its maximum cross section is on the order of 5.25 X 5.25 m. The primary mirror is 4 m in diameter. A transient dynamic analysis was performed to estimate the order of magnitude of ring down time after moving the telescope and pointing at a new target for science planning purposes. Without uncertainty factors, results from a simple re-pointing maneuver indicate that primary to secondary mirror LOS errors are on the order of 10^{-4} pico-m after 5 minutes. Also, a frequency response analysis was performed to predict the impact of planned micro-thruster vibrations on required stability. Based on provided noise level associated with the micro-thrusters and loading assumptions and without uncertainty factors, the assessed vibrations do not impact predicted performance requirements.

Keywords: HabEx, Space Telescope, Extreme Stability, Transient ring down, Jitter

1. INTRODUCTION

In preparation for the 2020 Decadal Survey in Astronomy and Astrophysics, Science and Technology Definition Teams (STDT) have been established to assess concepts for a next large mission to follow James Webb Space Telescope (JWST) and Wide Field Infrared Survey Telescope (WFIRST). One such proposed mission is the HabEx. Numerous design and analysis iterations have been performed over multiple years to evolve the HabEx design to the current state. As part of that, analyses were performed for this Pre-Phase A/feasibility effort to predict performance with respect to dynamic stability while in service.

Analyses were performed to predict the vibration amplitude five minutes after a simple re-orienting maneuver of the system. A specified thrust profile was used as input to the Finite Element Analysis (FEA) and a required damping level of .05% was utilized to make that prediction. Similarly, analyses were performed to determine the order of magnitude of Line Of Site (LOS) misalignment that would occur due to the colloid micro-thruster noise. Additionally, results from the subject FEA were provided to HabEx systems engineers and were utilized to predict Wave Front Error (WFE). The latter results are not included in this paper.

No Uncertainty Factor (UF) was applied to results. It is left to the HabEx Systems Engineering community to do so.

2. FINITE ELEMENT MODEL

The design was modeled via Finite Elements (FE). The telescope was modeled by NASA/MSFC personnel and the Spacecraft (SC) was modeled by Jet Propulsion Lab (JPL) personnel who also combined the two yielding the integrated HabEx Finite Element Model (FEM). Table 1 list what the FEM was comprised of. Figure 1 presents the SC, Telescope, and the integrated HabEx FEM as well as the FEM coordinate system. The origin is located 0.375 m forward of the aft plane of the SC. The FEM's mass properties are shown in Table 2. The Primary Mirror (PM) and Secondary Mirror (SM) FEM's are shown in Figure 2.

Table 1: HabEx FEM

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

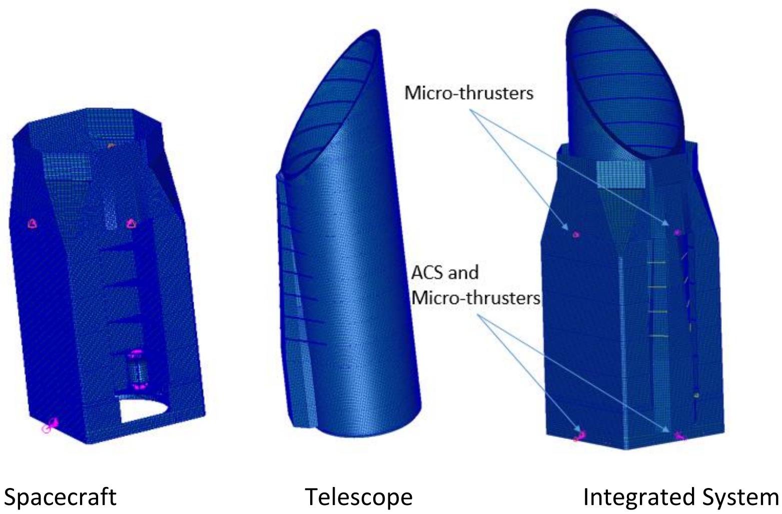

Figure 1. Finite Element Model

Table 2. FEM Mass Properties

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

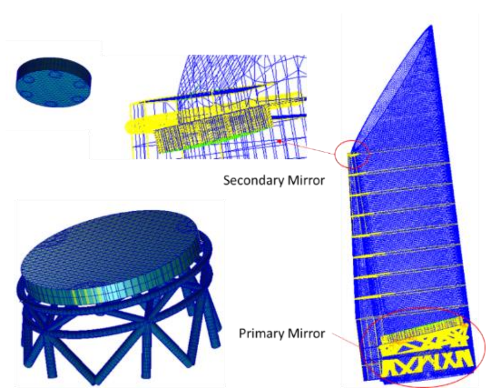

Figure 2. Primary and Secondary Mirrors

3. ANALYSIS

Two analyses were performed. One for the ring down time and the other for the LOS jitter assessment. Both included the required damping of 0.05%. The ring down analysis was a transient dynamic analysis and jitter was assessed via a frequency response analysis.

Guidance Navigation and Control (GN&C) components are the only dynamic disturbance sources in the HabEx design. HabEx has 4 Attitude Control System (ACS) thrusters located 90° apart near the aft end of the SC. The two on the Y axis were selected as the input locations for this Pre-Phase A ring down analysis. There are 8 micro thruster pods used for steering and maintaining position. Four located with the ACS thrusters and 4 on the mid-ring. Figure 1 shows the thruster locations. The micro-thruster noise was used as the input to the jitter analysis.

3.1 Ring down

Ring down is a transient event. It was assessed via an MSC/NASTRAN Solution 112 analysis which is a modal transient analysis. The simulation was run 5 minutes beyond the second pulse as shown in Figure 3. NASTRAN multi-point constraint equations were utilized to compute Relative Motions (RM) for all 6 Degrees of Freedom (DOF) between the center of the PM and the SM.

The disturbance utilized in this analysis was representative of a simple maneuver to re-orient the system to a new target. The corresponding thrust force levels and durations were provided by JPL HabEx GN&C personnel. Figure 3 shows the profile.

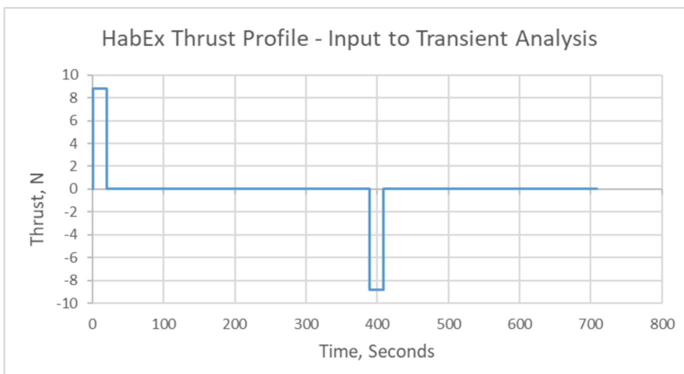

Figure 3. Thrust Profile

The thrust forces were applied at the ACS thruster locations shown in Figure 4.

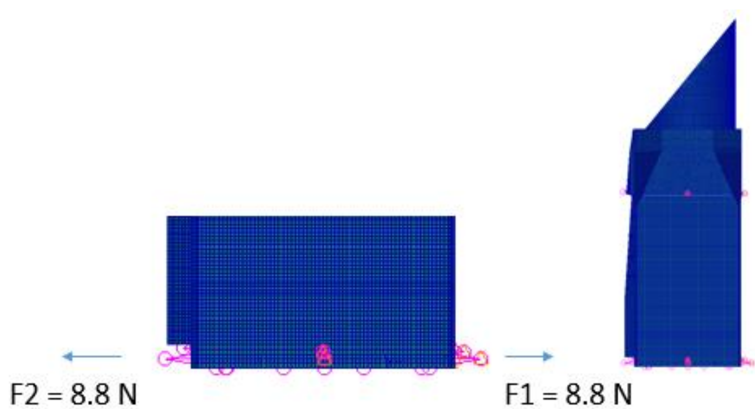

Figure 4. Thruster Locations

3.2 Jitter

Jitter is considered as a continuous disturbance as opposed to the transient associated with thruster firings. The noise associated with the micro-thrusters is the only identified dynamic disturbance during science windows.

Jitter was assessed via an MSC/NASTRAN Solution 111 analysis which is a modal frequency response analysis. All modes up to 300 Hz were included in the solution. The load or input disturbance to the analysis was the provided micro thruster noise level. There are two micro thruster sizes incorporated in the design. The smaller is located on the mid-ring and the larger are co-located with the ACS thrusters. The mid-ring micro-thrusters have specified noise of 0.1 µN up to 10 Hz and those located with the ACS thrusters 0.2 µN up to 10 Hz. This load was conservatively applied from 0.1 to 20 Hz in the Jitter analysis to assess potential impacts to performance.

The specified noise for all 8 micro-thruster pods was applied simultaneously. The motion of the center of the PM, SM, and the Tertiary Mirror (TM) was predicted as was the relative motion between PM/SM, PM/TM, and SM/TM.

4. RESULTS

4.1 Ring down results

Figures 5 through 10 show the ring down transient analyses complete response time history as well as the tail of each. The tail is magnified to show the magnitude of RM's at the end of the simulation.

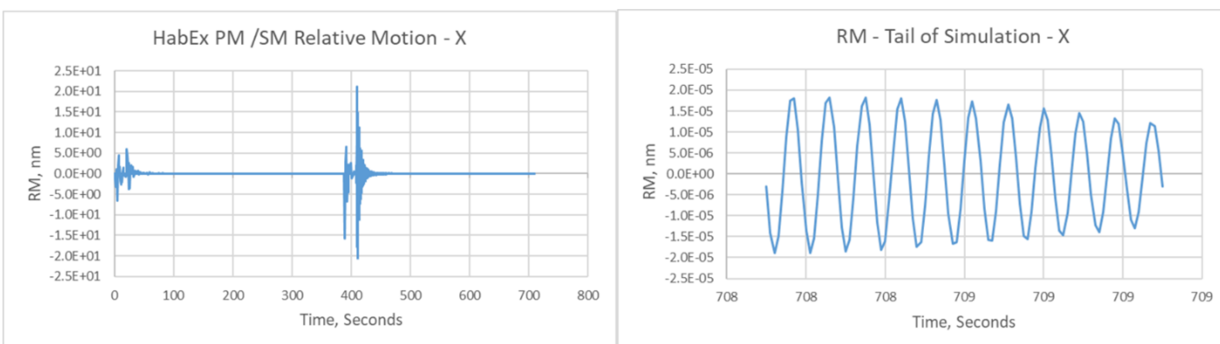

Figure 5. PM/SM X Direction Relative Motion

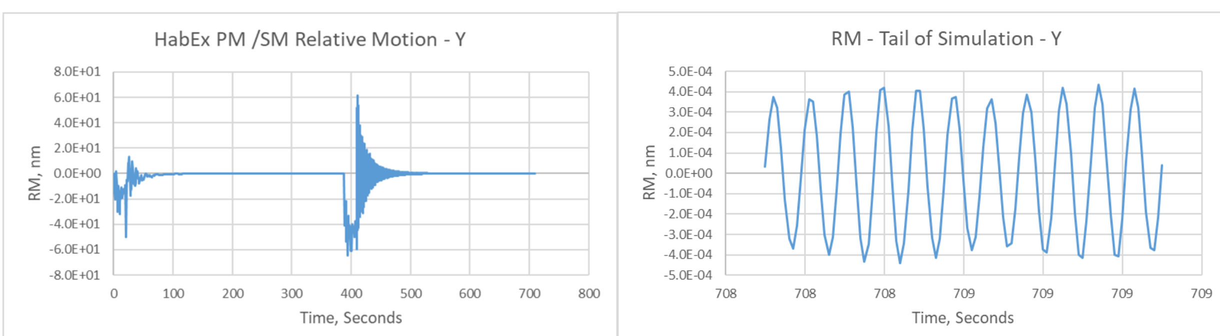

Figure 6. PM/SM Y Direction Relative Motion

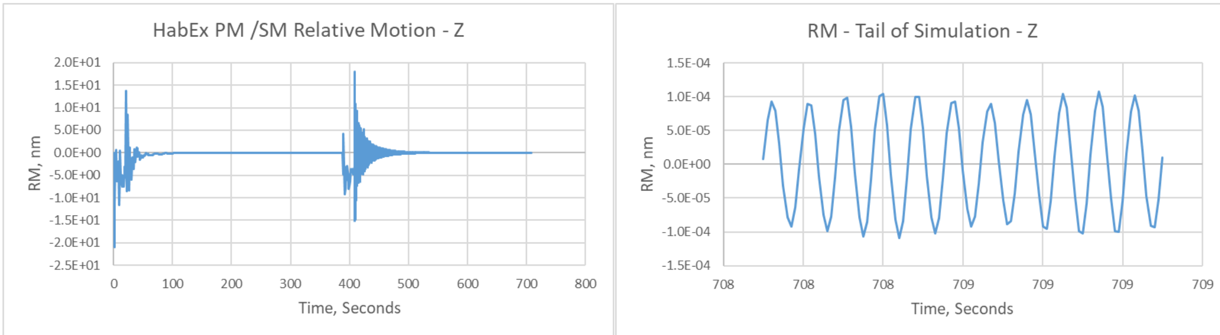

Figure 7. PM/SM Z Direction Relative Motion

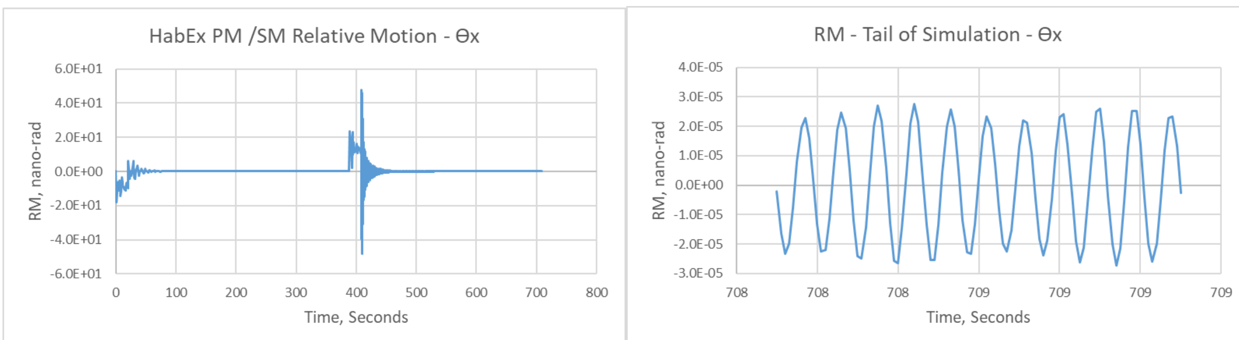

Figure 8. PM/SM X Rotation Direction Relative Motion

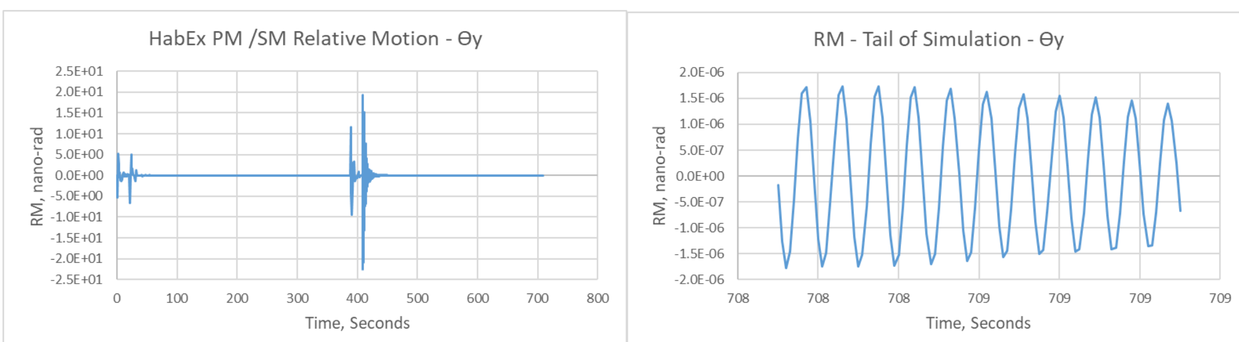

Figure 9. PM/SM Y Rotation Direction Relative Motion

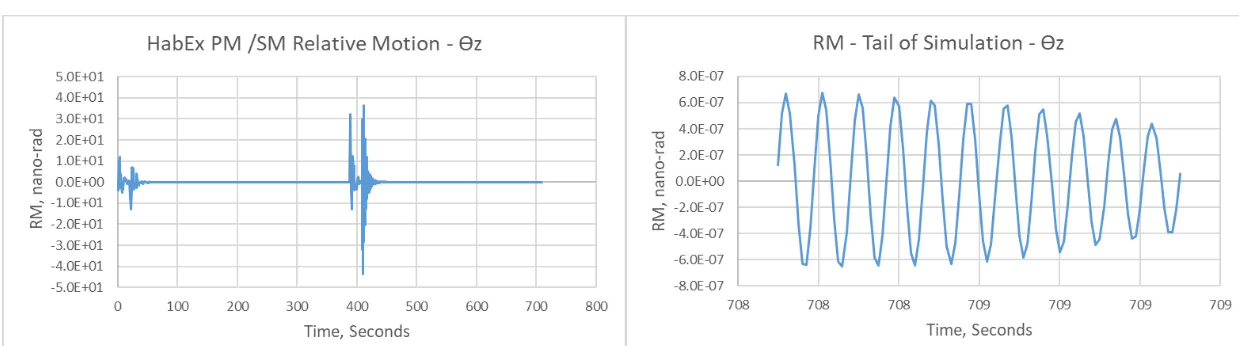

Figure 10. PM/SM Z Rotation Direction Relative Motion

4.2 Jitter results

Figures 11 present all 6 DOF of RM's between PM/SM, PM/TM and SM/TM.

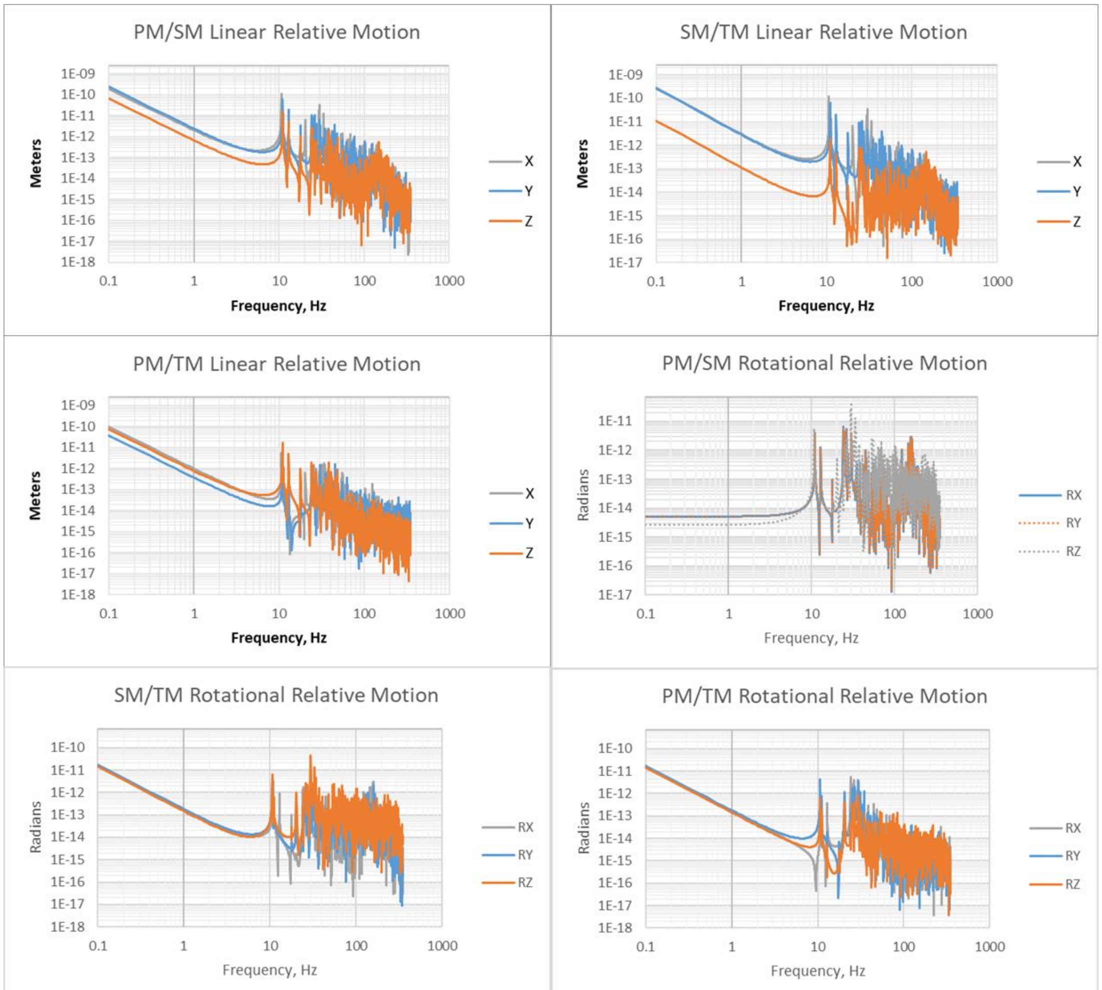

Figure 11. Relative Motion Results

5. CONCLUSIONS

This Pre-Phase A HabEx effort has not defined a requirement for allowable ring down time after a maneuver. The predicted order of magnitude of LOS misalignment between the PM and SM due to a simplified representation of a GN&C maneuver is considered a reasonable metric of feasibility. Five minutes after that maneuver, the highest relative motion was 4E-4 pm. It occurred in the Y direction which is consistent with intuition since that is the direction of the applied load.

In the absence of missions specific GN&C simulated micro-thruster applied loads, the only identified dynamic input during science windows is the noise of those devices. Additionally, the rate at which thrust levels at each location ramp up or down is expected to be slow, therefore, their frequency content is expected to be low. No other disturbances with frequency content were identified. The predicted relative motion between each mirror pair (PM/SM, PM/TM, SM/TM) in all 6 DOF was provided to the HabEx Systems Engineering team to be used in integrated performance predictions. Margin was said to be on the order of 10%.