Integrated Modeling for the James Webb Space Telescope (JWST) Project: Structural Analysis Activities

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May 6, 2004

Overview

- **JWST Overview**
- **Observatory Structural Models**
- **Integrated Performance Analysis:**
  - Performance Budget
  - Linear Optical Analysis
  - Structural-Thermal-Optical
  - Optical jitter dynamics
- **Future Work and Challenges**

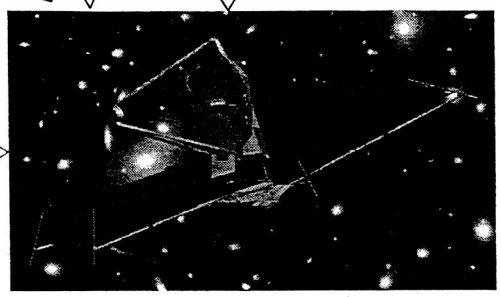
JWST Mission Concept

Constraints
- Launch by 2011
- Cost capped
- Significant International Contributions
- Spacecraft from Prime Contractor (IRT Finding)
- Use existing Launch Vehicle Capabilities

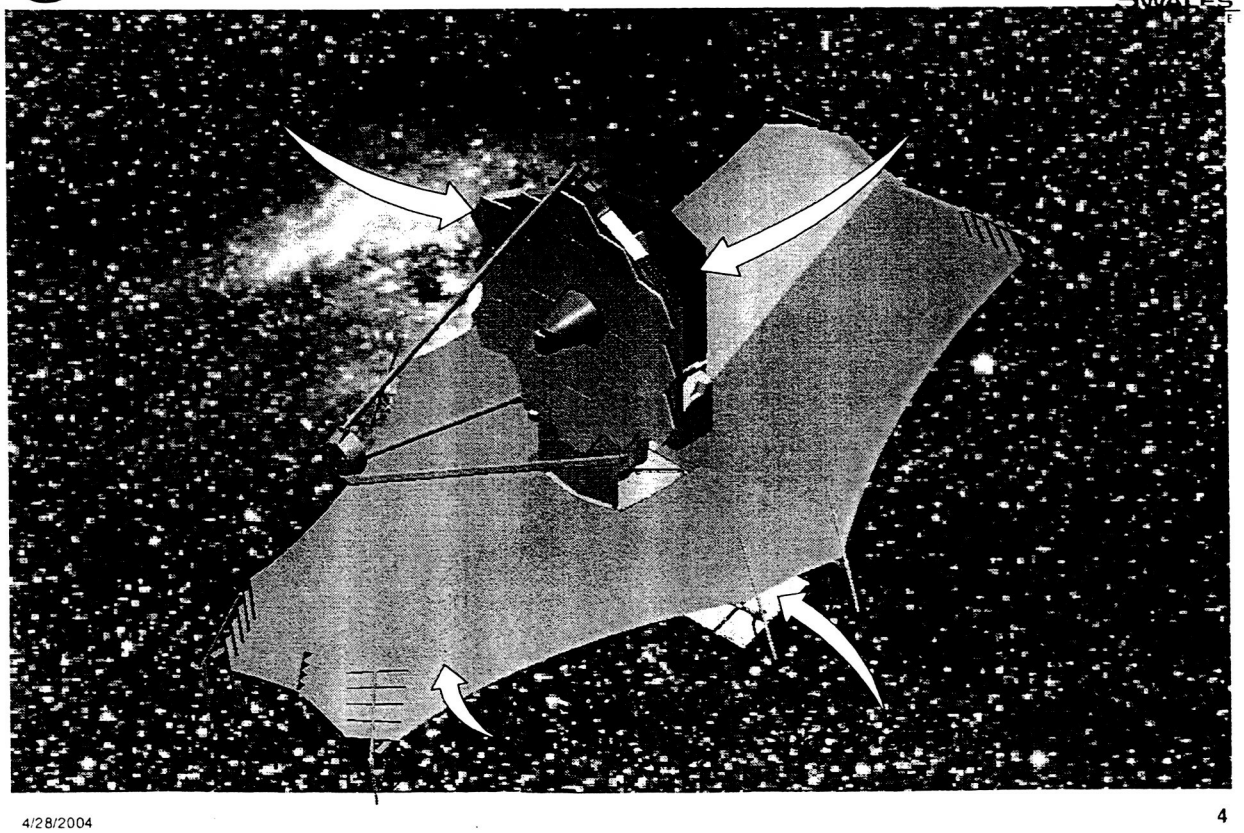
Science Requirements
- Measure the luminosities, morphologies, and environments of galaxies within the spectral band 0.6 – 10 μm
- Measure the spectra of 2500 galaxies over the redshift range $1 < z < 5$
- Obtain a total observing time of at least 1.1×10^8 seconds. JWST is designed for at least a 5-year lifetime.

Key Mission Trades
- Orbit, Method to Orbit
- Launch Vehicle/Shroud Configurations
- Filled vs Partially-Filled Apertures
- Thermal Management
- Instrument Packaging
- Sky Coverage
- Communications Strategy

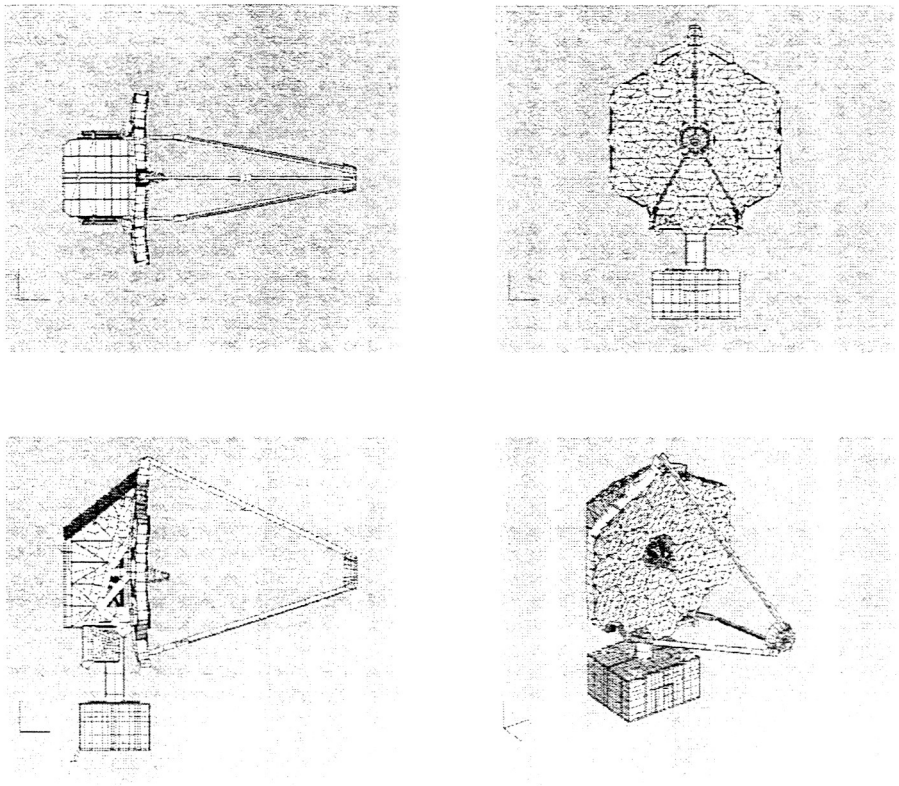
Science Instruments
- **NIR Imaging Camera [NIRCam]**
  - 8 square arc minutes field of view
  - Spectral resolution R ($\lambda/\Delta\lambda$) = 100
  - Wavelength range 0.6-5 μm
- **Multi-object spectrograph [NIRSpec]**
  - Observing > 100 objects/observatory pointing
  - 9 square arc minutes field of view
  - R ~1000 over wavelengths 1-5 μm
  - R ~100 over wavelengths 0.6-5 μm
- **MIR instrument [MIRI]**
  - Imaging and spectroscopy
  - 2 square arcminutes field of view
  - R ~1500 spectroscopy over wavelengths 5-28 μm.



Observatory Architecture



Observatory Structural Model



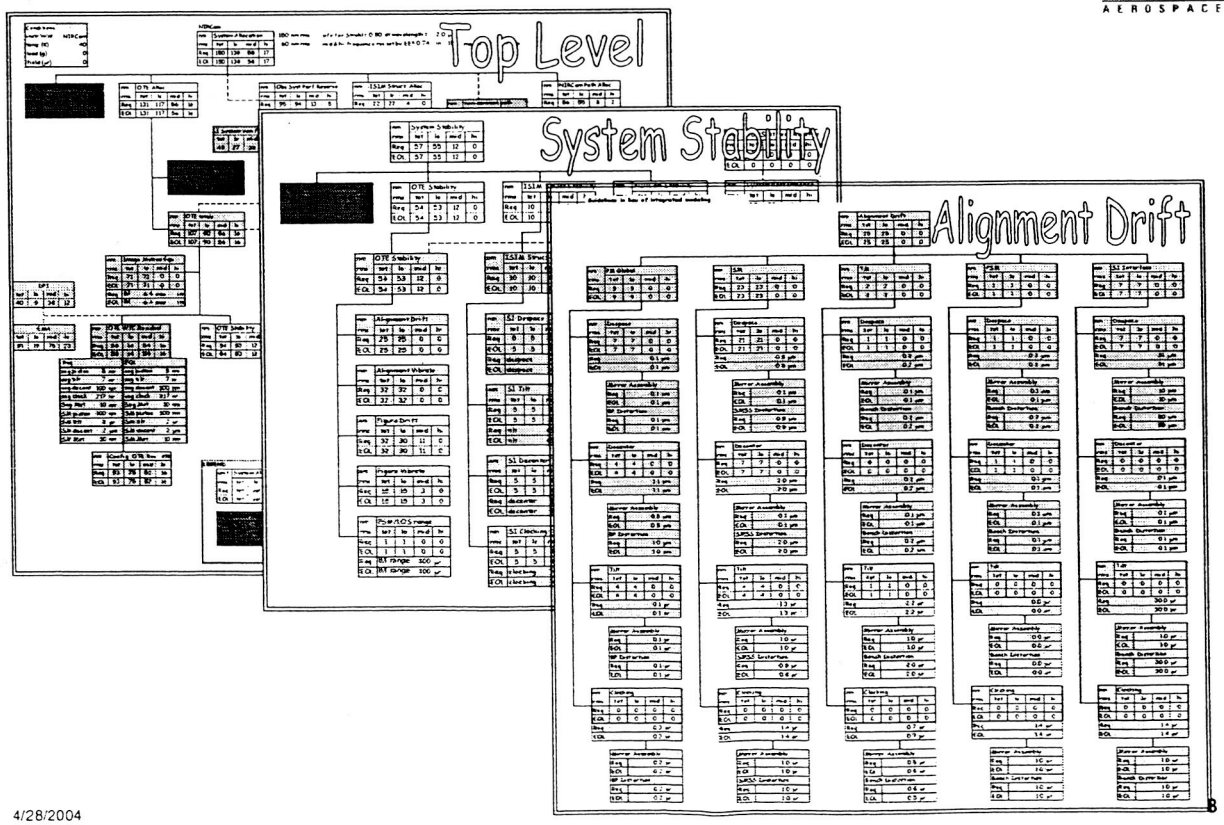
Integrated Performance Analysis

- **Overview**
  - Multi-disciplinary analysis
    - Thermal, Optical, GN&C, and Structural
    - Tight requirements drive the project toward more integrated analysis
  - Performance budget
    - Northrup-Grumman Space Technology (NGST) has adopted a very detailed optical performance budget allocating wavefront error
    - Seek to place the project in a position to intelligently comment on this budget as the contractors estimate the telescope's performance
  - Linear optical model
    - MATLAB-based tool to allow non-optical engineers to estimate wavefront error
- **Baseline Analyses:**
  - STOP
  - Jitter

Performance Budget

- **NGST allocates and tracks optical performance with a spreadsheet**
- **Rooted in project Strehl ratio and Encircled Energy requirements**
  - Calculations translate these into total allowable WFE
    - Allocated into 3 spatial-frequency bands (cycles/aperture)
    - Allocations for both beginning and end of life
- **Two main branches divisions at top level**
  - Active control
  - Stability
- **Geometry errors of optics divided into "figure" and "alignment"**
- **Temporal performance is allocated to either "drift" or "vibrate"**
- **Lowest-level requirements often related to equivalent mechanical requirements**

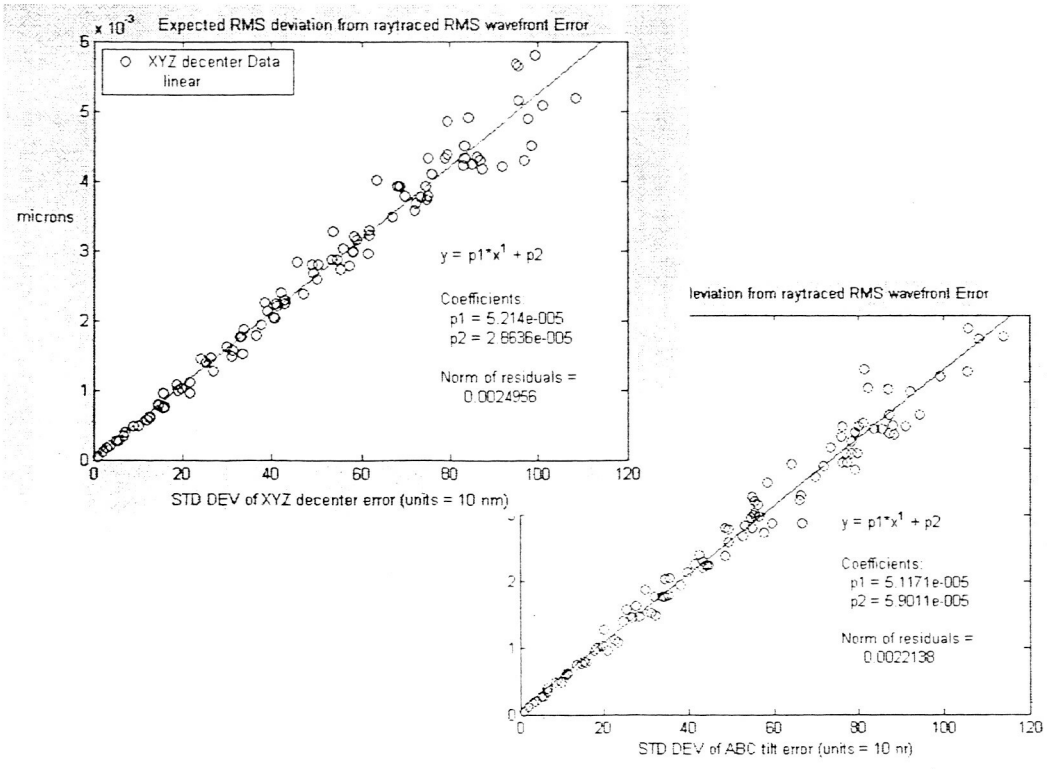
Performance Budget



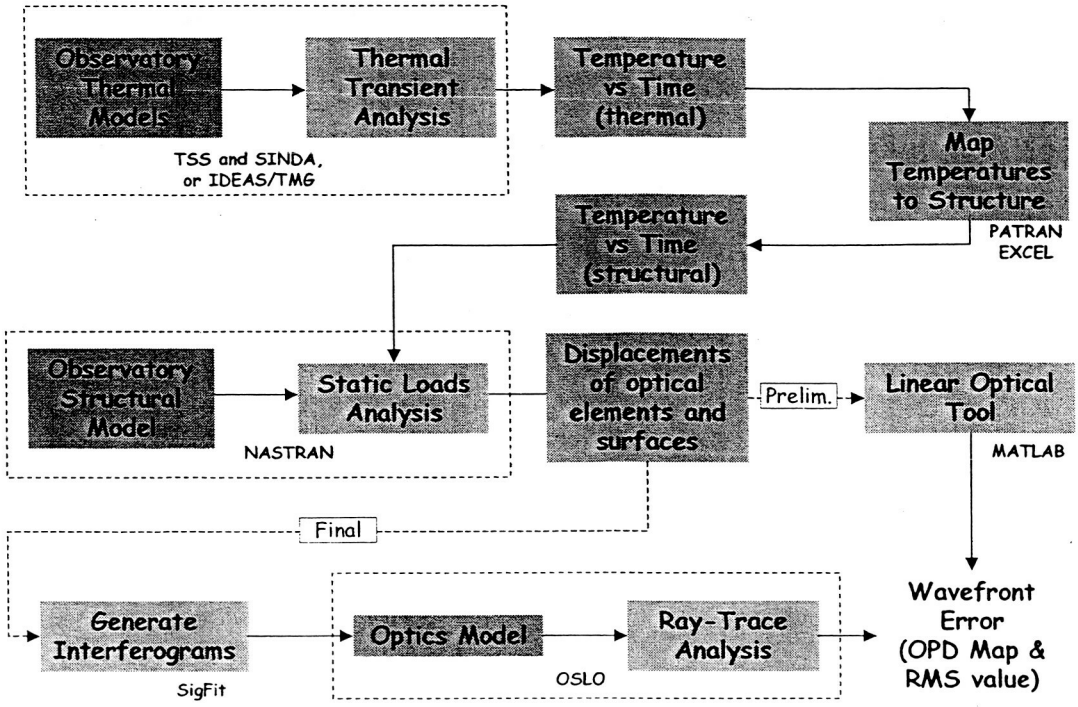
Linear Optical Analysis

- **Provides accurate estimate of OPD wavefront error for perturbed systems (within the limits of the model)**
- **Coefficients created by ray-tracing runs in OSLO**
  - 10nm (nrad) motion introduced in each of optical DOF
  - 100x100 array showing OPD at exit pupil generated in MATLAB for each optical perturbation
- **Arrays scaled and summed in MATLAB based on actual motion in each of the 132 DOF**
  - Displacements multiplied by appropriate array
  - OPD maps summed
  - FSM manipulated to minimize RMS wavefront error
  - Results are reported as "Best Fit Plane" with global piston offset removed

Linear Model Accuracy

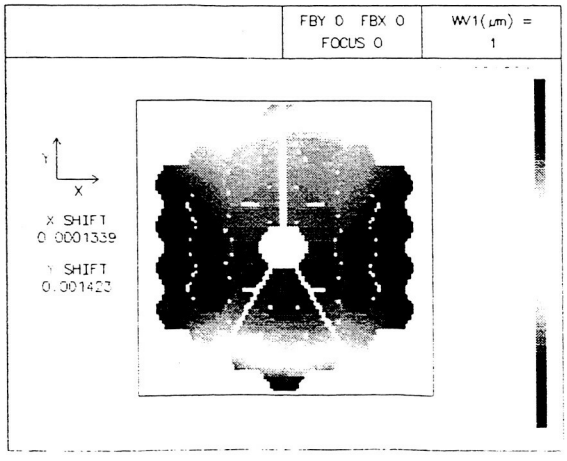


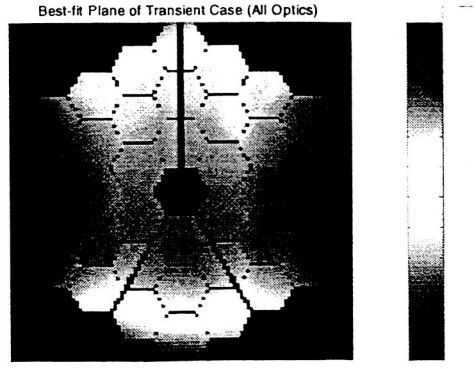
Structural-Thermal-Optical (STOP) Analysis



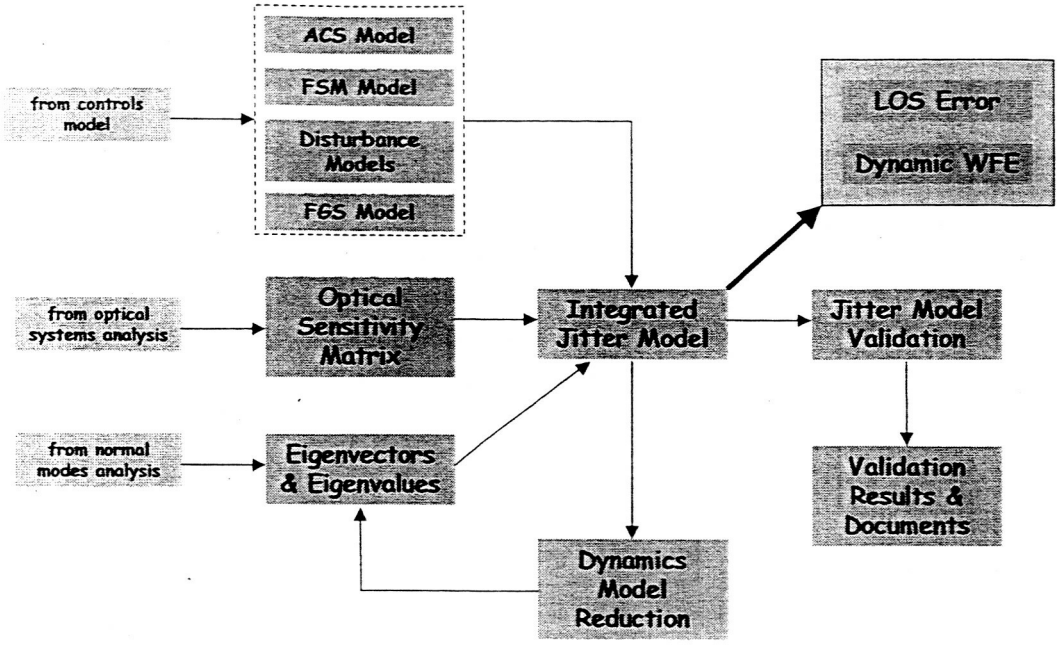
STOP Analysis – WFE Predictions

- **STOP analysis of slew maneuvers requires pairs of linear statics runs**
  - Calculate delta between displacements of two room to operational thermal-loaded runs
- **Most STOP analyses use linear optical tool for WFE prediction**
  - Current generation thermal models rarely include PM segment details
  - Beryllium PM segments not expected to develop substantial gradients



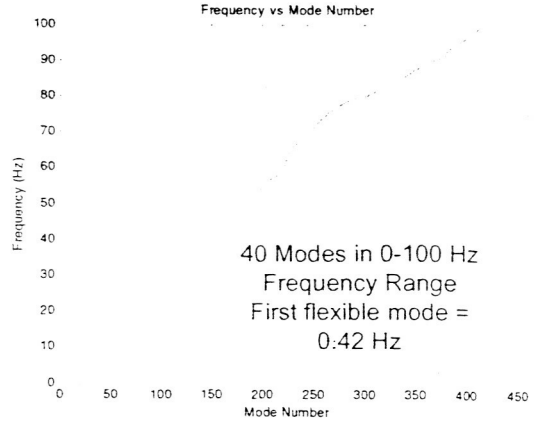


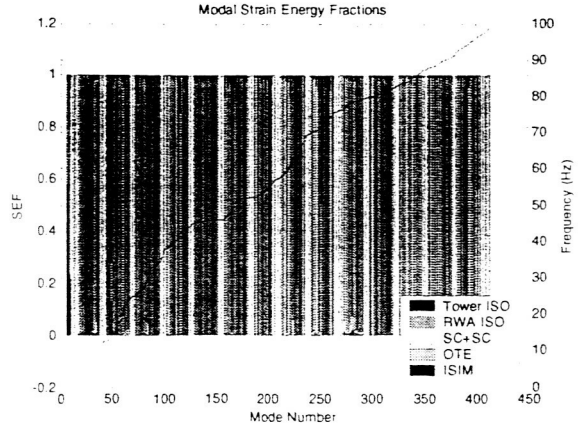
Optical Jitter Dynamics (Jitter) Analysis



Jitter Analysis – Modal Analysis and Damping

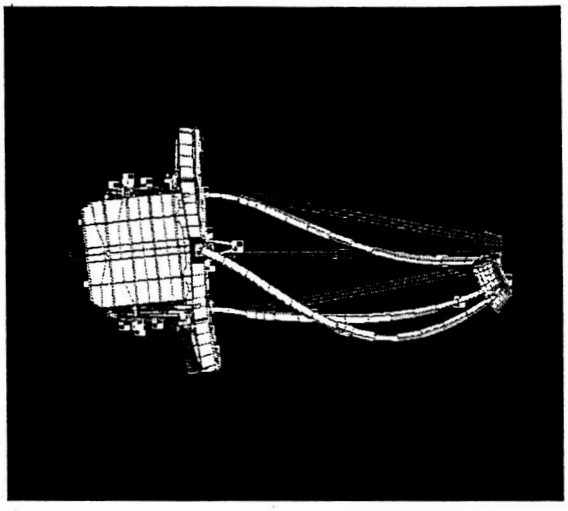
- **The structures discipline provides frequencies, mode shapes, and modal damping values for use in integrated modeling (IM) and attitude control system (ACS) studies:**
  - Mode shapes (mass normalized) are partitioned based on DOF corresponding to predefined reference points (optics, RWAs, etc).
  - Modal damping values are either:
    - Uniform
    - Variable (Based on group participation determined using modal strain energy fractions)



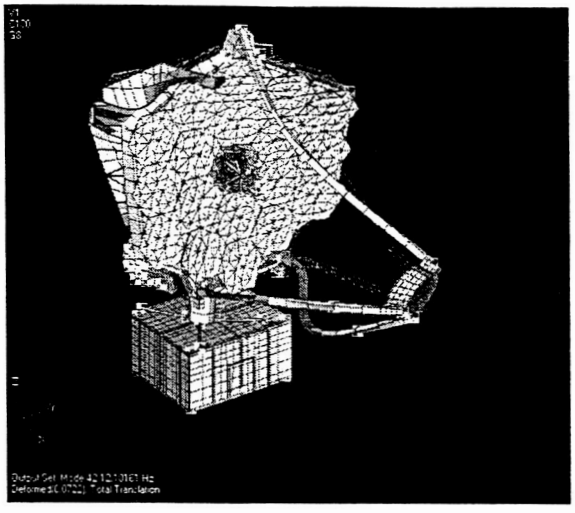


Jitter Analysis: Mode Shapes

Secondary Mirror Support Structure Bending Mode @ 8 Hz

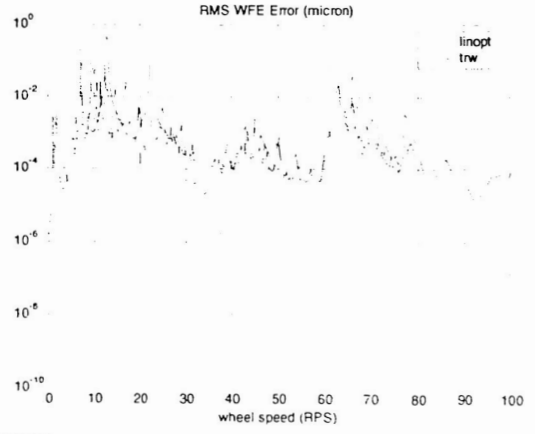


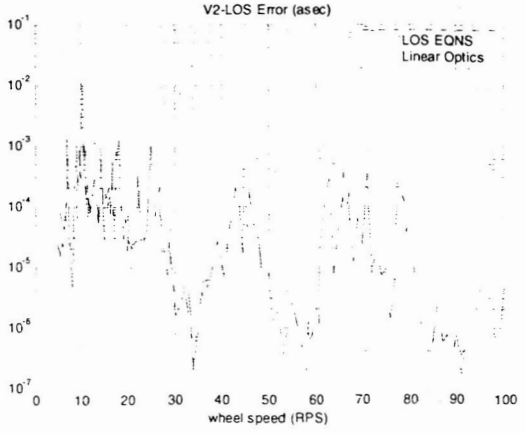
Backplane Twisting Mode @ 12 Hz



Jitter Analysis – LOS and WFE Predictions

- **Reaction Wheel Assemblies (RWAs) are largest jitter disturbance source:**
  - Harmonic disturbances
  - Excite spacecraft and telescope structural modes when the RWA spin speed or harmonics align with the lightly damped structural modes.





Challenges and Future Work

- **Future Work:**
  - Program plans on following a schedule of analysis cycles:
    - STOP/Jitter/Launch analyses
    - First such cycle is underway (6 month duration)
  - Need to verify budget allocations by means of integrated modeling
  - Government team performs indepentent modeling analysis to validate prime contractor
    - Performance predictions
    - Requirements placed on subcontractors/partners
- **Challenges:**
  - Constant pressure exists to create accurate, detailed models while keeping run times tolerable:
    - Need for high-fidelity (multi-million DOF solid element) structural model anticipated for CDR distortion analysis.
    - Superelement approaches under investigation
  - Need to understand sensitivity of results to variations in material properties
  - Need to expand linear optical tool to calculate WFE at multiple field points and FOV locations