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

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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

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 1.1x10⁹ seconds.
JWST is designed for at least a 5-year lifetime.

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

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 (λ/Δλ) = 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

4/28/2004
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
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

![Graph showing linear model accuracy](attachment:graph.png)

- Expected RMS deviation from raytraced RMS wavefront Error
- Coefficients:
  - $p_1 = 6.214e-005$
  - $p_0 = 9.938e-005$
- Norm of residuals = 0.002455

![Graph showing linear model accuracy](attachment:graph.png)
**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)

40 Modes in 0-100 Hz
Frequency Range
First flexible mode = 0.42 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 independent 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