Attachment E

Joint Dark Energy Mission (JDEM) Project

Code 448

Math Models Guidelines Document

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1.0 Introduction

This document governs the format, content and documentation that will accompany mathematical analysis models for the JDEM program. These models are required for pre-flight performance prediction, design verification and post-flight assessment of the fully integrated Observatory. The purpose of this document is to describe the models being used and provide guidelines on how they will be used. Models will be provided for each of the mission elements and transmitted amongst the participants performing the necessary analysis. Some of the models for the primary disciplines to be used are as follows:

- Design, solid or CAD models
- Thermal
- Structures
- Dynamics
- Attitude Control Subsystem (ACS)
- Electro-Optics, including
  - ¬ Optics
  - ¬ Stray Light and
  - ¬ Radiometry, including detector and processing electronics noise, and
- Contamination

The integration of discipline analyses is also the subject of this document. Examples are:

- Structural-thermal-optical-controls
- Thermal-contamination-stray light, and
- Observational sensitivity model

The primary mission elements for the JDEM program are the spacecraft (SC), optical telescope assembly (OTA) and the science instrument(s). Each of the primary mission elements will contain logical subsystems. For example, SC subsystems include the thermal, attitude control and structural/mechanical subsystems. OTA subsystems include the forward and aft metering assemblies and the outer baffle assembly (OBA) and the supporting electronics assemblies.

2.0 Global Modeling Guidelines

If not specifically stated otherwise in the discipline sections, the guidelines specified in this chapter shall apply to all of the disciplines.

2.1 Documentation

Each discipline model shall be described in an associated document, either Word, PowerPoint or text file. This document will reside in the model folder along with the model data files. The documentation shall describe particular design features included since the prior model update. Model heritage shall include descriptions of the parent models, e.g. the optical prescription and the mechanical design, structural, and/or modal models that form the basis for the model. Configuration in terms of the component deployment state shall be described. Software code and version numbers used in the creation of the model and analysis results shall be noted. The documentation shall also include results for example cases. Input files will be included along with the documentation to allow the results to be regenerated for crosscheck.

2.2 Coordinate System

The observatory uses a right-handed coordinate system fixed in the observatory body. The origin of the body-fixed observatory coordinate system lies in the separation plane of the launch vehicle Payload Attachment Fitting (PAF). The X-axis is collinear with the geometrical centerline of the observatory. The +X direction lies along the center of the telescope field of view. The Z-axis is collinear with the sun/anti-sun line. The +Z axis is the sun side. The +Y-axis is the cross-product of the +Z-axis and the +X-axis. The terms Roll axis, Pitch axis, and Yaw axis refer to the X, Y, and Z observatory axes, respectively.

2.3 Mass Conventions

Models submitted shall conform to the JDEM Mass Properties Report. Constituent models will be supplied at either their allocated or predicted masses, as determined by discipline and analysis situation. The predicted mass is the estimated mass + contingency.

2.4 Units

All analysis models delivered for inclusion for integrated modeling shall be formulated in the SI (metric) system, using fundamental units of meters, kilograms, seconds and Kelvin; and derived units of Newtons, Pascals, Joules and Watts. Manufacturing and drawing precision dictates that design models shall be formulated in meters.

3.0 Materials Data Package Archive

All material property data used in an analysis will be incorporated into the Materials Data Package. MDP updates to previous submittals need only indicate data that has been added or revised.

3.1 Materials Data Package

Templates have been created. Other software formats of the MDP are acceptable provided it captures the required content.

The content of the Materials Data Package must be detailed and shall include the following:

- Cover page: preparer's name, analyst's name, company and/or organization, address, date of preparation, name, date and document number of associated analysis, if any. If the data is subject to ITAR regulations, put the ITAR legend on the cover. If the document contains proprietary data, mark the cover page appropriately.
- Contents page: listing of each material and type of property data included in package.
- Material property data: the preferred order for presenting materials is composites, metals, ceramics, polymers, adhesives, coatings, and other. The preferred order for presenting property data is mechanical, thermal, electrical/electromagnetic, optical, physical/contamination. Additional details about presenting the data are given in the sub-bullets that follow.

- It is acceptable to submit separate files if the overall data package file size becomes too large to transmit. The separate files should be consistent in presenting materials as previously stated (composites, metals, ceramics, etc).
    - *Material identification* – provide as much information as possible, as material properties can differ even for the same material with different processing histories. The significance of material specifics depends on the objectives of the modeling effort; for instance, a first-order sensitivity analysis does not require the same accuracy in property inputs as a high-fidelity model predicting performance in a critical area. Also, certain properties are more sensitive to material specifics (notably strength in the case of metals, also thermal and electrical conductivity). Specifics consist of the industry designation or manufacturer's trade name and part number, and details of the processing history or construction. For metals this entails alloy, heat treat condition and perhaps form (e.g. aluminum 6061-T6 4-in. (102 mm) plate, beryllium O-50 rolled 0.25-in. (6.4 mm) plate from VHP billet). For composites this includes fiber and matrix resin type (e.g. M55J/954-6), fiber volume content, ply lay-up configuration (e.g. $[0, +60, -60]_s$) or type of fabric (e.g. 5HS), and fabrication process (e.g. resin transfer molded (RTM) or vacuum bag cured). For other materials sufficient detail should be given to identify the specific material (e.g. Kapton E versus Kapton HN polyimide film). If the data sought is unavailable for the material to be used, and data for a very similar material is being used as an approximation (e.g. M55J/954-3 versus M55J/954-6), then both the material being modeled and the material from which the property data inputs were obtained need to be clearly identified.
    - *Property description* – be sure to provide specifics about the material property direction for which the property data apply, if appropriate. In some situations, properties vary in different directions relative to a fabrication operation.
    - *Property data* – provide the value(s) from the data source and the value(s) used in the analysis, which may be different due to conservatism, extrapolation, or estimation based on a material similar to that being modeled. Data values used in the analysis should be presented in a format amenable to data entry in the model.
    - *Thermal expansion/CTE data* – thermal expansion data shall be adjusted to have a common zero-thermal-strain temperature, or reference temperature, of $T_{ref} = 293.0$ K. Tangent (Instantaneous) CTE data shall identify the temperature at which it applies. Thermal expansion and other temperature dependent material data shall be documented in the MDP as a single polynomial fit to the data, scaled and centered on T_{ref}. A scaling parameter of 200K is suggested.
    - Critical material data – material data that has significant influence on the ability to model the performance of the observatory or design the observatory with respect to mission requirements shall be given special emphasis. The *source data shall be presented* for referral. Presentation may be in the form of a spreadsheet table and graph for electronically collected test data. For hardcopy tables or graphs, a high resolution scanned image of the source data shall be provided (preferably compressed format), along with an electronic spreadsheet that captures the data used. Spreadsheet inputs may be generated by manual entry or high resolution digitization of the source graph. The *property values used in the model* shall be given along with a description of the *basis by which the values were derived* from the available set of data (mean value, least-squares

curve fit, B-basis allowable, etc.). For critical property data, *assess and estimate the uncertainty in the data*. Factors to be considered are accuracy of test equipment and test method, sample population size (representativeness) and data distribution (variability); extrapolation based on available data, and approximation based on similarity to another material from which the data was obtained. The estimate of uncertainty may be given as a percentage variance or as upper and lower bounds on the property value used.

- *Units* – property values shall be given in the SI (metric) system.
- *Sources* – identify the data source(s) for each material property entry. Most simply this may be done as a numeric footnote keyed to a list of references.
- *Proprietary data* – identify any specific property data considered proprietary.

References: listing of sources for material property data collected, in standard format for bibliographic citations. For unpublished sources such as memos and test reports, include the author, company or organization, title, document number if any, and date. For vendor data include manufacturer's name, product name, title or type of literature, and date. For electronic database include database name, database custodian or publisher, database version or date.

4.0 Optical Model Guidelines

The guidelines for the optical modeling provide the guidance that will result in the optical models and the accompanying documentation that is needed for predicting the optical performance of the JDEM optical systems and providing the modeling interface information that allows integration with the thermal, structural/dynamic, and control modeling. These guidelines apply to subsystem optical models, and science instruments, as well.

4.1 Format

The JDEM optical ray trace model will be communicated in OSLO LEN file format. Resulting wavefront error models will be output in Knoll Zernikes, with the numbering convention established in Born and Wolf. For communication with non-ray trace codes, the output may be output in three formats. The native format will be MATLAB *.mat files which may be converted to fits files or ascii files. These are the same formats that will be used for outputs from the IPAM code.

4.2 Coordinate Systems

The payload uses a right-handed coordinate system fixed in the payload body. The origin of the payload coordinate system lies at the virtual vertex of the telescope primary mirror. The Z-axis is collinear with the geometrical centerline of the observatory. The +Z direction points into the telescope baffle. The X-axis is collinear with the sun/anti-sun line. The +X axis is the sun side. The +Y-axis is the cross-product of the +Z-axis and the +X-axis.

4.3 Surface numbering

Numerical labeling of surfaces will be systematic and have supporting notes for individual surfaces (e.g. "Secondary Mirror", "Field Stop", etc.) to prevent any confusion, especially when non-optical surfaces are introduced into the optical models that correspond to surfaces in other models.

4.4 Optical Material Properties

Optical material properties are to be consistent with the JDEM Material Property Database. Properties for materials not found in the database are to be provided to the JDEM project for inclusion in the database. The anticipated properties of interest will be mass density, modulus, thermal coefficients of expansion (including integrated strain from room temperature to cryogenic temperatures), thermal properties including heat capacitance and thermal conductivity, electrical conductivity, spectral reflectance for mirror coatings, and for transmissive elements, spectral transmission, spectral absorptance, index of refraction including the differential change with temperature, stress optic coefficients and any changes in index of refraction, mass density, and color transmission with exposure to radiation. Proposed materials that have no data over the expected temperatures will be designated as such and subjected to characterization testing. The property database will be continually updated with testing results. Model data input files and documentation will reference the material database version utilized.

4.5 Model Verification Checks

Suites of analyses will be developed to verify the optical models' results. These verification analyses are to be performed for each new revision of the optics models (static and controllable). For analyses (a)-(d) and (g)-(h), the OSLO macro used to generate the analysis will be provided.

These model verification analyses will include:

a) Mirror position in global coordinates
b) Effective focal length vs. FOV
c) RMSWFE vs. FOV
d) Exit pupil maps (wavefront maps) at field points representing the center and corners of each instrument's parent FOV per the latest allocation
e) Exit pupil size, location and orientation vs. FOV
f) Differential distortion analysis vs. FOV for guide star locations at the center and corners of the FGS Guider allocated FOV
g) Focal surface centroid locations at field points representing the center and corners of each instrument's parent FOV per the latest allocation, in local and global coordinates
h) Uncompensated RMSWFE sensitivity analysis for 6 degree of freedom motions of each mirror
i) Pupil position sensitivity analysis for 6 degree of freedom motions of each mirror (monolithic primary) with no compensation
j) PSF anisotropy versus FOV sensitivity analysis for 6 degree of freedom motions of each mirror
k) Spectral resolving power

4.6 Optical Model Documentation

Descriptive documentation of optical models and modeling processes will be provided in an Engineering Memorandum type format for each subassembly and system model. Assumptions and methods for computations of Zernike decomposition of optical errors must be documented and provided with simulation results. In most cases, comments will also be included in the model input and output data files. If model updates are submitted, they will also be accompanied by similar documentation. If only a single model component is updated (rather than the whole subassembly model), then only the component model file need be transmitted, along with its documentation, including a description of the changes and impact on the system model.

4.6.1 Format and Media

The optics model documentation files will be delivered in Microsoft Word compatible format. The models will be delivered in the appropriate format for the analysis tool used.

4.6.2 Description

The model documentation will summarize the optical system, annotate the characteristics of each surface in the models (e.g. curvature, aspheric parameters, aperture size, etc.), and provide an explanation for surfaces that have no optical relevance, such as reference surfaces tied to structural models. All relevant surfaces that obstruct the system throughput will be described. Enough information and precision will be provided in the supporting documentation to allow for complete manual conversion of the OSLO model to other formats (e.g. MACOS). Other applicable system parameters, including focal length, field-of-view, and entrance and exit pupil locations (including paraxial locations), will be documented. Any other structures used for controlling stray light (e.g. baffles) will also be described in the documentation. The documentation will include any other environmental parameters (e.g. thermal, gravity) affecting the optical performance of the system. Where parameters are based on measurements or design data bases that include tolerancing, the tolerance values will also be provided.

4.6.3 Plots of Nominal Analysis Results

Model diagnostics, including spot diagrams, point spread functions (PSF), and pupil maps will be provided to check each of the optical models (static and controllable) at the various field locations. Plots of model diagnostics results for items (b), (c), (e) and (f) of Section 4.5 will be provided.

4.6.4 Plots of Thermal Distortion Analyses Results

The optical analysis results for thermal distortion cases, including optical performance results (wave front error, etc.) for the thermal steady state and transient (observatory slew) cases will be provided.

4.6.5 Model Version

A revision history of the model will be maintained, and include reasons for any significant model updates, describe the impact of these model updates on component and system response, and include background data, or references, for updates from previous versions, based on correlation with test results. The documentation will identify the version of the analysis program used with the model, as well as any known problems or results sensitivity with respect to using other program versions. The documentation will also identify any known compatibilities or differences with respect to other models: such as optics model using a geometry based on a particular design model, etc., and note when coordinate system offsets would be needed when using point locations from different models.

4.7 Optical Model Files To Be Delivered

4.7.1 Static Models

The static optical models will be provided as a OSLO sequence file or text files that have the equivalent prescription information. The OTA and instrument optical models will be maintained as individual models. The model files will include obstructions in system and accurate aperture information for each optical component, as well as baffles and any other components or characteristics affecting throughput. These models will be updated as necessary to reflect the "as built" condition for the respective telescope and instruments.

4.7.2 Controllable Models

Active optical control models will be in a MATLAB or MATLAB/Simulink format. The models will be capable of providing simulated images for the effects of both individual and coordinated actuator control for the active degrees of freedom for optical control of the OTA. The model will also be able to model the optical modes of the instrument used for Wavefront Sensor and the Fine Guidance Sensor.

5.0 Mechanical Design Model Guidelines

Due to precision issues in CAD models and requirements for optical alignment, it is anticipated that most if not all design models will be specified in milli-meters, not meters.

5.1 Design Drawings

Drawings will be in PDF (Portable Document Format) electronic format. This includes, at a minimum, piece part, assembly, interface control, installation, source control and ground support equipment drawings. Together, the drawing package constitutes a complete description of the Observatory. A criterion for a good drawing is that it is stand-alone. Hence required documentation is minimal. Piece part drawings will identify the parts and materials employed. These materials will be included in the Project Approved Materials/Parts List (PAM/PL). The PAM/PL is maintained by the Materials and Processes Department of the contributing organization. The Material Property Database will strive to be traceable to the PAM/PL. Multiple sheet drawings will be zipped together into one file.

5.2 Solid Models

A solid model is required for each program element, as well as for the Observatory. Models in both the stowed and deployed configurations are required, as applicable. For each solid model two files will be created. One file will be the native software file format. If the native software produces multiple files (such as Pro-E), then these files will be collected into one Zipped file. The second will be a STEP AP214 file format. There will be three files per solid configuration (native, STEP & documentation). All three files will be placed together and named after that solid configuration.

6.0 Structural Model Guidelines

6.1 Format

Models shall be MSC/NASTRAN Version 2005 compatible.

6.1.1 Coordinate Systems

Each model shall have its own local, basic coordinate system referenced to the Observatory coordinate system (CORD2R 0), All grids shall explicitly include both a location system and an output (displacement) system. It is acceptable to use the Observatory coordinate system (CORD2R 0) for this purpose.

6.1.2 Element Selection & Criteria

6.1.2.1 Rigid Elements and Multi-Point Constraints

Rigid elements have some behaviors which may result in inaccurate results. These behaviors are:

1. They do not model thermal strain (ability to apply CTE to RBE elements may resolve this but must be verified through model validity checks)
2. They can introduce spurious thermally-induced loads and displacements when attached redundantly with other structure; and
3. They do not model the strain energy due to geometric stiffness, and hence introduce grounding into pre-loaded structure.

Rigid elements (RBAR, RBE1, RBE2) and MPCs shall not be used to provide displacement connectivity between non-coincident grids in most cases. This shall apply unless connecting rigid element is of very short length and shown to have insignificant effect on thermal distortion results by passing the model checks in this document:

Portions of the Observatory are exempt (they may use rigid elements); typically appendages such as solar arrays and radiators. RBE3's can be used to spread load and mass for devices such as electronic boxes and tanks or propellant if it is ascertained that they are not replacing structures that would have an effect on dimensional stability. As a guideline, RBE3's are not the preferred method to transmit load between flexible structures.

In places where rigid elements and RBE3's might typically be employed, stiff CBARs may be used. Their stiffness and CTE should provide a reasonable match to the structure being replaced.

MPCs may be used to represent relative motions, optical sensitivities, and other parameters that do not affect load paths. In order for all MPCs to be included, set ID MPC = 1,000,000 must be used in all models delivered for inclusion in the integrated model.

6.1.2.2 Direct Matrix Input

Because of model conditioning considerations, DMIGs should be avoided, but if they are necessary, double-field format shall be used.

6.1.2.3 K6ROT

To prevent high levels of artificial stiffness, and to assure uniformity of results, a value of K6ROT = 1.0 N-m/rad shall be used in all models delivered as bulk data and which will enter into the integrated Observatory models.

6.1.2.4 SNORM

The default value of SNORM = 20 will be employed.

6.1.2.5 Element Geometry Checks

The default NASTRAN element geometry checks shall be performed (see Executive statement GEOMCHECK). While not inherently disqualifying, failure to meet these requirements will likely contribute to degraded analytic performance and possible failure of other modeling checks. Large numbers of exceedances or gross exceedances will warrant an explanation.

6.1.2.6 Use of PCOMP (Verify)

Since PCOMP does not accept temperature dependent material properties, models shall employ PSHELLs for plate element properties and CTE values shall be provided for the laminate. PCOMPs shall not be present in any thermal distortion model unless isolated from the optical support structure by means of flexures.

6.1.3 Section Properties

Nominal sizes and thicknesses will be used.

6.1.4 Treatment of Damping

A nominal minimal level of structural damping shall be assumed for each program element subdivision of the model. The preferred method of inclusion is the structural damping coefficient, `GE`, on the material property cards. Components having known levels of heavy damping, such as reaction wheel and payload isolators or snubbers, shall use the `GE` coefficient exclusively. The use of frequency based modal damping look-up tables is discouraged.

The modal strain energy technique shall be used to convert the material damping to modal damping ratios. Either coupled or un-coupled approaches may be used. In situations having high damping and closely spaced natural frequencies, the coupled approach can provide augmentation in the lightly damped regions. This is at the expense of greatly increased run times.

When component models are incorporated wholesale, as in a Craig-Bampton coupling, a loss factor for the component can be applied to the component stiffness matrix, and added onto the system structural damping matrix, `K4`. One approach for doing this is the Case Control DMIG scale factor K42GG.

The source of the damping value should be described in the model documentation. Preferably this value will be derived from material or assembly tests. Frequently, especially at the beginning of the program, the value must be conservatively derived based on experience with similar prior structures and on available material test data, at temperature if possible.

6.2 Numbering Scheme and Mesh Density

6.2.1 Observatory Numbering Scheme

Unique identification (ID) numbers shall be used within all grids, within all elastic and rigid elements, within all properties, within all materials, and within coordinate systems.

The overall numbering scheme is provided in Table 6-1.

	ID Range		DoF
	lower	upper	
Observatory			
MPC	100	100	
Spacecraft			
General	100,001	899,999	
Reaction Wheels	900,001	900,006	
OTA/OBA Interfaces	900,101	900,106	
Launc Vehicle Interface	999,999	999,999	
OTA/OBA			
Optical Telescope Assembly	1,000,001	1,199,999	
Outer Baffle assembly	1,200,001	1,299,999	
Payload Interfaces	1,900,001	1,900,999	
Payload			
Instruments	1,000,001	1,199,999	

Table 6-1 Structural Model Numbering Scheme

Major subcomponents shall have numbering ranges, as shown for the OTA/OBA above. This feature facilitates sub-model breakout.

6.2.2 Model Size and Discretization

Going forward the emphasis on the integrated model will be accuracy in thermal distortion and high frequency jitter, at the expense of model size and computation time. Limitations on the degrees of freedom (dof) in each program element have been allocated upon that basis. Allocations to subsystems within program elements have also been made as a guide to development of the element models. These dof allocations are provided in Table 6-1.

Program elements shall deliver models within these limits while providing sufficient model resolution to capture the fidelity required for integrated model purposes. Exceptions may be negotiated only after demonstration that this criterion cannot be met.

6.2.3 Model Symmetry

All models shall be “full” models with no symmetry assumptions made to reduce model size.

6.3 Margins and Uncertainty Factors

6.3.1 Mass

TBD

6.3.2 Dynamic Model and Verification Requirements

6.3.2.1 Exemption from Flexible Body Model

Components or subsystems such as electronics boxes may be modeled as rigid bodies, lumped at their c.g., if it can be shown that:

A. their first mode is above 120 Hz;
B. their gravity-induced deformations are not optically significant; and
C. they are not likely to cause interaction of the optical train through jitter amplification (e.g. wheel or wheel isolator modes below 300 Hz may be significant).

6.3.3 Frequency Margin

Where models are required to meet certain minimum frequencies, the model shall do so with margin of 15%.

6.4 Opto-Mechanical Modeling of the Integrated Model

This section deals with opto-mechanical models intended for eventual integration into the Observatory structural model.

6.4.1 Rigid Optics Models

In the case where optical elements are sufficiently stiff that flexible models are not required, the structural model shall include a grid located on the optical surface at its geometric center, connected to the mirror degrees of freedom (typically at the element c.g.). This applies to all models in the optical train. The connection shall simulate the CTE properties of the optical element.

6.4.2 Flexible Optics Models

Optical elements with flexibility shall be modeled with grid points on the optical surface, and member offsets to the neutral surface.

6.5 Model Checks

All models delivered for integration into the Observatory model, as well as the Observatory model itself, will be subject to verification by the following model self-checks. In certain areas there are known modeling difficulties that may make these more a goal than a requirement.

6.5.1 Stiffness Matrix Conditioning

Ill-conditioning of the model stiffness matrix can lead to inaccurate results. The following are the minimum requirements to check for such ill-conditioning.

6.5.1.1 Grounding

A separation ratio check with the DMAP supplied in the Appendix B and the NASTRAN GROUNDCHECK case control shall be performed, and the diagnostics shall be reported. Grounding forces should be less than 1.0 N, and moments less than 0.5 N-m. Separation ratios should be less than 1.0E-8.

Grounding forces shall be determined by applying unit rigid body displacements and rotations to a stiffness matrix of the unsupported model, and determining the resultant grid point forces. Full capability of NASTRAN GROUNDCHECK case control can be used to determine grounding forces and moments.

Separation ratios are the ratio of grounding force or moment in each dof to the corresponding diagonal element of the stiffness matrix.

6.5.1.2 Maximum Diagonal Ratio

The maximum ratio of any diagonal term to its corresponding term of the triangular factor matrix should be less than 5.0E7. The evaluation should be performed in a static decomposition with restraints applied to remove rigid body modes. A negative value of NASTRAN Param, Bailout, forcing program execution with near singularities shall not be used.

6.5.1.3 NASTRAN Epsilon

In NASTRAN static analysis (for instance unit gravity and thermal load checks), epsilon is a measure of the error in the load predicted from the product of stiffness matrix and solution set displacement compared to the actual input load vector $\varepsilon = \frac{u^T \{P - Ku\}}{u^T \{P\}}$. Epsilon should be less than 1.0E-8.

6.5.1.4 Unit Gravity Constraint Loads

With the model constrained at appropriate interfaces, and 1-G inertial loadings applied separately in three orthogonal directions, the sum of constrained forces in the loading direction should be within 0.01% of the model weight. The magnitude of the sums orthogonal to the loading direction should be less than 1.0 N.

6.5.2 Free-Free Modal Checks

In the unconstrained condition, the deployed on-orbit model should have six rigid body modes with frequencies below 0.005 Hz, with a goal of 0.0005 Hz, and the ratio of the lowest elastic mode frequency and the highest rigid body mode frequency should be greater than 10, with a goal of 100. In their unconstrained condition, the stowed dynamics and thermal distortion models should have six rigid body modes with frequencies below 0.01 Hz, with a goal of 0.001 Hz.

6.5.2.1 Mass and Inertia Check

Mass and Mass moment of inertia shall be accurately represented by rigid body modes within 5%.

6.5.3 Mass Properties

The NASTRAN Grid Point Weight Generator shall be used to determine the model mass, center of gravity (CG) location, and the mass moment of inertias (MMI). Mass should be within 1% of the total allocated mass.

6.5.4 Material Coordinate Systems

Non-isotropic material coordinate systems shall be defined such that accurate material properties are represented. Documentation of non-isotropic material coordinate systems defined shall be provided and shall include verification of its accuracy.

6.5.5 Temperature Loading Checks

For distortion critical structures, two checks should be made: a zero change in temperature ($T=T_{ref}$) and a small perturbation in temperature about the operating temperature range.

6.5.5.1 $T = T_{ref}$

After the model has been constrained appropriately at its interfaces, the material reference temperature of T_{ref} =293K shall be applied as a loading to the whole model. The resulting internal loads and displacements should be very small: forces and moments less than 0.01 N and 0.01 N-m, and displacements less than 1E-12 m. Among other things, this is a check that reference temperatures are applied consistently.

6.5.5.2 Temperature Perturbation about $T_{nominal}$ ($\Delta T = 0.2$)

The free expansion of the thermal distortion model under thermal loading should be verified by means of a uniform small temperature increase, ΔT=0.2K, from a uniform nominal operating condition, T_{nom}. This check is performed on a modified version of the model where thermal expansion properties of all materials are identical.

The material CTE properties can be implemented in the form of a secant CTE TABLEM4, $\alpha_{sec}(T)$. An alternative approach can be to assign an identical constant CTE value on each material card.

The nominal operating temperature shall be T_{nom} = TBD K. The constant CTE or curve should produce a secant value at $T_{nominal}$ consistent with the major material constituent in the model. As a whole a secant value of 0.5 ppm/K at T_{nom} is suggested, producing a cool down strain of approximately 125 micro-strain.

The model shall be constrained kinematically to allow stress-free expansion. The preferred method is grounding of a single point on the optical axis in all six degrees-of-freedom. All other grids should expand spherically outward from the constrained node. Two load cases are run:

Case	**Bulk Data**	**Case Control**
1	TEMPD = T_{nom}	TEMP(BOTH) = 1
2	TEMPD = $T_{nom} + \Delta T$	TEMP(BOTH) = 2

A selection of optically significant grids on each individual component and the integrated model should be identified. The displacement magnitude, relative to the fixed constrained point, shall be differenced at each grid to obtain, $\Delta\mathbf{D}_{model} = \mathbf{D}_2\text{-}\mathbf{D}_1$. This difference is compared to the theoretical values calculated using the tangent CTE value at the mid-temperature between the two cases as $\mathbf{R} + \Delta\mathbf{D}_{theor} = \mathbf{R} + \alpha_{tan(\,Tnom+\,\Delta T/2)}\,\Delta T\,\mathbf{R}$**,** where **R** is the radius vector to the grid from the constrained static point. (*Note that when CTE is a constant, the secant and tangent values are equal,* $\alpha_{tan(\,Tnom+\,\Delta T/2)} = \alpha_{sec}$.)

An alternative approach to multiple, repetitive differencing calculations is to use virtual strain gauge elements in the analysis model. CROD elements can be created between the fixed constraint point and the individual significant optical points of the model. Selecting suitable element and material properties will allow for direct results output of extensional strains which be used to calculate displacements at the optical points of interest.

The worst-case difference in magnitude between the model and analytic prediction at any optically significant point should be less than 1e-9 meters. This check will exercise most thermal distortion aspects of the model, including numerical precision effects engendered by differencing moderate cool-down distortions.

Analysis models and control decks as well as sample calculations should be submitted as part of the thermal distortion validation check.

6.6 Documentation

6.6.1 Model Description

The following is a list of items that should be included in the description documentation delivered with each element or observatory model:

1. Model version, purpose, size
2. Coordinate descriptions
3. Interface grids and boundary conditions
4. Pictures of model
5. Critical assumptions (joints, damping, etc.)
6. Material usage and references to the Material Property Database
7. Numbering system
8. NASTRAN Grid Point Weight Generator Output
9. Summary of model check-outs, including comparisons to existing detailed models
10. Summary of loading conditions
11. Analysis code version
12. Link to pertinent reported mass properties
13. Summary of properties for each element property ID.
14. Summary of reference points introduced for Integrated Modeling, e.g. LOS MPCs, mirror & instrument reference points.

6.6.2 Model Files to be Delivered

This section describes the structural model files and analysis results files that will be delivered.

1. NASTRAN input decks (including DMAP) for all model check and benchmark analyses.
2. NASTRAN output files for all model check and benchmark analyses

6.6.3 Bench Mark Modal Analyses

Documentation of modal analyses shall include modal frequencies, effective masses and descriptions and/or plots of significant modes. Boundary conditions appropriate to the model and its role in the overall Observatory model will be employed.

Separation Ratio Check DMAP for NASTRAN 2005

```
COMPILE SUBDMAP=SEKR,SOUIN=MSCSOU
ALTER 1,1   $
SUBDMAP SEKR  KGG,USET,EQEXINS,SILS,GPLS,KNN,
BGPDTS,SCSTM,CSTMS,CASES,MEDGE,VGQ/
KSF,KFS,KSS,KTT,KFF,LOO,GOT,LAO,ORSEQ/
ERROR/FIXEDB/ALTRED/STATICS $
ALTER 2,2 $
TYPE DB KAA1,KTT1,KOA,KOT,LTO $
$$
COMPILE SUBDMAP=SEKMR,SOUIN=MSCSOU
$ALTER 11   $
ALTER 26,26   $
IF ( NOKTT=-1) CALL SEKR  KGG     ,USET     ,EQEXINS ,SILS     ,GPLS     ,
KNN      ,BGPDTS  ,SCSTM   ,CSTMS   ,CASES   ,
MEDGE   ,VGQ     /
KSF     ,KFS     ,KSS     ,KTT,KFF ,LOO     ,
GOT     ,LAO     ,ORSEQ   /
ERROR   /FIXEDB  /ALTRED  /STATICS $
VECPLOT, ,BGPDTS,EQEXINS,CSTMS,,,,/RBGT,,///4 $ V70.7
TRNSP    RBGT/RBG $
VEC      USET/VRBA/'G'/'COMP'/'A' $
PARTN    RBG,,VRBA/,RBA,,/1 $
$  SEPARATION RATIO  CHECK $
$  G-set
MPYAD       KGG,RBG,/FGRNDG  $
DIAGONAL    KGG/KGGD/'SQUARE'/1.0   $
MATMOD      KGGD,,,,,/KGGNULL,/12/S,N,NPG/1   $
```

```
IF (NPG>0) THEN  $
MESSAGE   //'!!!!!!!    KGG has zeros on diagonal @    !!!!!!!!'/   $
MATGPR     GPLS,USET,SILS,KGGNULL//'G'/'G'//   $
PARAML     KGG//'TRAILER'/1/S,N,GSIZE   $
MATGEN,     /VECTG/1/GSIZE/    $
ADD        VECTG,KGGD/KGGDINV///2     $
ELSE    $
DIAGONAL    KGG/KGGDINV/'SQUARE'/-1.0    $
ENDIF   $
MPYAD      KGGDINV,FGRNDG,/SEPRATIG  $
MESSAGE   //'!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!'/   $
MESSAGE   //'!!!!!!!    SEPARATION RATIO CHECK, G-SET  !!!!!!!!'/   $
MESSAGE   //'!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!'/   $
MATGPR     GPLS,USET,SILS,SEPRATIG//'H'/'G'//V,Y,SRTING=1.E-8  $
MESSAGE   //'!!!!!!! Overall Grounding CHECK (MSFC) G-SET  !!!!!!!'   $
MPYAD      RBGT,FGRNDG,/MSFCG   $
MATGPR     GPLS,USET,SILS,MSFCG//'H'/'H'//V,Y,STING=1.E-8  $
$  N-SET
VEC        USET/NLINK/'G'/'COMP'/'N'   $
PARTN      RBG,,NLINK/,RBN,,/0  $
MPYAD      KNN,RBN,/FGRNDN  $
DIAGONAL    KNN/KNND/'SQUARE'/1.0   $
MATMOD     KNND,,,,,/KNNNULL,/12/S,N,NPN/1   $
IF (NPN>0) THEN  $
MESSAGE   //'!!!!!!!    KNN has zeros on diagonal @    !!!!!!!!'/   $
MATGPR     GPLS,USET,SILS,KNNNULL//'N'/'N'//   $
PARAML     KNN//'TRAILER'/1/S,N,NSIZE   $
MATGEN,     /VECTN/1/NSIZE/    $
ADD        VECTN,KNND/KNNDINV///2     $
```

```
ELSE    $
DIAGONAL    KNN/KNNDINV/'SQUARE'/-1.0    $
ENDIF   $
MPYAD       KNNDINV,FGRNDN,/SEPRATIN  $
MESSAGE   //'!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!'/   $
MESSAGE   //'!!!!!!!    SEPARATION RATIO CHECK, N-SET  !!!!!!!!'/   $
MESSAGE   //'!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!'/   $
MATGPR      GPLS,USET,SILS,SEPRATIN//'H'/'N'//V,Y,SRTINN=1.E-8  $
MESSAGE   //'!!!!!!! Overall Grounding CHECK (MSFC) N-SET  !!!!!!!!'   $
TRNSP       RBN/RBNT   $
MPYAD       RBNT,FGRNDN,/MSFCN   $
MATGPR      GPLS,USET,SILS,MSFCN//'H'/'H'//V,Y,STINN=1.E-8  $
$  F-set
VEC         USET/FLINK/'G'/'COMP'/'F'   $
PARTN       RBG,,FLINK/,RBF,,/0  $
MPYAD       KFF,RBF,/FGRNDF  $
DIAGONAL    KFF/KFFD/'SQUARE'/1.0   $
MATMOD      KFFD,,,,,/KFFNULL,/12/S,N,NPF/1   $
IF (NPF>0) THEN  $
MESSAGE   //'!!!!!!!    KFF has zeros on diagonal @    !!!!!!!!'/   $
MATGPR      GPLS,USET,SILS,KFFNULL//'F'/'F'//   $
PARAML      KFF//'TRAILER'/1/S,N,FSIZE   $
MATGEN,     /VECTF/1/FSIZE/    $
ADD         VECTF,KFFD/KFFDINV///2     $
ELSE    $
DIAGONAL    KFF/KFFDINV/'SQUARE'/-1.0    $
ENDIF   $
MPYAD       KFFDINV,FGRNDF,/SEPRATIF  $
MESSAGE   //'!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!'/   $
```

.

```
MESSAGE   //'!!!!!!!    SEPARATION RATIO CHECK, F-SET  !!!!!!!!'/   $
MESSAGE   //'!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!'/   $
MATGPR      GPLS,USET,SILS,SEPRATIF//'H'/'F'//V,Y,SRTINF=1.E-8  $
MESSAGE   //'!!!!!!! Overall Grounding CHECK (MSFC) F-SET  !!!!!!!'   $
TRNSP       RBF/RBFT   $
MPYAD       RBFT,FGRNDF,/MSFCF   $
MATGPR      GPLS,USET,SILS,MSFCF//'H'/'H'//V,Y,STINF=1.E-8  $
$ EXIT  $
```

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7.0 Thermal Model Guidelines

7.1 Format

All thermal geometry models (TGM) that will be integrated into an observatory thermal geometric model shall be constructed using Thermal Desktop (TD), version 5.2 or newer. All thermal math models (TMM) that will be integrated into an observatory thermal math model shall be constructed using SINDA/FLUINT, version 5.2 or newer. Note the thermal math models may be constructed within TD. Models not in TD and SINDA/FLUINT native formats shall be translated and functionally verified by the model provider prior to delivery for integration. Sample output for TMM models shall be delivered as proof of model functionality.

7.1.1 Units of Measure

Thermal models shall be constructed using SI units, as follows:

Power dissipation – Watts [W]
Length – meters [m]
Temperature – Kelvin [K]
Mass – kilograms [kg]
Thermal capacitance – Joules/Kelvin [J/K]
Linear thermal conductance – Watts/Kelvin [W/K]
Radiation thermal conductance – Watts/Kelvin^4 [W/K^4]
Time [s]

7.1.2 Coordinate Systems

Thermal model geometry should be defined in the modeling-system defined in Section 2.2. TD models should be defined with appropriately named submodels.

7.1.3 Section Definitions

When practical, user created conductors should be defined in an expanded format such that each portion of the product is easy to identify.

7.1.4 Mass Conventions

All TMM's should include realistic masses. The thermophysical property database (tdp file) shall be delivered with the thermal models.

7.1.5 Thermal Dissipation Conventions

Observatory component heat dissipations by mode are published in the JDEM Thermal Dissipation Document, which will be updated periodically. Another source for heat dissipation data are the power estimates published in the JDEM Observatory Power Database, which is updated monthly. This database refers to the modes defined in the JDEM Observatory Mode Power Estimates document.

7.1.6 Symmetry and Boundary Conditions

Models may not be artificially reduced using the assumption of symmetry or by assuming adiabatic boundary conditions. The only allowable boundary (fixed-temperature) nodes in SINDA/FLUINT models are defined in the thermal parameters document.

Models shall be delivered with comment lines clearly stating all boundary nodes included in the model. The boundary nodes included for the convenience of running a component or element model independently of an integrated observatory model should be clearly labeled.

7.1.7 Model Size

Models should be as small as is reasonably possible, but sufficiently detailed to demonstrate that the thermal requirements of the modeled network are met for all modes of operation. The number of surfaces in a TGM is dependent on geometric complexity, but the total number of nodes in a TMM is largely left to analytical judgment.

Models used to determine structural deformation and performance of the OTA do not require a high-fidelity representation of the spacecraft bus structure, payload, or solar array. Similarly, models used for detailed design of the instrument radiator do not require high-fidelity representations of the spacecraft bus structure, payload, or solar array. However, the spacecraft bus, payload, and solar array models provided will be of sufficient fidelity to adequately predict the OTA and instrument radiator temperatures. For this reason, the simple models of the spacecraft bus structure, payload, and solar array are detailed in the thermal parameters document.

The reduced thermal OTA and instrument radiator models shall follow the model size guidelines shown below.

Maximum Number of Nodes	
Reduced OTA	Reduced Instrument Radiator
5,000	1,000

Table 7-1. Size Guidelines for reduced OTA and radiator Thermal Models

Notes for Table 1:

1. The TD thermophysical file (*.tdp), optics file (*.rco), and all symbol files (*.sym), used in the thermal modeling shall be delivered with the models.
2. The orbit parameters shall be embedded in the TD file (.dwg).
3. "Internal" radiation conductors are allocated for cavity geometry. "External" radiation conductors are allocated for geometry which views space.

7.1.8 Order of Declaration

Node replicator cards (GEN, SIM, etc.) with increments other than one are prohibited. Conductor replicator cards with zero as the conductor number increment are prohibited. In addition, conductor replicator card increments that overlap other conductor numbers are prohibited. The intent of this rigor is to facilitate model debugging.

7.2 Thermal Distortion Analysis

Thermal models shall be constructed in a way that facilitates thermal distortion analysis. Specific provisions must be made during model construction for mapping predicted temperature distributions to structural FEM models.

7.2.1 Geometry Source Data when Thermal Math Models are Not Provided

Some component providers are supplying structural models but not thermal models. In those instances the source geometry for the thermal model generated shall be the 1D-2D FEM version of the structural model, specifically bar and plate elements and associated grids, defined in Nastran bulk data format. These source structural models shall comply with the conformity requirement defined in Section 7.2.2. Once sufficiently quantified by detailed analysis, truss structure joint resistance data shall also be supplied.

7.2.2 Geometric Conformity

To ensure accurate mapping, the thermal and structural geometry must be conformal. If distortion-critical structure is to be represented in a TGM, or if a “conduction-only” dummy TGM is built, it must overlay the structural model well. In the case of truss structures the 1D portions of the structural source model should exist within the tube dimensions of the 3D structural model, as close to the center-line as practicable.

If distortion-critical structure is represented in a TMM only, then a correspondence between thermal nodes and structural nodes must be provided. This correspondence shall include the thermal node number, the associated structural node (not element) number, the structural node coordinates, and the structural node coordinate system.

7.2.3 Thermal Prediction Uncertainties

Predicted temperatures of distortion-critical JDEM hardware shall incorporate estimates of the likely uncertainties in prediction of static temperatures resulting at a particular observatory attitude, as well as the uncertainty in the thermal stability ΔT that results when the observatory attitude changes. The static temperature distribution will be used by structural engineers to determine the appropriate local values of material CTE and modulus of elasticity. ‘Hot-biased’ and ‘cold-biased’ static temperature distributions shall be generated for each attitude. These temperature distributions encompass the variation about the nominal temperature distribution that can arise due to variability in material properties and insulation schemes; i.e., they account for the ‘known unknowns’.

Uncertainties in thermal design properties will also result in a ‘worst-case’ thermal stability ΔT distribution. Thermal stability shall also be calculated resulting from a thermally worst-case change in observatory attitude.

It is important to note that the uncertainty ranges applied to static temperature distributions and the thermal stability ΔT distribution account only for uncertainties in the prediction of temperature. They do not account for un-modeled features of thermal performance, nor are they related to structural modeling uncertainties.

7.3 Analytical Assumptions

7.3.1 Material Properties

Material properties (thermal conductivity and specific heat) are to be consistent with the material property database described in section 3 of this document. Properties for materials not found in the database are to be provided in the format required by the Material Review Board. Estimates of material properties referenced in models shall be noted with appropriate caveats.

Thermo-optical properties for coatings and materials such as solar absorptance (α_S), normal emittance (ε_n), hemispherical emittance (ε_h), specularity (ρ_s), and transmittance (τ) should be defined using standard thermal design practice. The following thermal "modes" of observatory operation, each with its own distinct set of optical properties, will be defined in the Thermal Design Criteria document: BOL-Launch (Hot), BOL-Operational (Cold), and EOL-Operational (Cold).

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Optical properties used in JDEM thermal analyses shall be reviewed and approved by the GSFC Thermal Engineering Branch coatings committee.

7.3.2 Environmental Conditions

Environmental constants (solar flux, earth albedo, Earth IR flux, etc.) shall be consistent with those defined in the Telescope Study Interface Requirements Document.

7.4 Model Checks and Diagnostics

7.4.1 Thermal Math Model Checks

7.4.1.1 Temperature relaxation criteria

DRLXCA and ARLXCA should be sufficiently small.

7.4.1.2 Energy balance criteria

EBALSA and EBALNA should be sufficiently small for steady-state runs.

7.4.2 Geometry Math Model Checks

Correspondence between thermo-optical properties in .TD *.dwg and optics files should be complete.

Coincident surfaces (those occupying the same volume) are prohibited.

Inactive blocking (active = none) surfaces are prohibited.

Internal geometry should not include surfaces with active sides that do not view other surfaces in the cavity. External and internal geometry should never be combined for calculation of radiation conductors. Internal geometry represents a radiation cavity that does not have a view to space or a test environment. External geometry has a view to space or a test environment.

Cavity models must be adequately closed out. ("Leaking" conductors to space should be commented out, not deleted, to provide a record of closeout adequacy.)

View factor sums should be very close to one, generally 0.98 or greater.

No radiation conductors should be discarded from TMM's used to predict OTA temperatures. Experience has shown that elimination of small radiation conductors between cold structure and warm surfaces can result in substantial under-prediction of the cold structure temperature.

7.4.3 Accuracy and Precision

All models shall be carefully scrutinized for numerical convergence. System level and nodal energy balances and temperature relaxation criteria shall be parametrically varied, within reason, to provide an understanding of their affect on temperature predictions and run-to-run consistency. Transient test case analyses shall be run to pseudo-steady state to insure convergence with the steady state results. Convergence accuracies of the model should be documented. Whenever a new TMM is developed, model convergence should be checked using a few steady-state or transient solution routines. Double precision is required for detailed models.

.

7.4.4 Diagnostic Heat Maps

Heat flow maps are a valuable diagnostic for discerning model behavior differences between configurations. Heat flows between nodal groups shall be used to verify that the results of steady-state thermal analyses have converged. For any given nodal group not containing boundary nodes, the sum of the internally generated heat and the net heat inflow must be nearly zero for an adequately converged model.

7.5 Documentation and Delivery

7.5.1 Information Embedded in Thermal Math Model

The following information should be embedded in the comment lines of the TMM:

- Author and contributors
- Model name, purpose, and brief description
- Version number and date created/modified
- Brief revision log describing major changes and updates
- Brief description of model interfaces
- Brief description of boundary nodes
- Instructions on how to integrate the model
- TMM-to-TGM correspondence information

7.5.2 Model Documentation

It is expected that formal model documentation will be rigorously defined program-wide in the near future. These are general guidelines for what such documentation should contain.

7.5.2.1 Summary Description

Describe or reference the configuration being analyzed. Describe the current version of model. Describe changes from previous versions. Provide history and dates of previous versions. Cite the mechanical design model from which the thermal model was derived.

7.5.2.2 Listing of Key Model Statistics

List the number of TMM nodes, linear conductors, radiation conductors. Provide a mass audit for comparison with the observatory mass budget. The intention is not to force the model to match the mass budget line items, but rather to report what the model is simulating.

7.5.2.3 Node Maps

Provide an illustration of nodalization scheme.

7.5.2.4 Material Properties

Describe assumed material properties. List properties and itemize those originating from the JDEM material property database. List properties not in the JDEM database and provide references for them.

7.5.2.5 Thermo-Optical Properties

Describe assumed thermo-optical properties. Provide a sketch describing surface locations.

7.5.2.6 Boundary Conditions

Describe each boundary condition. List environmental parameters used in the analysis.

7.5.2.7 Interface Definition

Describe computation of interface conductances. Describe assumptions made for ill-defined or generic design features.

7.5.2.8 Discussion of Model Sensitivity

Discuss and present results for the studies of performance sensitivity to characteristics such as nodal density, material property variation, geometry, section property variation, etc. In particular provide assessment of overall model accuracy and predictability. Identify which areas of the model required high modeling detail, and which did not.

7.5.2.9 Discussion Accuracy and Precision

Report results for analysis convergence and precision studies.

7.5.2.10 File Listing

List and describe the contents of each electronic data file delivered.

7.5.2.11 Multi-Layer Insulation

Describe assumed performance characteristics of multi-layer insulation, including reasonable ranges of ε*.

7.5.2.12 Power Dissipation

Provide tabular listing of heat dissipations and locations. Reference appropriate documents for dissipation figures.

7.5.2.13 Requirements

List requirements that the model was built to verify. Provide node or mnemonic vs. requirement listings.

7.5.2.14 Heaters or Thermal Control Components

For heaters and other thermal control components, reference specification or list power, nodal locations, and performance parameters.

7.5.3 Model Delivery

Delivered models shall include the TGM, TMM, and any "conduction" geometry used for thermal distortion analysis. If distortion-critical structure was modeled without geometry, then a thermal-to-structure node correspondence as defined in 7.2.2 must be provided.

8.0 Attitude Control System Model Guidelines

8.1 Scope Of Attitude Controls Model

The Attitude Control Subsystem (ACS) model shall be a high-fidelity time-domain software program that simulates the ACS performance during normal science operations. The model shall include the following major components:

1) On-board controls algorithms (including slew performance)
2) Spacecraft rigid and flexible dynamics, including fuel slosh.
3) External disturbance torques (solar)
4) Spacecraft sensor models (IRU, star trackers, and sun sensors)
5) Spacecraft actuator/mechanism models (reaction wheels, thrusters, and HGA drive)
6) Fine pointing system hardware (fine guidance sensor)
7) Disturbance models (reaction wheels, HGA, instrument filter wheel)

Solar disturbance torques and forces are determined based upon the surface model. Disturbance models of the reaction wheels, HGA and instrument filter wheel will be provided, in the form of forces and moments at the appropriate structural model nodal locations.

8.1.1 Modeling Software Languages

The ACS model shall be compatible with MATLAB Simulink. Compiled blocks and look-up tables can be used. Scripts to load parameter sets and run canned cases will operate on the model.

Each major component model shall have a parameter script that sets model parameters, which could change between configuration options. The parameter script file name (filename.m) shall follow the same convention of naming as the model file it is associated with.

8.1.2 Model Naming Convention

The sensor/actuator model's highest-level block diagram shall be a single block named after the component or element being modeled and with all inputs and outputs labeled and documented. The sensor/actuator model file's name (filename.mdl) shall be the name of the component or element being modeled followed by a version number under configuration control, e.g., FGS7 is the 7^{th} revision of the Fine Guidance Sensor.

8.1.3 Coordinate Systems

The JDEM ACS modeling coordinate system shall be consistent with the coordinate system described in Paragraph 2.2 of this document. All component model inputs and outputs shall be in the local coordinate system. It is the responsibility of a higher-level model incorporating lower level models to handle input and output coordinate transformations before passing signals to the lower level model. Each local coordinate system and the transformation to the observatory coordinate system shall be documented.

The local coordinate system shall be rectangular with the same orientation as the structure to which the component or element attaches.

For motions defined in coordinates other than the local coordinate systems, a description and definition of that coordinate system shall be documented.

8.2 Controls Model Documentation

The following information shall be provided in Engineering Memorandum type format for each subassembly and component model. If model updates are submitted, they shall also be accompanied by similar documentation. If only a single model component is updated (rather than the whole subassembly model), then only the component model file need be transmitted, along with its documentation, including a description of the changes and impact on the system model.

8.2.1 Format

The controls model documentation files shall be in Microsoft Word compatible format.

8.2.2 Top-level Model Description

The model architecture and topology shall be provided. Script file and all the parameters required to run the program shall be provided.

8.2.3 Component Model Description

Component models include the models of on-board control algorithms, spacecraft dynamics, sensors, actuators, and environmental disturbances. Each component model description shall provide model functionality and input/out parameter descriptions.

8.2.4 Benchmark Cases and Checks

Test cases will include but are not limited to conservation of momentum checks. Case scenarios and scripts used to run test cases will be provided. Cases will be documented with plots of key parameters.

8.2.4.1 Inertia Tensor Check

Transfer function checks shall be performed to verify that mass and mass moments of inertia of the modal model are accurately represented by its rigid body modes within 5%.

8.2.4.2 Actuator Transfer Function DC Check

Given actuator stiffness, DC gain of actuator transfer function of its relative rotations (or displacement) to actuator moment (or force) shall match static actuator relative rotation (or displacement) within 10%.