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Development and Integration of Control System Models
Final Report

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Summary

The design of a pointing control system requires an iterative procedure that includes mathematical modeling of the multi-body mechanical system, dynamics and control simulation, and performance analysis and evaluation. Since the performance of a pointing control system is determined from the interaction of the control system and the dynamics of the mechanical system, the design of a control system that meets performance requirements depends on how well the dynamics of the mechanical system is understood and can be modeled. Most mechanical systems are comprised of rigid and flexible multibodies dynamic systems that could yield undesirable vibration due to any disturbance and could deteriorate the performances of pointing control systems. Therefore, in order to meet the performance requirements, the control system and mechanical system must interact favorably to suppress these disturbances.

The computer simulation tool, TREETOPS, has been developed and used at MSFC to model these complicated mechanical systems and to perform their dynamics and control analysis with pointing control systems. It has been shown that TREETOPS, in conjunction with various tools of MATLAB, provides an effective approach for the control engineer to model and analyze of pointing control systems through various projects at MSFC. This TREETOPS tool has been used to develop dynamics and control models of the Suppression of Transient Accelerations By Levitation Evaluation (STABLE) and the Active Rack Isolation System (ARIS) projects.

Under this NASA contract, the TREETOPS simulation is being maintained on work-stations of ED11, NASA/MSFC and continuously upgraded to account for increasing sophistication of control system missions. A TREEOPS model of Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) dynamics and control system was developed to evaluate the AXAF-I pointing performance for Normal Pointing Mode (NPM). An optical model of the Shooting Star Experiment (SSE) was also developed using the Modeling and Analysis for Controller Optical Systems (MACOS) software developed by JPL. These mathematical models and performance analyses were completed with cooperation of Mr. Mark West and Mr. William Lightsey of NASA/MSFC. The description of the TREETOPS dynamics and control model of AXAF-I and the numerical results of the AXAF-I NPM pointing accuracy and stability analysis are documented in Section 2. The description of MACOS model of the SSE optical system and its optical performance analysis results are documented in Section3.

2. AXAF-I TREETOPS Dynamics and Control Modeling

2.1 Introduction

Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) is being designed and manufactured by TRW under the program management of NASA Marshall Space Flight Center (MSFC) with the flight scheduled in December 1998. This study was done to assist the pointing control analysis team of NASA/MSFC to evaluate the AXAF-I pointing performance.

The objective of this study is to develop a multi-body dynamics and control model of the AXAF-I for TREETOPS simulation to evaluate the AXAF-I pointing performance for the Normal Pointing Mode (NPM). The unfavorable effects on the AXAF-I pointing performance, due to the static and dynamic unbalance of reaction wheels, and possible interaction between the flexible modes of solar arrays and the dynamics of reaction wheels with isolators are also investigated. The TREETOPS model of AXAF-I dynamic system consists of one rigid body spacecraft, the non-rotating masses and the rotating masses of six reaction wheels with their isolators, and two flexible solar arrays.

The modal data of the flexible solar array was generated off-line using NASTRAN simulation with a NASTRAN data of solar array provided by TRW Space and Electronics Group. This modal data is incorporated with the AXAF-I TREETOPS model using TREEFLX simulation. This section describes the details of TREETOPS model of AXAF-I dynamics and pointing control system for Normal Pointing Mode. This section also presents the results of the NPM pointing control analysis obtained from the TREETOPS simulation. The parameters of the NPM pointing control law and the mass properties of AXAF-I observatory including solar arrays, reaction wheels, and isolators are provided by TRW [1]. The AXAF-I NPM PID control law was coded in FORTRAN with the cooperation of Mr. William Lightsey of NASA/MSFC and combined with the AXAF-I TREETOPS dynamics model. For detailed information on the analytical formulation and modeling aspects of TREETOPS and TREEFLX, the reader is referred to the user's guide [2].

2.2 Description of AXAF-I TREETOPS Simulation

A TREETOPS model of AXAF-I dynamics and control system that includes one rigid body spacecraft, six reaction wheels with isolators, two flexible solar arrays, and Normal Pointing Mode (NPM) control is described in this section.

The AXAF-I spacecraft including the telescope, aspect camera and science instruments is modeled as one rigid body with three rotational degrees of freedom (DOF). Two solar arrays are modeled as flexible bodies using modal data obtained from NASTRAN simulation and fixed to the AXAF-I spacecraft. The AXAF-I has six reaction wheels mounted on the telescope with six isolators to reduce the vibration transferred to the spacecraft. Each reaction wheel isolator (RWI) is modeled as one rigid body connected to the spacecraft using a six DOF hinge with corresponding torsional and linear stiffness. Each reaction wheel (RW) is modeled as two rigid bodies (one non-rotating base rigid body and one rotating rigid body). The non-rotating base body of reaction wheel is assumed to be fixed on the isolator. The rotating bodies of the reaction wheels have one rotational DOF about their spin axes. Therefore, the AXAF-I TREETOPS model consists of total twenty-one bodies with fifty-seven DOFs. The configuration of the AXAF-I TREETOPS model is shown in Figure 2.2-1.

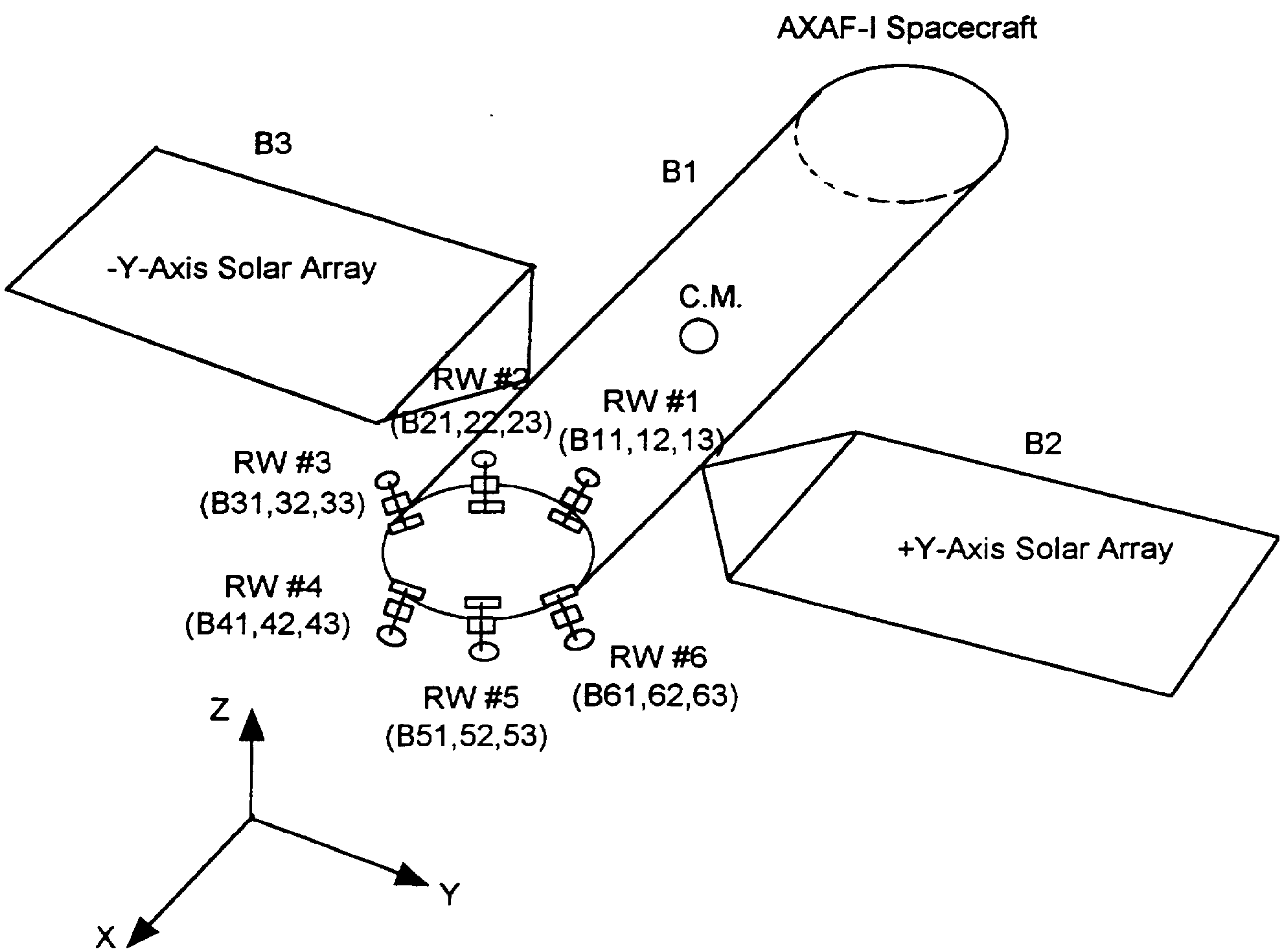


Figure 2.2-1: Configuration of AXAF-I TREETOPS Model

Total mass and moments of inertia of the AXAF-I observatory are available from Reference [1]. Mass properties of the solar arrays were determined from NASTRAN simulation with the NASTRAN model of a solar array provided by TRW. Mass properties of the reaction wheel isolators were also given by TRW. Mass properties of AXAF-I spacecraft were estimated by subtracting mass properties of two solar arrays from total mass properties of the AXAF-I observatory. Mass properties of non-rotating and rotating bodies of the reaction wheels are estimated from the technical data provided by the vendor, TELDIX.

In this study, in order to measure the angular velocity and the attitude angular errors about X, Y, and Z axis of the AXAF-I spacecraft, three ideal TREETOPS Rate Gyro Sensors and one IMU Sensor were used instead of the detailed models and control logic of rate gyros and aspect camera hardware. Also, the detailed control logic of the reaction wheels was not used, but the dynamics of each reaction wheel is determined through TREETOPS simulation with the torques distributed to six reaction wheels by the control torque distribution law. Six reaction wheels are spinning at nominal speeds pointing to the corresponding directions to contribute zero angular momentum to the AXAF-I spacecraft for orbiting equilibrium condition. Each reaction wheel is mounted on its isolator and the direction of the spin axis of reaction wheel is set by connecting the reaction wheel isolator to the AXAF-I spacecraft with the appropriate rotational angle using the TREETOPS Hinge notation.

It should be noted that even though the default printout units are *mks* units in the AXAF-I TREETOPS input file (AXAFI.INT file), Appendix B, the actual units of length, mass, and force used in the AXAF-I TREETOPS model are *ft, slug* and *lbf*, respectively. Since the NASTRAN modal output of solar array has units of *inch, lbf-sec^2/in, lbf* for length, mass, and force, respectively, the conversion factors (0.08333, 12, 1) are used for length, mass, and force units used in the AXAF-I TREETOPS model. All rigid bodies excluding the two solar arrays are defined by specifying mass properties (mass and moments of inertia) and nodal points for the center of mass and body connecting points in the local body coordinate system. The two solar arrays are defined in a flexible body modal data file (AXAFI.FLN file) that is created by importing the mass properties, nodal points, and modal data for selected modes (specified in AXAFI.RET file) from the NASTRAN output using TREEFLX. The AXAFI.FLN and AXAFI.RET are in Appendix C and D, respectively. Although all bodies and connecting hinges are defined in their local body coordinate systems, TREETOPS determines the kinematics and dynamics of the AXAF-I observatory in inertia coordinate system using the proper coordinate transformations.

AXAF-I Pointing Control and Aspect Determination (PCAD) flight software has various control modes, however, this study considers only the Normal Pointing Mode (NPM) control. The NPM pointing control logic was coded in FORTRAN in the User Supplied Discrete Controller (USDC) subroutine. The USDC subroutine is in APPENDIX A.

2.2.1 AXAF-I Structural Model

The AXAX-I observatory was modeled as a twenty-one multi-body dynamics system (one rigid body for the spacecraft, two flexible bodies for two solar arrays, six rigid bodies for six reaction wheel isolators, and twelve rigid bodies for six reaction wheels) and all bodies are connected with the same number of hinges according to the tree topology of TREETOPS simulation.

2.2.1.1 AXAF-I Body Models

The AXAF-I TREETOPS rigid body models are defined by providing the input data for the mass properties (total mass and moments of inertia) and the nodal points that correspond to the center of mass, the origin of local body coordinate systems, and hinge connecting points). Two AXAF-I solar arrays are modeled for TREETOPS simulation by converting the NASTRAN modal output to the appropriate format using TREEFLX.

The AXAF-I spacecraft is defined by Body #1 according to the TREETOPS tree topology and assumed to be linked by Hinge #1 with three rotational DOFs to the origin of the inertial coordinate system. For Body #1, twelve nodal points are defined to represent the center of mass (C.M.), the origin of local body coordinate system, two connecting points to two solar arrays, and six connecting points to six reaction wheel isolators. The mass properties of Body #1 were estimated by subtracting mass properties of two solar arrays from total mass properties of AXAF-I observatory.

The positive y-axis flexible solar array of AXAF-I is defined as Body #2 and the negative y-axis flexible solar array is defined as Body #3. A normal modes analysis was done off-line using NASTRAN model of the AXAF-I solar array. The NASTRAN data of the AXAF-I solar array was provided by TRW, Appendix E. The mass properties (mass and moments of inertia) and the output of normal modes analysis of AXAF-I solar array were obtained from NASTRAN and are in Appendix F. In order to define Body #2 and #3 of the AXAF-I TREETOPS model, the NASTRAN output file was assigned to each Body #2 and #3, and then TREEFLX was used to create a AXAFI.FLN file. The AXAFI.FLN file contains the mass properties, selected mode shapes, mode slopes and the coordinates of the selected nodes. For this study ten nodes and first six modes were selected.

The mass properties (Mass, Moment of Inertia about C.M.) and the locations of C.M. of Body #1, #2, #3 used for this study are described in Table 2.2.1.1-1.

Table 2.2.1.1-1: Mass properties and locations of C.M. of AXAF-I Body #1, #2, #3

Body ID	Mass ($Slug$)	$I_{xx}, I_{yy}, I_{zz}, I_{xy}, I_{xz}, I_{yz}$ ($Slug - ft^2$)	Location of C.M. in inertial coordinates (ft)
1	310.57	5903, 35830, 37314, -94, 737,-89	(31.32, -0.02, 0.09)
2	2.57	141, 11.66, 166.24, 0, 0, 0.17	(37.65,19.19,0.05)
3	2.57	141, 11.66, 166.24, 0, 0, 0.17	(37.65,-19.19,0.05)

The nodes of AXAF-I spacecraft (Body #1) are described in Table 2.2.1.1-2 (B1N2 denotes node #2 of Body #1).

Table 2.2.1.1-2: Nodes Definition of TREETOPS AXAF-I Body #1

Node	Description	Location in body coordinates (ft)
B1N1	C.M. of Body #1	(31.32, -0.02, 0.09)
B1N2	Origin of Body #1 coordinate	(0,0,0)
B1N3	Attaching point of #1 reaction wheel isolator	(40.08, 2.70,-2.70)
B1N4	Attaching point of #2 reaction wheel isolator	(38.79, 2.70,-2.70)
B1N5	Attaching point of #3 reaction wheel isolator	(37.51, 2.70,-2.70)
B1N6	Attaching point of #4 reaction wheel isolator	(40.08, -2.70,-2.70)
B1N7	Attaching point of #5 reaction wheel isolator	(38.79, -2.70,-2.70)
B1N8	Attaching point of #6 reaction wheel isolator	(37.51, -2.70,-2.70)
B1N9	Attaching point of +Y-axis solar array	(37.65,4.94,0)
B1N10	Attaching point of -Y-axis solar array	(37.65,4.94,0)
B1N11	Attaching point of IRU A	(31, 2.12, 2.63)
B1N12	Attaching point of IRU B	(31.28, 3.28, 1.98)

Since AXAF-I +Y-axis solar array (Body #2) and -Y-axis solar array (Body #3) have same mass properties and configuration, the NASTRAN modal output of either one of solar arrays can be used for both Body #2 and #3. The nodes of Body #2 and #3 are asymmetric about X-axis and described with the external and internal NASTRAN Grid ID numbers in Table 2.2.1.1-3.

Table 2.2.1.1-3: Nodes Definition of TREETOPS AXAF-I Body #2 and #3

TREETOPS Node #	NASTRAN internal Grid ID #	NASTRAN external Grid ID #	Location in body coordinates (ft)
B2N2, B3N2	72	63001	(0, 0, 0)
B2N3, B3N3	50	60000	(3.36, 4.70, 0.06)
B2N4, B3N4	54	60003	(-3.36, 4.70, 0.06)
B2N5, B3N5	30	60400	(3.36, 12.00, 0.06)
B2N6, B3N6	34	60403	(-3.36, 12.00, 0.06)
B2N7, B3N7	10	60800	(3.36, 19.30, 0.06)
B2N8, B3N8	14	60803	(-3.36, 19.30, 0.06)
B2N9, B3N9	1	61100	(3.36, 26.26, 0.06)
B2N10, B3N10	4	61103	(-3.36, 26.26, 0.06)

Six reaction wheels are mounted on their isolators that are fixed to Body #1 with their spin directions shown in Figure 2.2.1.1-1 [1]. Each isolator of reaction wheels #1, #2, #3, #4, #5, and #6 was respectively defined by Body #11, #21, #31, #41, #51, #61. These RW isolators are linked to the corresponding attaching nodes of Body #1 by Hinge #11, #21, #31, #41, #51, #61. Each hinge has three rotational and three translational DOFs with appropriate stiffness.

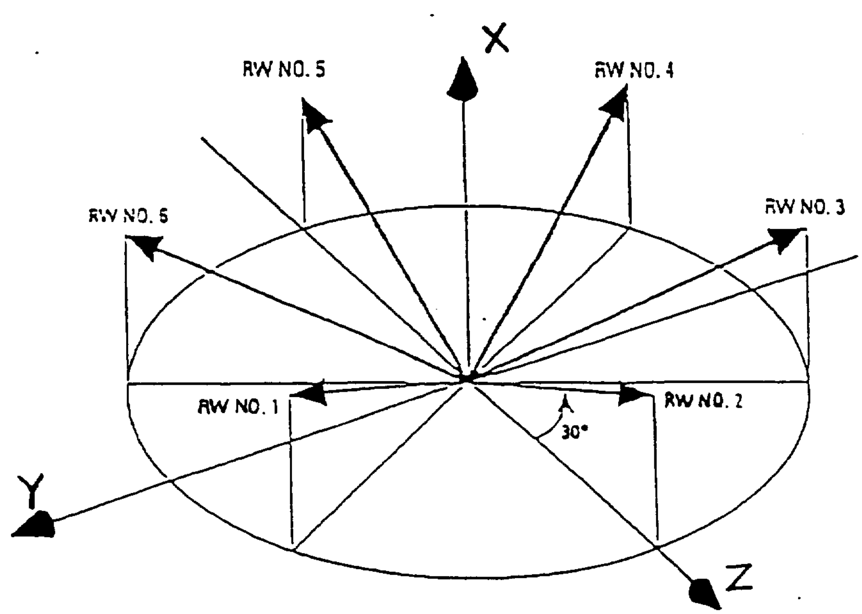


Figure 2.2.1.1-1: AXAF-I RW Positive Spin Vectors Relative to Body #1 Coordinates

Each reaction wheel was modeled as two rigid body dynamics systems (one non-rotating base rigid body and one rotating rigid body). Each non-rotating rigid body of reaction wheels #1, #2, #3, #4, #5, and #6 was respectively defined by Body #12, #22, #32, #42, #52, #62 and assumed to be fixed to the its isolator by defining Hinges #12, #22, #32, #42, #52, #62 with zero DOF. Also, each rotating rigid body of reaction wheels #1, #2, #3, #4, #5, and #6 was respectively defined by Body #13, #23, #33, #43, #53, #63 and linked to its corresponding non-rotating rigid body by Hinge #13, #23, #33, #43, #53, #63. The mass properties (Mass, Moment of Inertia about C.M.) of the reaction wheel isolators and the reaction wheels used for this study are described in Table 2.2.1.1-4.

Table 2.2.1.1-4: Mass properties of reaction wheels and isolators

Body	Mass (Slug)	$I_{xx}, I_{yy}, I_{zz}, I_{xy}, I_{xz}, I_{yz}$ $(Slug - ft^2)$
Reaction wheel isolator (Body #11, #21, #31, #41, #51, #61)	0.23	1.54E-2, 1.54E-2, 2.36E-2, 0, 0, 0
Non-rotating body of reaction wheel (Body #12, #22, #32, #42, #52, #62)	0.1823	1.475E-2, 1.475E-2, 2.2125E-2, 0, 0, 0
Rotating body of reaction wheel (Body #13, #23, #33, #43, #53, #63)	0.3659	0.03961, 0.03961, 0.07921, 0, 0, 1E-6

For each reaction wheel isolator and reaction wheel, two nodal points are defined with respect to each body's coordinate system to represent the center of mass, the origin of local coordinate system. Table 2.2.1.1-5 summarized the nodes of the reaction wheel isolators (Body #11, #21, #31, #41, #51, #61), the non-rotating bodies of reaction wheels (Body #12, #22, #32, #42, #52, #62), and the rotating bodies of reaction wheels (Body #13, #23, #33, #43, #53, #63). The unbalance of reaction wheels was defined by specifying non-zero products of inertia and the C.M. offset of the rotating bodies of the reaction wheels as shown in Table 2.2.1.1-4 and Table 2.2.1.1.-5.

Table 2.2.1.1-5: Nodes Definition of TREETOPS AXAF-I Reaction Wheel Isolators and Non-Rotating and Rotating bodies of Reaction Wheels

Body	Node	Description	Location in body coordinates (ft)
B11,21,31,41,51,61	N1	Center of Mass	(0,0,0)
B11,21,31,41,51,61	N2	Origin of each body coordinate	(0,0,0)
B12,22,32,42,52,62	N1	Center of Mass	(0,0,0.1936)
B12,22,32,42,52,62	N2	Origin of each body coordinate	(0,0,0)
B13,23,33,43,53,63	N1	Center of Mass	(0,-5E-6,0)
B13,23,33,43,53,63	N2	Origin of each body coordinate	(0,0,0)

2.2.1.2 AXAF-I Hinge Models

According to the tree topology of TREETOPS modeling, the number of hinges that connects neighboring bodies must be equal to total number of bodies. Therefore, AXAF-I TREETOPS model has twenty-one hinges and each hinge defines nodal points of two connecting bodies, the relationship of each body's coordinate system and DOFs of relative motion between two bodies. The definitions of all hinges of AXAF-I TREETOPS model are summarized in Table 2.2.1.2-1.

Table 2.2.1.2-1: Hinges Definition of AXAF-I TREETOPS Model

Hinge	Connecting nodes	No. of DOF	L1_in - L1_out	L3_in - L3_out
1	B0N0 - B1N1	3 RDOF	(1,0,0) - (1,0,0)	(0,0,1) - (0,0,1)
2	B1N9 - B2N2	0 DOF	(0,1,0) - (0,1,0)	(1,0,0) - (1,0,0)
3	B1N10 - B3N2	0 DOF	(0,-1,0) - (0,1,0)	(1,0,0) - (1,0,0)
11	B1N3 -B11N1	3 RDOF, 3 TDOF	(0.5,0.75,0.4330127) - (0,0,1)	(0.8660254,-0.4330127, -0.25) - (0,1,0)
12	B11N2 - B12N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
13	B12N1 - B13N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
21	B1N4 -B21N1	3 RDOF, 3 TDOF	(0.5,0,0.8660254) - (0,0,1)	(0.8660254,0,-0.5) - (0,1,0)
22	B21N2 - B22N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
23	B22N1 - B23N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
31	B1N5 -B31N1	3 RDOF, 3 TDOF	(0.5,-0.75,0.4330127) - (0,0,1)	(0.8660254,0.4330127, -0.25) - (0,1,0)
32	B31N2 - B32N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
33	B32N1 - B33N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
41	B1N6 -B41N1	3 RDOF, 3 TDOF	(0.5,-0.75,- 0.4330127) - (0,0,1)	(0.8660254,0.4330127, 0.25) - (0,1,0)
42	B41N2 - B42N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
43	B42N1 - B43N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
51	B1N7 -B51N1	3 RDOF, 3 TDOF	(0.5,0,-0.8660254) - (0,0,1)	(0.86602540,0.5) - (0,1,0)
52	B51N2 - B52N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
53	B52N1 - B53N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
61	B1N8 -B61N1	3 RDOF, 3 TDOF	(0.5,0.75,-0.4330127) - (0,0,1)	(0.8660254,-0.4330127, 0.25) - (0,1,0)
62	B61N2 - B62N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
63	B62N1 - B63N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)

The Hinges between Body #1 and six reaction wheel isolators (HI #11, #21, #31, #41, #51, #61) have 204.5 *lb-ft/rad* of rotational stiffness and 0.362 *lb-ft/rad/sec* of rotational damping and also, 2121.3 *lb/ft* of translational stiffness and 3.75 *lb/ft/sec* of translational damping. For nominal equilibrium condition, reaction wheels #1, #3, #5 have positive 2250 *rpm* of rotational speed and reaction wheels #2, #4, #6 have negative 2250 *rpm* of rotational speed resulting in zero sum of angular momentum to Body #1. The Hinges for spin axes of six reaction wheels (HI #13, #23, #33, #43, #53, #63) have zero rotational stiffness with initial 2250 *rpm* of angular velocities.

2.2.2 AXAF-I TREETOPS Sensor and Actuator Models

For the NPM pointing control of AXAF-I spacecraft, the angular attitude and angular velocity errors of AXAF-I spacecraft are measured and fed back to a PID controller to determine the control torque to obtain the desired pointing accuracy. AXAF-I has two Inertial Reference Unit (IRU) boxes and each IRU has two rate gyros. Since one gyro measures the angular velocities about two axis, total eight angular velocity measurements are available from two IRU boxes. Therefore, the angular velocity at the C.M. of AXAF-I spacecraft can be determined by transferring the eight angular velocity measurements of the two IRUs to the C.M. of AXAF-I spacecraft. AXAF-I has an Aspect Camera that measures the position of the selected Stars to determine the angular attitude error of the AXAF-I spacecraft. The AXAF-I flight software estimates the attitude errors and gyro drift errors of the AXAF-I spacecraft by processing the outputs of the rate gyros and the aspect camera with an attitude and aspect determination algorithm.

In this study, the detailed models of the IRUs, the aspect camera, and the attitude and aspect determination algorithm are not included. Instead, only functional outputs of these hardware sensors are obtained from the ideal TREETOPS sensor models. For the AXAF-I TREETOPS simulation, three ideal TREETOPS Rate Gyros are used to measure three angular velocities of the AXAF-I spacecraft about X, Y, Z axes and one TREETOPS IMU sensor is used to measure three rotational angles of the AXAF-I spacecraft with respect to the inertial coordinates. Three TREETOPS Integrating Gyros are attached on the C.M. of AXAF-I spacecraft to measure the integrals of the angular rate outputs of Rate Gyros. The descriptions of AXAF-I TREETOPS sensors are summarized in Table 2.2.2-1.

Table 2.2.2-1: Definition of TREETOPS AXAF-I Sensors Model

Sensor ID	Type	Attached node	Direction	Description
1	IMU Sensor	B1N1	(1,0,0),(0,1,0),(0,0,1)	Euler angles w.r.t. inertial frame
11	Integrating Gyro	B1N1	(1,0,0)	$\int \omega_x$
12	Integrating Gyro	B1N1	(0,1,0)	$\int \omega_y$
13	Integrating Gyro	B1N1	(0,0,1)	$\int \omega_z$
14	Rate Gyro	B1N1	(1,0,0)	ω_x
15	Rate Gyro	B1N1	(0,1,0)	ω_y
16	Rate Gyro	B1N1	(0,0,1)	ω_z

The AXAF-I has six reaction wheels to generate the control torque to compensate the attitude and angular velocity errors of the spacecraft under NPM control. The control torque at the C.M. of the spacecraft is determined from the AXAF-I NPM control law and distributed to six reaction wheels according to the RW steering law. For the AXAF-I TREETOPS simulation, six TREETOPS Torque actuators are mounted along the spin axes of the six hinges between the non-rotating and rotating bodies of the six reaction wheels. The inputs to these actuators are to be determined by the AXAF-I NPM control law defined in the USDC subroutine in Appendix A. The TREETOPS actuators for AXAF-I are described in Table 2.2.2-2.

Table 2.2.2-2: Definition of TREETOPS AXAF-I Actuators Model

Actuator ID	Type	Acting Node	Description
13	Torque Motor	Hinge 13	Torque about the spin axis of RW #1
23	Torque Motor	Hinge 23	Torque about the spin axis of RW #2
33	Torque Motor	Hinge 33	Torque about the spin axis of RW #3
43	Torque Motor	Hinge 43	Torque about the spin axis of RW #4
53	Torque Motor	Hinge 53	Torque about the spin axis of RW #5
63	Torque Motor	Hinge 63	Torque about the spin axis of RW #6

2.2.3 AXAF-I NPM Control Law Model

The AXAF-I Normal Point Mode (NPM) control is designed to point the telescope at the science target with the required pointing accuracy and stability after the Normal Maneuver Mode (NMM) control acquires the acquisition stars within the allowable error. The AXAF-I flight software uses a Proportional-Integral-Derivative (PID) control law for the NPM pointing control of the spacecraft. The requirements of the NPM control law are given in Table 2.2.3-1 [1].

Table 2.2.3-1: Requirements of the AXAF-I NPM control law

Description	Requirement
Attitude Control Error (arcsec, 1 σ, per axis)	4.0
Attitude Control Stability (arcsec, rms per axis, 95% of all 10-second intervals)	0.120
Period of not requiring pointing and stability after completion of momentum unloading	15 minutes

For the AXAF-I TREETOPS simulation, the NPM control law and control parameters that were developed by TRW are combined with the AXAF-I TREETOPS dynamics model. The hierarchy of AXAF-I TREETOPS dynamics and NPM control model is shown in Figure 2.2.3-1.

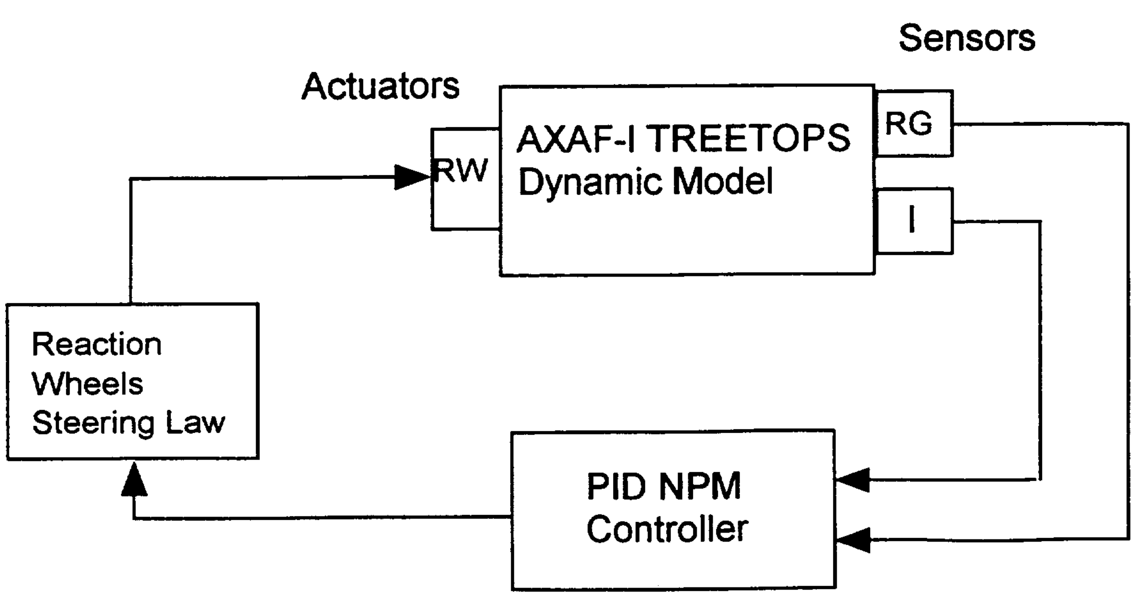


Figure 2.2.3-1: AXAF-I TREETOPS Dynamics and NPM Control Model Layout

The NPM PID control law has about 0.01 Hz of control bandwidth for roll motion and about 0.03 Hz of control bandwidth for pitch and yaw motions. The block diagram of AXAF-I NPM PID control law is shown in Figure 2.2.3-2 [1].

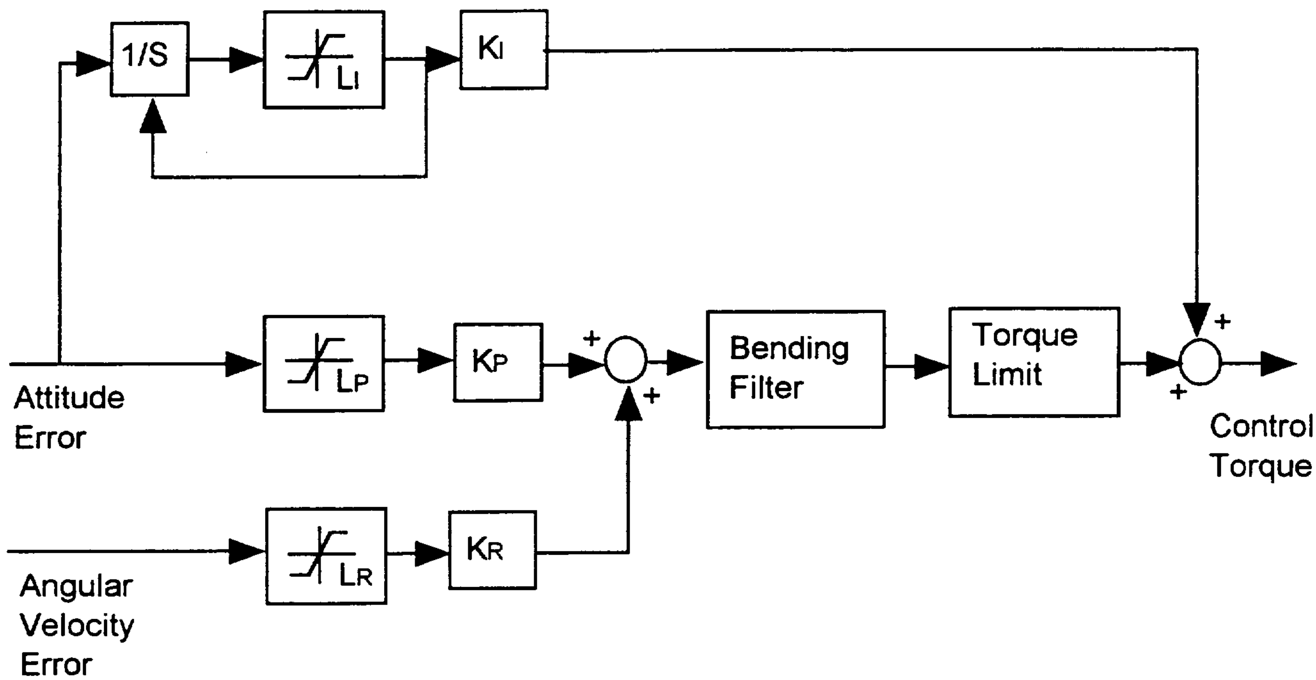


Figure 2.2.3-2: Block Diagram of AXAF-I NPM PID Control Law

The AXAF-I has six reaction wheels in a pyramidal configuration shown in Figure 2.2.1.1-1. The total torque acting on the C.M. of the spacecraft by the six reaction wheels are given by the following equation

$$T_{SC} = B\, T_W$$

where $T_{SC} = [T_X, T_Y, T_Z]^T$ is the torque about X,Y, Z axis on the C.M. of the spacecraft in the inertial coordinates and $T_W = [T_1, T_2, \cdots, T_6]^T$ is the torque on the six reaction wheels.

The transfer matrix, B consists of six columns that are the unit vectors of the spin axes of the six reaction wheels and is given by

$$B = \begin{bmatrix} 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0.75 & 0.0 & -0.75 & -0.75 & 0.0 & 0.75 \\ 0.433 & 0.866 & 0.433 & -0.433 & -0.866 & -0.433 \end{bmatrix}$$

For the AXAF-I TREETOPS NPM control simulation, the attitude errors and angular velocity errors of the AXAF-I spacecraft are obtained from the outputs of one TREETOPS IRU sensor and three TREETOPS Rate Gyro sensors. The AXAF-I NPM control law determines the control torque, T on the C.M. of the spacecraft to compensate for attitude errors and angular velocity errors. This control torque, T is opposite to the total torque acting on the spacecraft due to the six reaction wheels, T_{SC}. Once the required control torque, T is calculated by the AXAF-I NPM PID control law, the control torque on each reaction wheel is determined using the following pseudo-inverse steering law which provides the inputs to the AXAF-I TREETOPS Torque actuators.

$$T_W = D\,T$$

The steering matrix, D is the negative pseudo-inverse matrix of B and is given by

$$D = -\begin{bmatrix} 0.3333 & 0.3333 & 0.1925 \\ 0.3333 & 0 & 0.3849 \\ 0.3333 & -0.3333 & 0.1925 \\ 0.3333 & -0.3333 & -0.1925 \\ 0.3333 & 0 & -0.3849 \\ 0.3333 & 0.3333 & -0.1925 \end{bmatrix}.$$

The AXAF-I NPM PID control law and the reaction wheel steering law were coded in the FOTRAN subroutine USDC, Appendix A. The parameters of AXAF-I NPM PID control law are summarized in Table 2.2.3-2.

Table 2.2.3-2: AXAF-I NPM PID Control Law Parameters

Control Parameters	Roll (X)	Pitch (Y)	Yaw (Z)
Proportional gain, K_P $(ft-lb/rad)$	6.506	68.382	72.908
Rate gain, K_R $(ft-lb/rad/\sec)$	325.3	3419.1	3645.4
Integral gain, K_I $(ft-lb/rad-\sec)$	6.506E-3	3.4191E-2	3.6454E-2
Bending filter, $\dfrac{a_0+a_1 Z^{-1}+a_2 Z^{-2}}{1+a_3 Z^{-1}+a_4 Z^{-2}}$	a_0 = 7.94213E-5 a_1 = 1.588426E-4 a_2 = 7.94213E-5 a_3 = -1.978409 a_4 = 0.978726	a_0 = 9.79132E-4 a_1 = 1.958264E-3 a_2 = 9.79132E-4 a_3 = -1.910409 a_4 = 0.914326	a_0 = 9.79132E-4 a_1 = 1.958264E-3 a_2 = 9.79132E-4 a_3 = -1.910409 a_4 = 0.914326
Position limit, L_P (rad)	0.05695	6.98E-4	6.98E-4
Integral limit, L_I $(rad-\sec)$	0.06	0.011	0.01
Rate limit, L_R $(rad/\sec)$	1E6	1E6	1E6
Body torque command limit, T_L $(ft-lb)$	0.25	0.25	0.25

2.3 AXAF-I TREETOPS Simulation Results

The NPM control mode is activated to achieve the required pointing accuracy and stability after the Normal Maneuver Mode (NMM) controller slews the AXAF-I to acquire acquisition stars with the allowable error (less than 100 *arcsec* per axis, 3-sigma). This subsection describes numerical results of AXAF-I NPM pointing control analysis from the TREETOPS simulation. The input files of AXAF-I TREETOPS simulation are in Appendix B, C and D. For the evaluation of the NPM pointing accuracy and stability of AXAF-I, a transient response analysis is performed with initial 100 *arcsec* of pitch (Y-axis) and yaw (Z-axis) attitude errors and initial 2.88 *arcsec/sec* of pitch and yaw angular velocity errors using TREETOPS simulation. These initial errors are defined in the input data of Hinge #1 of the AXAF-I TREETOPS model. The numerical results of the transient response analysis with initial attitude and angular velocity errors are shown in Figure 2.3.1-1 through Figure 2.3.1-4.

Figure 2.3.1-1 shows the attitude and angular velocity errors of AXAF-I spacecraft under NPM control when the initial attitude and angular velocity errors of the spacecraft are given. It is noticed that the initial 100 *arcsec* of pitch and yaw attitude errors are reduced to about 0.75 *arcsec* in 500 seconds under NPM control thus satisfying the AXAF-I pointing accuracy requirement. It is also noticed that the changes of the pitch and yaw attitude are less than 0.01 *arcsec* for 10 seconds in 500 seconds thus satisfying the AXAF-I pointing stability requirement.

In Figure 2.3.1-2 the control torque on six reaction wheels required to correct the 100 *arcsec* of pitch and yaw attitude errors and 2.88 *arcsec/sec* of pitch and yaw angular velocity errors of AXAF-I spacecraft are plotted. Maximum torque of 0.043 *ft-lb* is loaded on reaction wheel #1. It is noted that the actual torque limit of reaction wheel hardware is about 0.1 *ft-lb*.

Figure 2.3.1-3 shows the spin speed changes of six reaction wheels from the nominal wheel speeds (± 2250 rpm) under NPM control when the initial attitude and angular velocity errors of the spacecraft are given. The spin speeds of reaction wheels #1, #2, #3, #4, #5, #6 are changed by 34, 24, -7, -34, -24, 7 rpm, respectively to compensate for the angular momentum due to the initial angular velocity errors.

Figure 2.3.1-4 shows the rotational angle about x-axis and the nutational angles (about y- and z-axis) of the reaction wheel isolator #1 due to the static and dynamic unbalance of the reaction wheel #1. From Figure 2.3.1-4 the amplitude of nutaional angles is about 45 *arcsec* and these angles contribute to the misalignment error of the spin axis direction of reaction wheel.

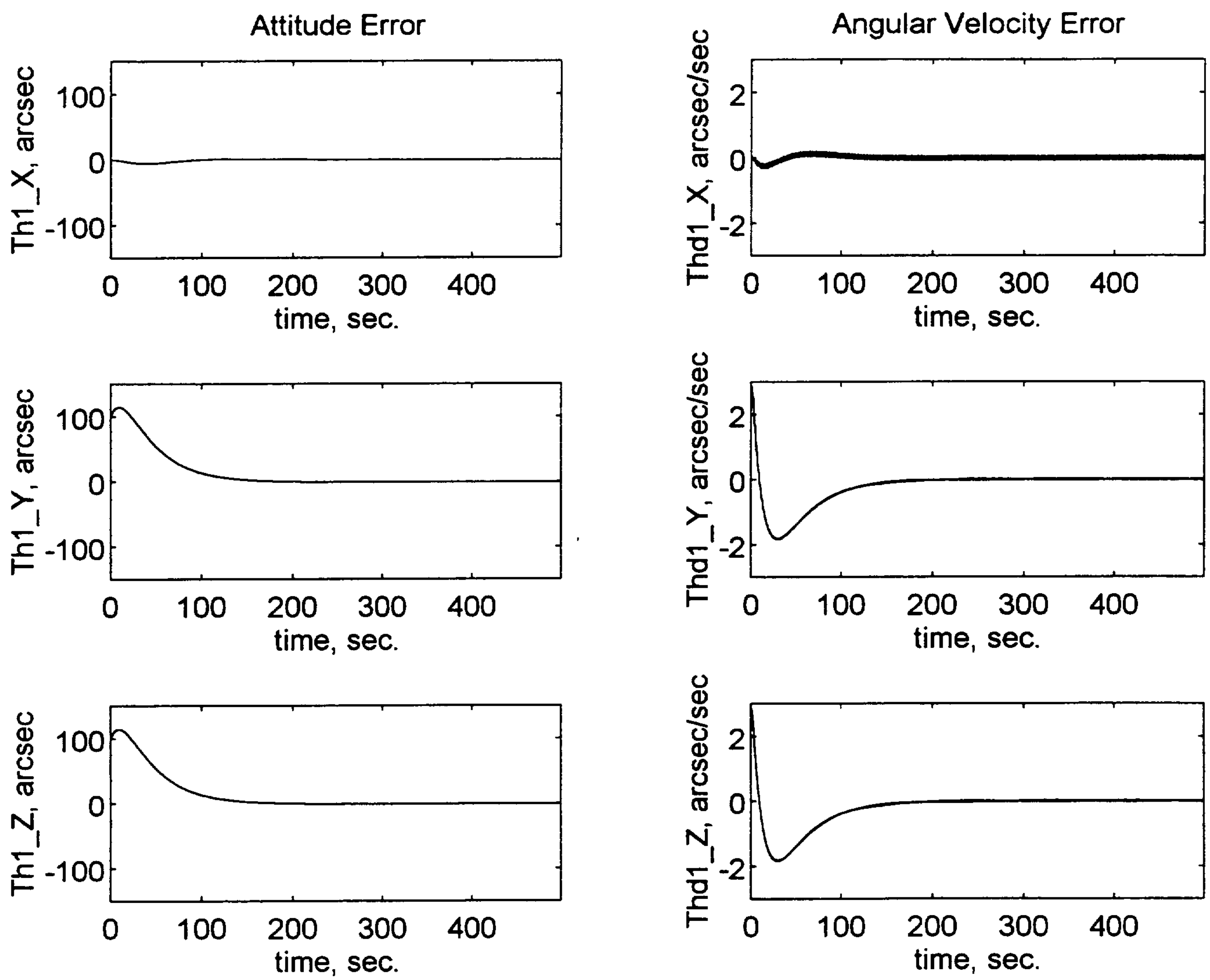


Figure 2.3.1-1: Attitude and Angular Velocity Errors of AXAF-I Spacecraft
under NPM Control with Initial Errors

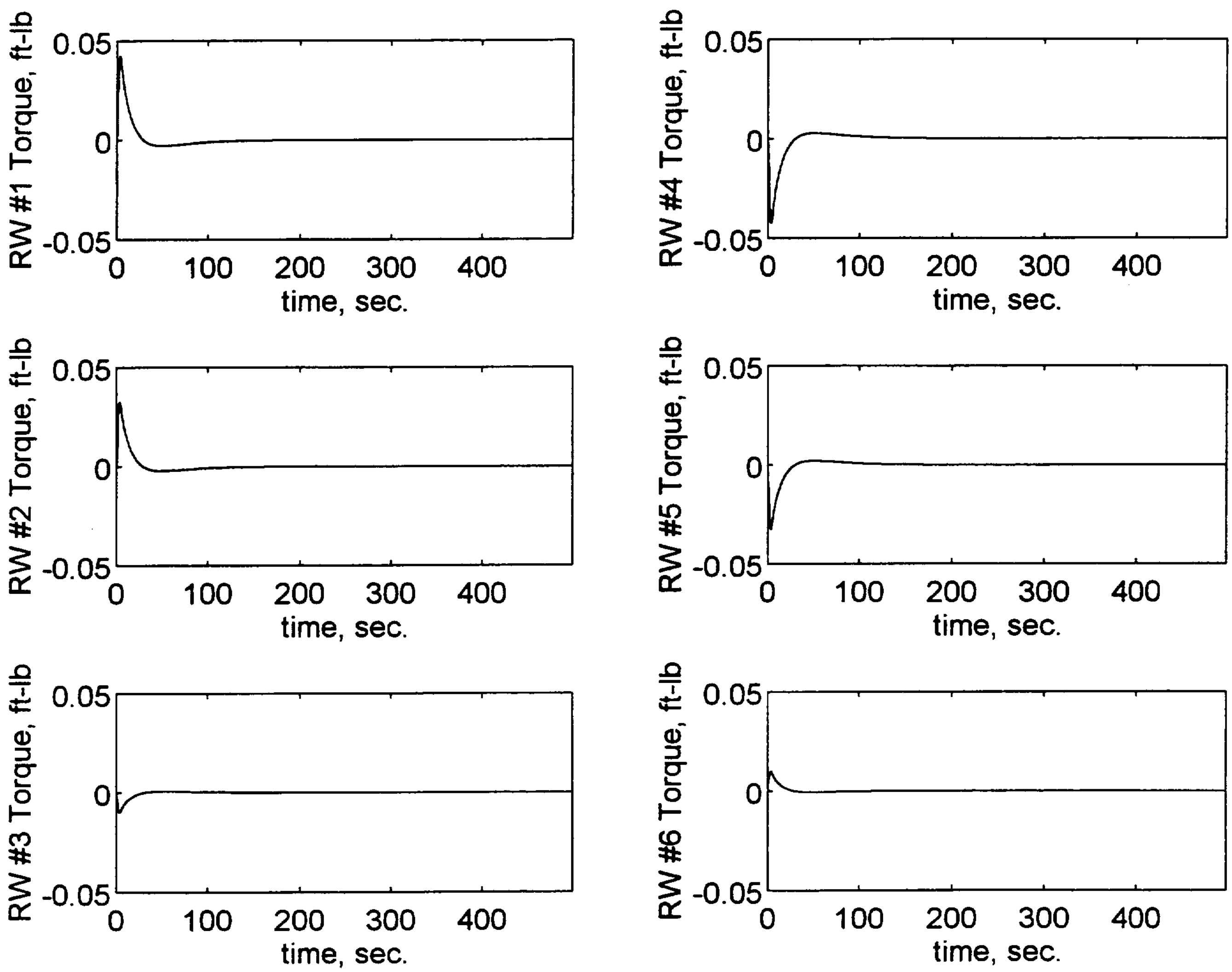


Figure 2.3.1-2: Control Torque on Six Reaction Wheels
under NPM Control with Initial Errors

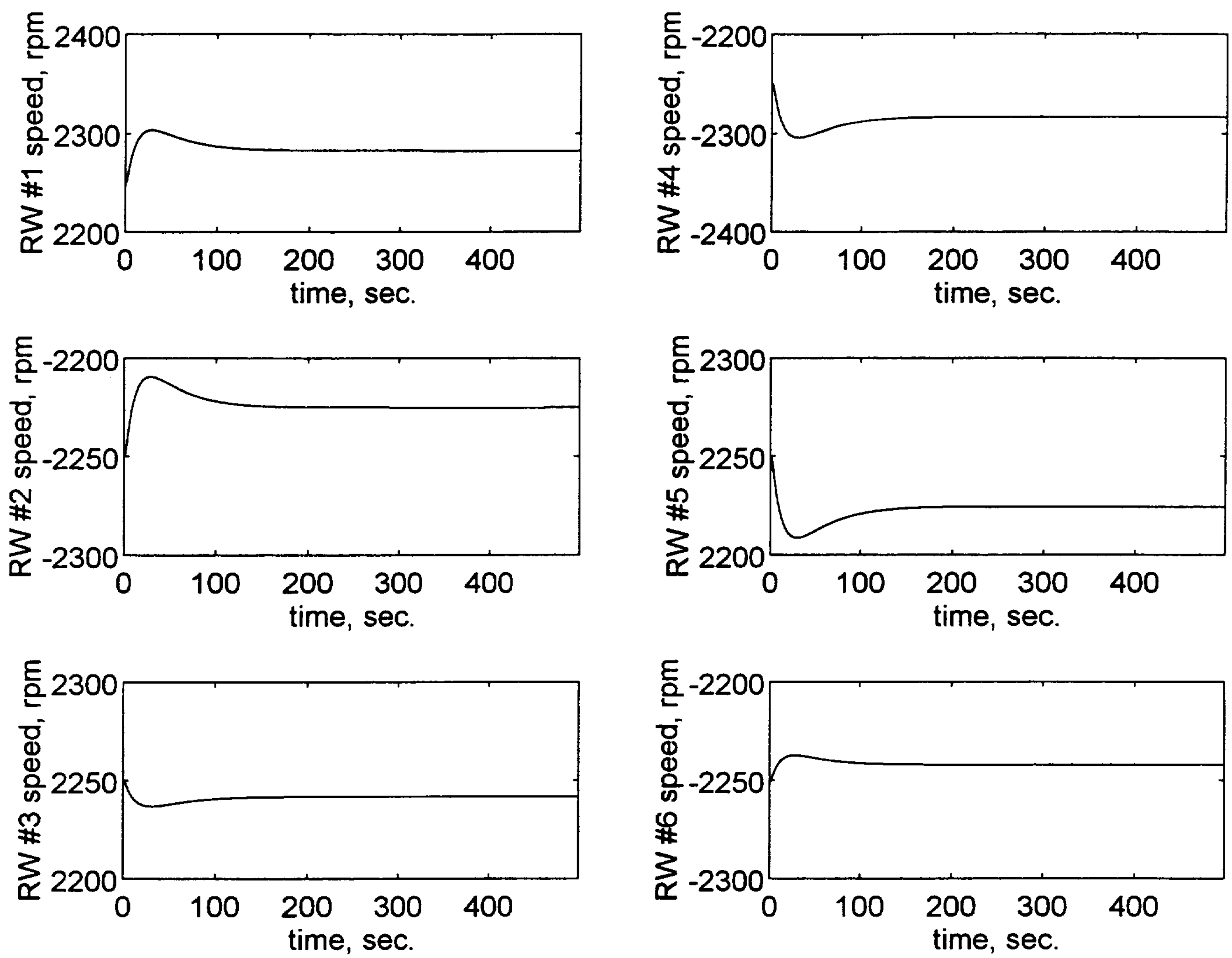


Figure 2.3.1-3: Spin Speeds of Six Reaction Wheels
under NPM Control with Initial Errors

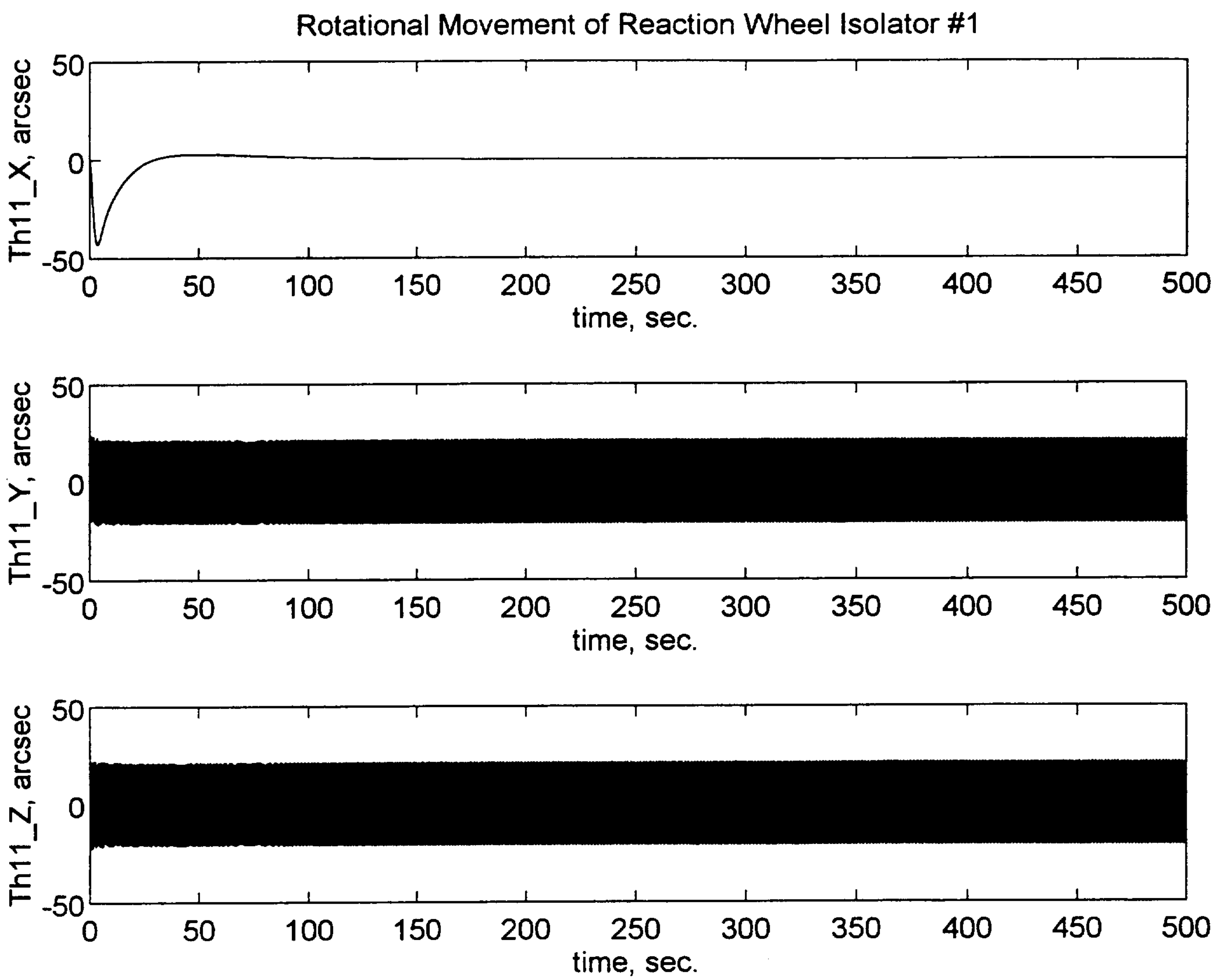


Figure 2.3.1-4 Angular movement of Reaction Wheel #1
under NPM Control with Initial Errors

2.4 Conclusion

A TREETOPS multi-body dynamics and control model of AXAF-I observatory was developed for NPM pointing control and documented in Section 1. The NPM pointing accuracy and stability of AXAF-I was evaluated from the numerical results of transient response analysis with initial attitude and angular velocity errors.

The simulation results indicated that the the pointing accuracy and stability requirements of AXAF-I could be met for the NPM operation. Possibly unfavorable effects on the pointing performance of AXAF-I due to the interaction between the dynamics of reaction wheels and the flexible solar arrays are negligible. It is noticed that there are two nutational modes (one increasing frequency and another decreasing frequency) for each reaction wheel isolator due to the gyroscopic effects of the spinning unbalanced reaction wheel. The effect of unbalanced reaction wheels, specified in Subsection 2.2.1.1, on the pointing performance of AXAF-I was insignificant for the NPM operation.

This study incorporated the simplified NPM pointing control logic with the ideal sensors of attitude and angular velocity errors in AXAF-I multi-body dynamics model for TREETOPS simulation. Additional studies, which include the detailed flight software control logic of AXAF-I pointing control and aspect determination with various control modes, are needed to evaluate in greater depth the pointing performance of AXAF-I on orbit.

2.5 References

[1] "AXAF-I Pointing Control and Aspect Determination Subsystem Critical Design Audit Volume 1- Subsystem Analyses," TRW-SE 11K, TRW Space & Electronics Group, January 1996.

[2] "User's Manual for TREETOPS, A Control System Simulation for Structures With a Tree Topology," NASA Contract NAS-36287, Marshall Space Flight Center, April 1990.

3. Optical Modeling and Analysis of SSE Optical System

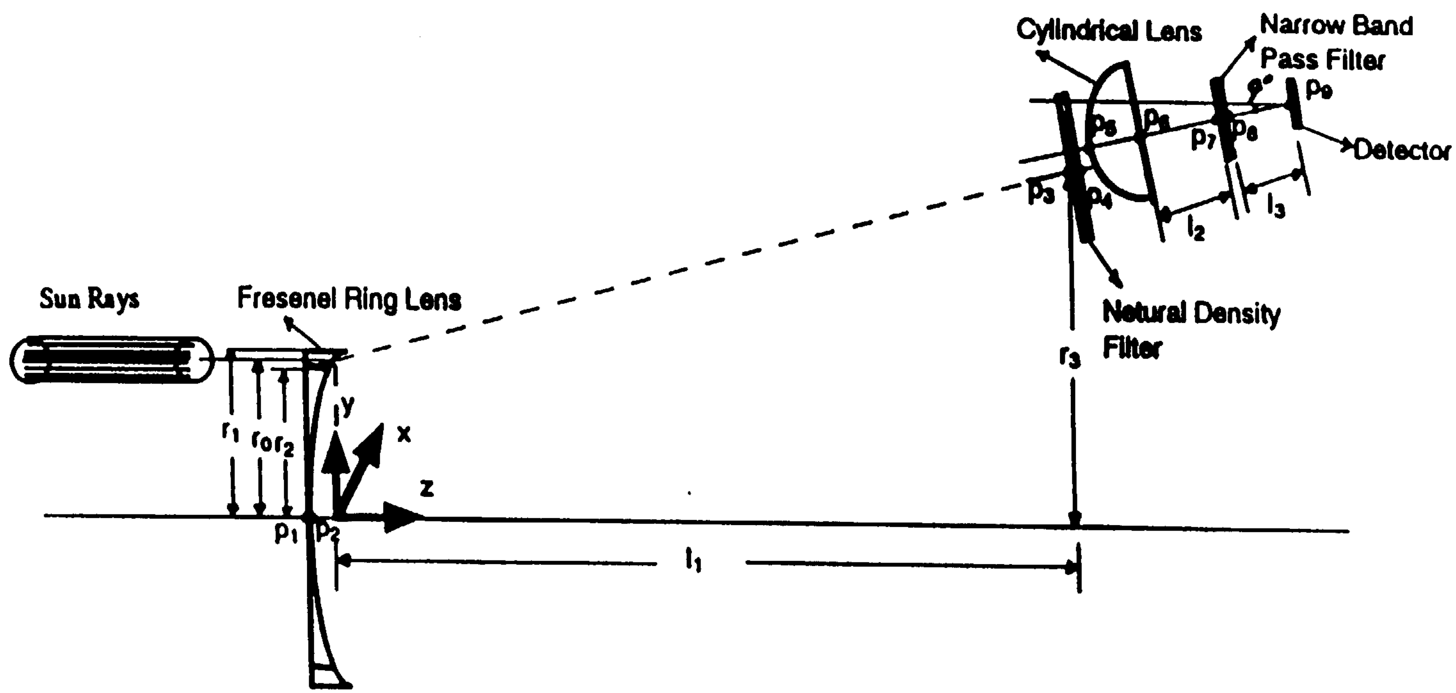
3.1 Introduction

This section documents the configuration and optical prescription of the optical system of the Shooting Star Experiment (SSE) provided by Mr. Gary W. Wilkerson, Micro Craft, Inc. in October 1997 and the performance analysis results of this optical system. This optical performance analysis was done using the Modeling and Analysis for Controller Optical Systems (MACOS) developed by JPL [1]. In order to determine the Sun pointing error, the SSE uses one Fresnel lens and four Sun image detecting optical assemblies that are located symmetrically on the spacecraft. Since the optical functions of four Sun image detecting optical systems are identical, only one Sun image detecting optical system that includes one Fresnel lens, two filters, one cylindrical lens, and one Charge Coupled Device (CCD) detector was modeled in this study. The ray tray analyses were performed to determine the Sun image movements on the CCD detector due to the rigid body motions of the SSE optical system and the motions of the Fresnel lens due to flexibility of inflatable supporting structure. These results may be easily translated to the other three Sun image detecting systems by adjusting coordinate systems.

3.2 SSE MACOS Optical Modeling and Analysis

In this section one Sun image detecting optical system that includes one Fresnel lens, two filters, one cylindrical lens, and one CCD detector was modeled via MACOS simulation. The hardware Fresnel ring lens that is made of multi-segments with various slopes was modeled mathematically as one aspheric surface lens whose curvature was derived by interpolating the various slopes of the multi-segments with center obscured. The difference of thickness between the hardware Fresnel lens and the MACOS model of Fresnel lens was corrected by moving back the vertex point of MACOS Fresnel lens by the thickness difference.

The pointing errors of the Fresnel lens to the center of Sun due to the rigid body motions of SSE optical system and the motions of Fresnel lens due to flexibility of inflatable supporting may be determined by measuring the movements of the center of the spot diagram on the CCD detector. This spot diagram was obtained for a bundle of collimated Sun rays from the ray tray analysis using MACOS. The nominal configuration of the SSE MACOS optical model and the coordinate system used for the ray tray analysis are shown in Figure 3.2-1.



<u>Ring Lens</u>:
r_1=7.59, r_2=7.19, r_0=7.39
Thickness=0.003,
Radius of Curvature=13.37423

<u>Cylindrical Lens</u>:
Thickness=1.41732, Radius of Curvature=4.80314
Length=6.5, Width=2.5,
Offset from center of N.D. filter=0.905510

<u>Detector</u>:
Thikness=0.1, Width=0.25, Length=1.18

<u>Netural Density Filter</u>:
l_1=73.367853, r_3=19.010962
Diameter= 6, Thickness=0.25
Gap to cylindrical lens=0.1

<u>Narrow Band Pass Filter</u>:
l_2=2.999994, l_3=2.095673
Diameter=4, Thickness=0.2

p_1=(0, 0, -1.37773), p_2=(0 , 0, -1.37473)
p_3=(0, 19.010962, 73.367853), p_4=(0, 19.050071, 73.614775)
p_5=(0, 19.960076, 73.571891), p_6=(0, 20.181793, 74.971761)
p_7=(0, 20.651096, 77.934820), p_8=(0, 20.682383, 78.132358)
p_9=(0, 21.010218, 80.202230) (Note: length unit = inch)

Figure 3.2-1: Configuration of SSE MACOS Optical Model

The Sun has an apparent diameter of about 0.54 degrees with respect to the Line of Sight (LOS) of the SSE Fresnel lens. Assuming that the apparent diameter of the Sun may have little effect on the movement of the center of spot diagram of the Sun rays on the CCD detector through 0.4 inch width of ring lens, 1 inch square area of collimated Sun rays coming into the center of the ring lens aligned to the cylindrical lens and the CCD detector are used for the ray tray analyses. The indices of refraction of lens and filter are chosen based on the wave length of 720 *nano-miter* for the ray tray analyses.

The rigid body translational motions and rotational motion about the LOS axis (z-axis) of the SSE optical system barely contribute to the movement of the center of spot diagram on the CCD detector. However, the rigid body rotational motions about x and y axis change the movement of the center of spot diagram on the CCD detector. Therefore, the relationship between the rigid body rotational angle about x-axis and the movement of the center of spot diagram on the CCD detector is to be investigated in this study. The inflatable supporting structure of the SSE vehicle can cause relative motion of the Fresnel lens with respect to the rest of SSE optical system. The relative torsional motion about the SSE optical axis may not affect the movement of the center of spot diagram on the CCD detector. The relative z-axis motion is believed to be considerably small and its effect on the movement of the center of spot diagram on the CCD detector is not considered in this study. The relationships of the relative translational y-axis motion and rotational motion about x-axis with the movement of the center of spot diagram on the CCD detector are also to be investigated in this study.

The MACOS model of the SSE Sun image detecting optical system consists of nine optical elements according to the definition of MACOS software. Each lens or filter is defined using two *Refractor* type of elements. A Fresnel ring lens is defined using element #1 (Circular Flat Refractor) and element #2 (Circular Aspheric Refractor) with center obscured. A neutral density filter is defined using element #3 (Circular Flat Refractor) and element #4 (Circular Flat Refractor). The neutral density filter is tilted by 9 degrees with respect to optical axis of Fresenel lens as shown in Figure 3.2-1. A cylindrical lens that consists of a x-axis directional conic surface and a y-axis directional flat surface could be modeled using MACOS Anamorphic Refractor and Flat Refractor elements. However, since the MACOS Anamorphic Refractor element with 9 degrees tilt yields numerical instability problem, a cylindrical lens was defined using element #5 (Rectangular Conic Refractor) and element #6 (Rectangular Flat Refractor). This approximation may introduce spot diagram errors only in the x-axis direction and has insignificant effect on the movement (y-axis directional) of the center of spot diagram on the CCD detector. A narrow band pass filter is defined using element #7 (Circular Flat Refractor) and element #8 (Circular Flat Refractor). A CCD detector is defined using element #9 (Rectangular Flat FocalPlane). The central optical line of cylindrical lens, narrow band pass filter and CCD detector is offset by 0.905510 inch with respect to the central optical line of neutral density filter as shown in Figure 3.2-1.

The dimensions of the SSE MACOS optical elements are defined in Figure 3.2-1. Each vertex point of nine elements is denoted as $p_i, (i = 1, \cdots, 9)$ and shown in Figure 3.2-1 with respect to the global coordinate system. Since the focal distance, l_1 was determined by the SSE optics design team for the Fresnel lens of 0.003 inch thickness, the vertex points of elements #2 and #3 (p_1 and p_2) are moved back by the height of the aspheric surface at the center of the ring lens from the origin of the global coordinate that located at the center of the ring lens on the SSE optical axis. The prescriptions of the SSE MACOS optical elements are summarized in Table 3.2-1.

Table 3.2-1: Optical Prescriptions of SSE MACOS Optical Elements
(length unit = inch)

Optical Element No.	Element Type	Surface Type	Radius of Curvature / Asperic Coeff.	Index of Refraction	Principal Axis Direction
1	Refractor	Flat	-1e22 / 0	1.595059	(0,0,-1)
2	Refractor	Aspheric	13.37423 / A=0.414552e-3, B=-0.344476e-5, C=0.199075e-7	1.	(0,0,-1)
3	Refractor	Flat	-1e22 / 0	1.454853	(0,-0.1564,-0.9877)
4	Refractor	Flat	-1e22 / 0	1.	(0,-0.1564,-0.9877)
5	Refractor	Conic	4.80314 / 0	1.512549	(0,-0.1564,-0.9877)
6	Refractor	Flat	-1e22 / 0	1.	(0,-0.1564,-0.9877)
7	Refractor	Flat	-1e22 / 0	1.454853	(0,-0.1564,-0.9877)
8	Refractor	Flat	-1e22 / 0	1.	(0,-0.1564,-0.9877)
9	FocalPlane	Flat	-1e22 / 0	1.	(0,-0.1564,-0.9877)

3.3 SSE Optics MACOS Simulation Results

A MACOS model of the SSE Sun image detecting system was first developed for the nominal configuration shown in Figure 3.2-1. The optical prescriptions and configuration of the SSE optical model provided by the SSE Optical Design Team were confirmed through the ray tray analysis using MACOS. The input file of the SSE MACOS simulation for the nominal configuration is attached in Appendix G. In order to determine the Sun image movement on the CCD detector due to the rigid body motion of the SSE optical system and the motion of the Fresnel lens that may result from the flexibility of inflatable supporting structure, the ray tray analyses were performed using MACOS for following three cases; case1: y-axis translational movement of Sun image on the CCD detector due to the rigid body rotational motion about the x-axis of total SSE optical system, case 2: y-axis translational movement of Sun image on the CCD detector due to the y-axis directional movement of the Fresnel lens only, case 3: y-axis translational movement of Sun image on the CCD detector due to rotation about the x-axis of the Fresnel lens only.

Case 1:

In order to determine the y-axis translational Sun image movement on the CDD detector due to the rigid body rotational motion of about the x-axis of total SSE optical system, all nine elements of the nominal SSE MACOS optical model were rotated about x-axis at node p_1 by various angles and the ray tray analyses were performed with a bundle of collimated rays fully covering the width of ring lens. The y-axis locations of chief ray and center of spot diagram of the collimated Sun rays at the ring lens and the CCD detector were calculated using MACOS for the various rotational angles of the SSE optical system and summarized in Table 3.3-1 with respect to the global coordinate system defined in Figure 3.2-1.

Table 3.3-1: SSE Rigid Body Rotation vs. Movement of Sun Image at Detector (length unit = inch)

Rigid body rotation about x-axis (degree)	Chief ray location at ring lens (y-axis)	Center of spot diagram location at ring lens (y-axis)	Chief ray location at detector (y-axis)	Center of spot diagram location at detector (y-axis)
-0.5	7.39	7.3844	21.1542	21.1508
-0.4	7.39	7.3845	21.0628	21.0593
-0.2	7.39	7.3845	20.8841	20.8801
0.	7.39	7.3892	20.7089	20.7048
0.2	7.39	7.3845	20.5364	20.5322
0.4	7.39	7.3845	20.3655	20.3612
0.6	7.39	7.3843	20.1954	20.1910
0.8	7.39	7.3839	20.0255	20.0134
1.0	7.39	7.3836	19.8549	19.8507
1.2	7.39	7.3829	19.6828	19.6786
1.4	7.39	7.3822	19.5084	19.5045
1.5	7.39	7.3818	19.4197	19.4159

w.r.t. global coordinate system

The actual Sun image movement on the CDD detector due to the rigid body rotation about the x-axis of the SSE optical system is determined by subtracting the movement of the CCD detector center from the movement of the spot diagram center of the collimated Sun rays at the CCD detector and plotted in Figure 3.3-1. The movements of the CCD detector center and of the spot diagram center of the collimated Sun rays at the CCD detector are obtained by calculating relative displacements with respect to nominal positions from Table 3.3-1. As shown in Figure 3.3-1, the 1.18 inch length of the CCD detector can allow rigid body rotation of the SSE vehicle about the x-axis from -0.5 degrees to 1.5 degrees. Since two Sun image detecting systems are located symmetrically about the center line of the SSE vehicle, total Field of View (FOV) allowed for the rigid body rotation of the SSE optical system about the x-axis is ±1.5 degrees.

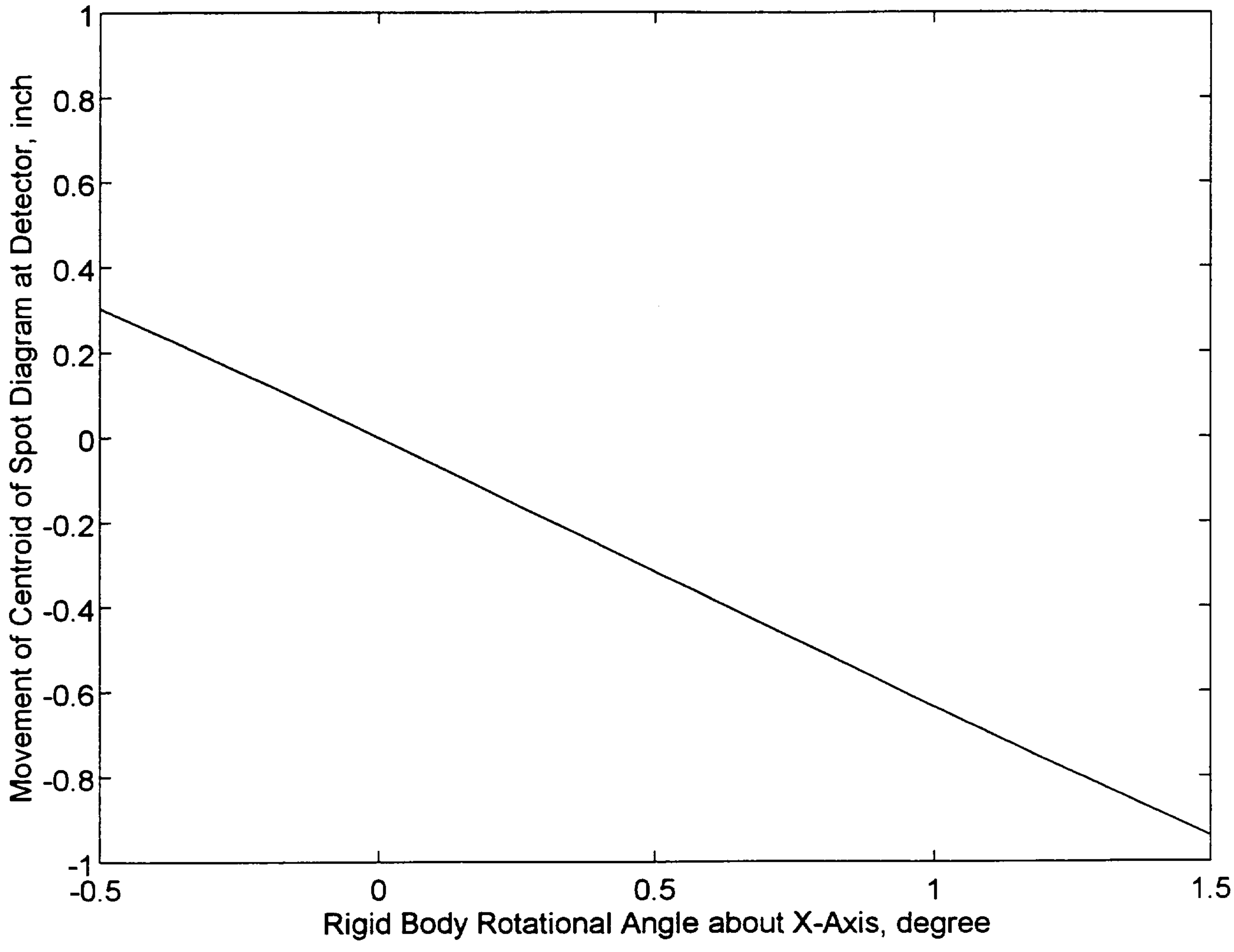


Figure 3.3-1: Movement of Centroid of Spot Diagram at Detector due to SSE Rigid Body Rotational Motion about X-Axis

Case 2:

In order to determine the y-axis translational movement of the Sun image on the CCD detector due to the y-axis translational movement of the Fresnel lens that may result from the flexibility of inflatable supporting structure, the incoming bundle of Sun rays and the Fresnel lens were moved by various distances in the y-axis direction and the ray tray analyses were performed. The y-axis locations of chief ray and center of spot diagram of the collimated Sun rays at the ring lens and the CCD detector were calculated using MACOS for the various movement of the Fresnel lens and are summarized in Table 3.3-2 with respect to the global coordinate system.

Table 3.3-2: Movement of Ring Lens vs. Movement of Sun Image at Detector
(length unit = inch)

Movement of ring lens (y-axis)	Chief ray location at ring lens (y-axis)	Center of spot diagram location at ring lens (y-axis)	Chief ray location at detector (y-axis)	Center of spot diagram location at detector (y-axis)
-0.9	6.49	6.4892	20.4400	20.4400
-0.8	6.59	6.5892	20.4675	20.4640
-0.6	6.79	6.7892	20.5246	20.5209
-0.4	6.99	6.9892	20.5841	20.5803
-0.2	7.19	7.1892	20.6457	20.6417
0.	7.39	7.3892	20.7089	20.7048
0.2	7.59	7.5892	20.7734	20.7692
0.4	7.79	7.7892	20.8388	20.8345
0.6	7.99	7.9892	20.9049	20.9005
0.8	8.19	8.1892	20.9714	20.9669
1.0	8.39	8.3892	21.0380	21.0335
1.2	8.59	8.5892	21.1046	21.1000
1.4	8.79	8.7892	21.1707	21.1663
1.6	8.99	8.9892	21.2362	21.2317
1.8	9.19	9.1892	21.3009	21.2963
2.0	9.39	9.3892	21.3644	21.3598
2.2	9.59	9.5892	21.4262	21.4217
2.4	9.79	9.7892	21.4862	21.4817
2.6	9.99	9.9892	21.5437	21.5393
2.8	10.19	10.1893	21.5983	21.5902

w.r.t. global coordinate system

The actual Sun image movement on the CDD detector due to the y-axis translational movement of the Fresnel lens is determined by calculating the relative displacements of the spot diagram center of the collimated Sun rays at the CCD detector with respect to the nominal positions from Table 3.3-2 and plotted in Figure 3.3-2. It is shown that the 1.18 inch length of CCD detector can allow relative y-axis translational movement of the Fresnel lens with respect to the rest of optical system from -0.9 inch to 2.8 inch. Since two Sun image detecting systems are located symmetrically about the center line of the SSE vehicle, total relative y-axis translational movement of the Fresnel lens with respect to the rest elements of the optical system due to the flexibility of the inflatable supporting structure is ±2.8 inch.

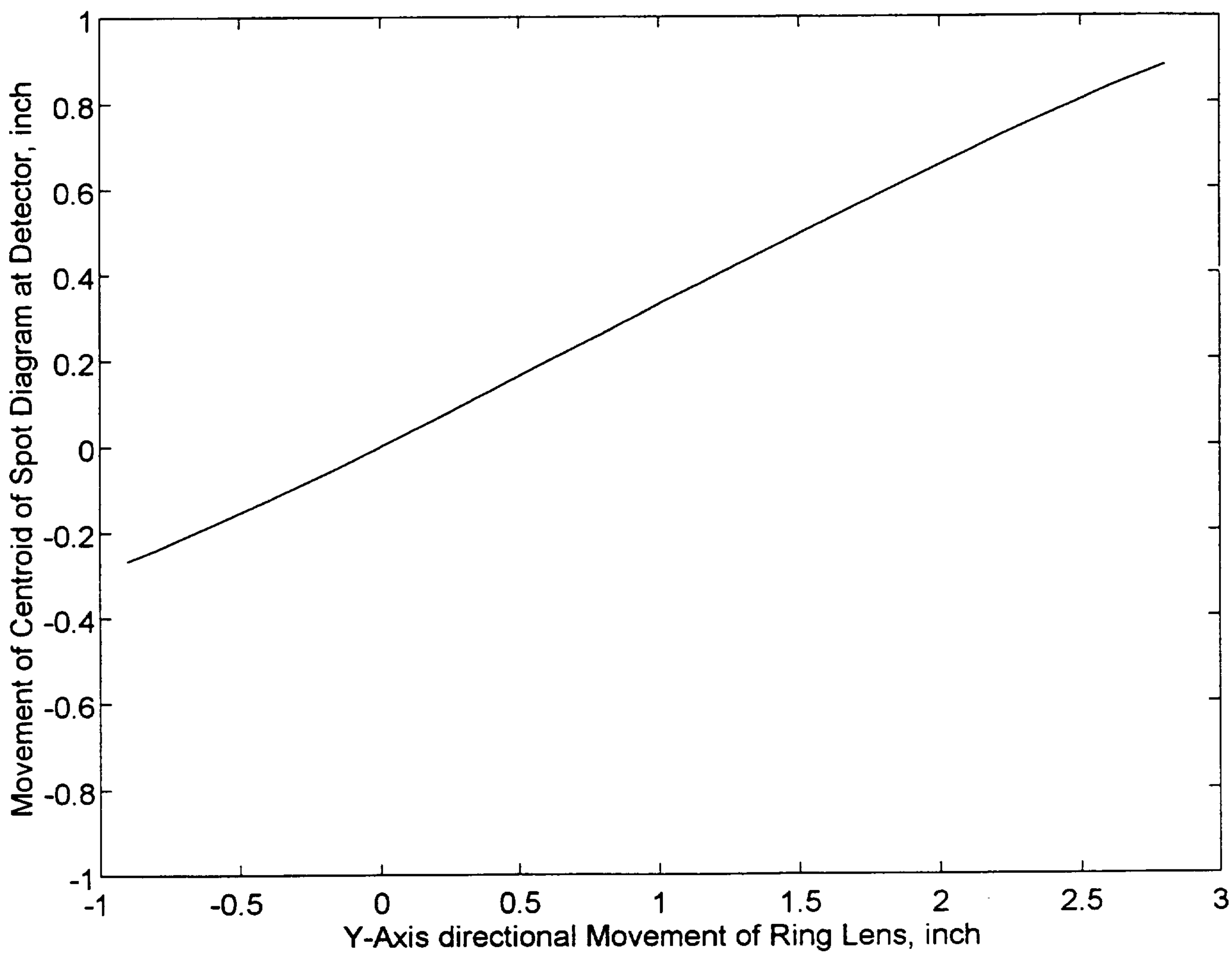


Figure 3.3-2: Movement of Centroid of Spot Diagram at Detector due to Y-Axis Directional Movement of Fresnel Ring Lens

Case 3:

In order to determine the y-axis translational movement of the Sun image on the CCD detector due to the rotation of the Fresnel lens about the x-axis that may result from the flexibility of the inflatable supporting structure, the Fresnel lens were rotated by various angles about the x-axis and the ray tray analyses were performed with a bundle of collimated rays fully covering the width of the ring lens. The y-axis locations of the chief ray and the center of the spot diagram of the collimated Sun rays at the ring lens and the CCD detector were calculated using MACOS for the various rotations of the Fresnel lens. The results are summarized in Table 3.3-3 with respect to the global coordinate system.

Table 3.3-3: Rotation of Ring Lens vs. Movement of Image at Detector
(length unit = inch)

Rotation of ring lens about x-axis (degree)	Chief ray location at ring lens (y-axis)	Center of spot diagram location at ring lens (y-axis)	Chief ray location at detector (y-axis)	Center of spot diagram location at detector (y-axis)
-6.0	7.39	7.3473	20.6521	20.6502
-5.5	7.39	7.3533	20.6542	20.6524
-5.0	7.39	7.3586	20.6569	20.6550
-4.5	7.39	7.3633	20.6600	20.6577
-4.0	7.39	7.3682	20.6636	20.6613
-3.5	7.39	7.3724	20.6676	20.6652
-3.0	7.39	7.3762	20.6721	20.6694
-2.5	7.39	7.3787	20.6771	20.6742
-2.0	7.39	7.3811	20.6825	20.6795
-1.5	7.39	7.3833	20.6884	20.6850
-1.0	7.39	7.3849	20.6948	20.6911
-0.5	7.39	7.3856	20.7016	20.6977
0.	7.39	7.3892	20.7089	20.7048
0.5	7.39	7.3856	20.7167	20.7127
1.0	7.39	7.3849	20.7249	20.7211
1.5	7.39	7.3833	20.7335	20.7301
2.0	7.39	7.3811	20.7426	20.7396
2.5	7.39	7.3787	20.7521	20.7495
3.0	7.39	7.3762	20.7621	20.7601
3.5	7.39	7.3724	20.7724	20.7712
4.0	7.39	7.3682	20.7832	20.7829
4.5	7.39	7.3633	20.7943	20.7951
5.0	7.39	7.3586	20.8058	20.8084
5.5	7.39	7.3533	20.8176	20.8217
6.0	7.39	7.3473	20.8298	20.8364

w.r.t. global coordinate system

The actual Sun image movements on the CDD detector due to the rotations of the Fresnel lens about the x-axis were determined by calculating relative displacements of the spot diagram center of the collimated Sun rays at the CCD detector with respect to the nominal positions from Table 3.3-3 and are plotted in Figure 3.3-3. It is shown that the relative rotation of the Fresnel lens about the x-axis with respect to the rest of the optical system due to the flexibility of the inflatable supporting structure is insignificant comparing to those of Case 1 and Case 2.

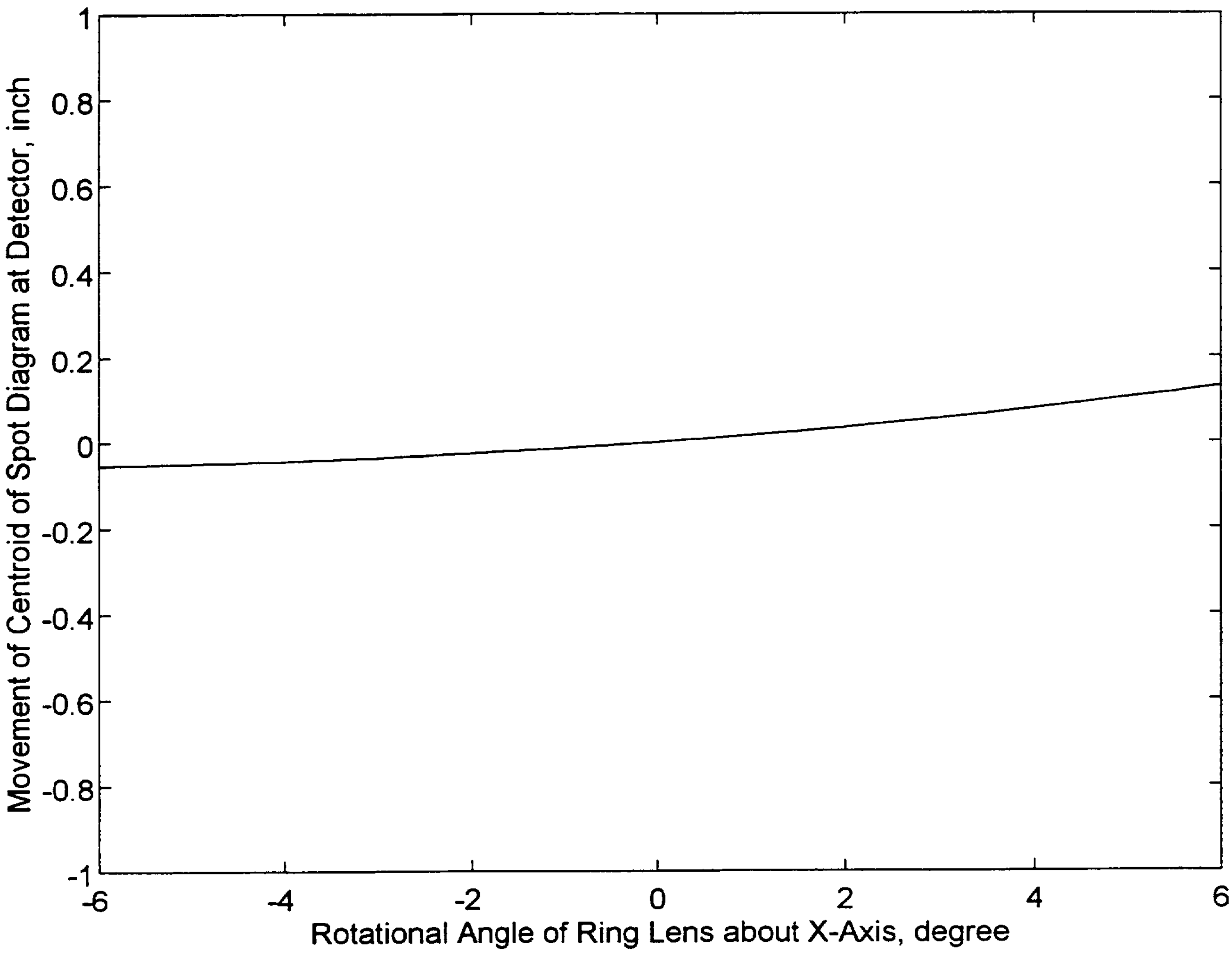


Figure 3.3-3: Movement of Centroid of Spot Diagram at Detector due to Rotational Motion of Fresnel Ring Lens about X-Axis

3.4 Conclusion

A mathematical optical model was developed for the up-to-date configuration and optical prescriptions of SSE Sun image detector system using MACOS software. In order to determine the Sun pointing error of the SSE optical system, the ray tray analyses were performed using the collimated Sun rays without the effects of apparent diameter of Sun and blur. Even though the 0.54 degrees of apparent diameter and blur of Sun may seem to have little effect on the movement of the center of spot diagram of the Sun rays on the CCD detector through 0.4 inch width of the ring lens, further study will be needed to confirm this assumption.

The rigid body rotations of the SSE vehicle about the x-axis and y-axis and the relative x-axis and y-axis translational movements of the Fresnel lens with respect to the rest elements of the SSE optical system result in dominant effects on the movement of the center of spot diagram of the Sun rays on the CCD detector. With the given 1.18 inch length of the CCD detector total field of view allowed for the rigid body rotation of the SSE system about the x-axis is ±1.5 degrees and the allowable relative x-axis and y-axis translational movements of the Fresnel lens with respect to the rest elements of the SSE optical system are ±2.8 inch without rigid body motion. The coupling effects of rigid body motion and flexible motion are not included in this study and further study is required to investigate these effects.

Since there are no distinctions between the movements of the center of spot diagram of the Sun rays on the CCD detector due to the rigid body rotations of the SSE vehicle about the x-axis and the relative y-axis translational movements of the Fresnel lens with respect to the rest of the SSE optical elements, these must be considered to design the attitude controller of the SSE vehicle.

3.5 References

[1] "Modeling and Analysis for Controlled Optical Systems User Manual," Jet Propulsion Laboratory, January 25, 1996

Appendix A
AXAF-I User Defined Controller Subroutine

```
      SUBROUTINE USCC(T,U,X,R,XDOT)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      DIMENSION U(1),X(1),R(1),XDOT(1)
C
      RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE USDC(T,U,R)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      INCLUDE 'DBP.F'
      INCLUDE 'DBC.F'
      DIMENSION U(1),R(1)
C
C======================================================================
C CONTROL LAW SUBROUTINES FOR AXAF.INT: JANUARY 1998
C     Written by William Lightsey/ED12/NASA
C     Modified by Young Kim/UAH
C======================================================================
C
C SUBROUTINE CONTAINING NORMAL POINT AND MANEUVER CONTROL LAW
C PROPORTIONAL GAIN
C       KP(1)=cntdta(1)=6.506D0
C       KP(2)=cntdta(2)=68.382D0
C       KP(3)=cntdta(3)=72.908D0
C INTEGRAL GAIN
C       KI(1)=cntdta(4)=6.506D-3
C       KI(2)=cntdta(5)=3.4191D-2
C       KI(3)=cntdta(6)=3.6454D-2
C RATE GAIN
C       KR(1)=cntdta(7)=325.30D0
C       KR(2)=cntdta(8)=3419.10D0
C       KR(3)=cntdta(9)=3645.40D0
C POSITION LIMITER, LP (rad)
C       THELIM(1)=cntdta(10)=0.05695D0
C       THELIM(2)=cntdta(11)=6.98D-4
C       THELIM(3)=cntdta(12)=6.98D-4
C INTEGRAL LIMITER, LI (rad-sec)
C       CILIM(1)=cntdta(13)=0.06D0
C       CILIM(2)=cntdta(14)=0.011D0
C       CILIM(3)=cntdta(15)=0.01D0
C RATE LIMITER, LR (rad/sec)
cyk       OMELIM(1)=0.0019D0
cyk       OMELIM(2)=0.0019D0
cyk       OMELIM(3)=0.0019D0
c according to DM05 dated on 2/28/97
C       OMELIM(1)=cntdta(16)=1.D06
C       OMELIM(2)=cntdta(17)=1.D06
C       OMELIM(3)=cntdta(18)=1.D06
C BODY TORQUE COMMAND LIMITER (ft-lb)
C       TPCLIM=cntdta(19)=0.25D0
C===================================================================
C
C
      DIMENSION OME(3),THE(3),OMP(3),CI(3),CIP(3),OMI(3),
     &OMR(3),TFF3(3),OMDMC(3),TGG(3),TPC(3),TCF(3),TC(3),
     &CILIM(3),OMELIM(3),THELIM(3),TQUNLD(3),D(6,3),TCRW(6)
C
      DOUBLE PRECISION IV(3,3),KP(3),KI(3),KR(3),KBF(5,3)
C
      IF (T .EQ. 0.D0) THEN          !beginning of initialization
```

```
C
C INITIALIZE PARAMETERS
C
      DO 2 I=1,3
 2       CIP(I)=0.D0
C
C DEFINE PID CONTROL PARAMETERS
C
C SAMPLING TIME
C
      DTFC=0.064D0
ccccccccccccccccccccccccccccccccccccccccccccccccccccc
C PROPORTIONAL GAIN
      KP(1)=cntdta(1)
      KP(2)=cntdta(2)
      KP(3)=cntdta(3)
C INTEGRAL GAIN
      KI(1)=cntdta(4)
      KI(2)=cntdta(5)
      KI(3)=cntdta(6)
C RATE GAIN
      KR(1)=cntdta(7)
      KR(2)=cntdta(8)
      KR(3)=cntdta(9)
C POSITION LIMITER, LP (rad)
      THELIM(1)=cntdta(10)
      THELIM(2)=cntdta(11)
      THELIM(3)=cntdta(12)
C INTEGRAL LIMITER, LI (rad-sec)
      CILIM(1)=cntdta(13)
      CILIM(2)=cntdta(14)
      CILIM(3)=cntdta(15)
C RATE LIMITER, LR (rad/sec)
c according to DM05 dated on 2/28/97
      OMELIM(1)=cntdta(16)
      OMELIM(2)=cntdta(17)
      OMELIM(3)=cntdta(18)
C BODY TORQUE COMMAND LIMITER (ft-lb)
      TPCLIM=cntdta(19)
ccccccccccccccccccccccccccccccccccccccccccccccccccccc
C
C PSEUDO-INVERSE MATRIX FOR RW STEERING LAW
C
      D(1,1)=-0.333333D0
      D(1,2)=-0.333333D0
      D(1,3)=-0.192450D0
      D(2,1)=-0.333333D0
      D(2,2)= 0.D0
      D(2,3)=-0.384900D0
      D(3,1)=-0.333333D0
      D(3,2)= 0.333333D0
      D(3,3)=-0.192450D0
      D(4,1)=-0.333333D0
      D(4,2)= 0.333333D0
      D(4,3)= 0.192450D0
      D(5,1)=-0.333333D0
      D(5,2)= 0.D0
      D(5,3)= 0.384900D0
      D(6,1)=-0.333333D0
      D(6,2)=-0.333333D0
      D(6,3)= 0.192450D0
C
C BENDING FILTER (2ND ORDER DIGITAL FILTER)
C
      KBF(1,1)=7.94213D-5
      KBF(2,1)=1.588426D-4
      KBF(3,1)=7.94213D-5
```

```
      KBF(4,1)=-1.978409D0
      KBF(5,1)=0.978726D0
C
      KBF(1,2)=9.79132D-4
      KBF(2,2)=1.958264D-3
      KBF(3,2)=9.79132D-4
      KBF(4,2)=-1.910409D0
      KBF(5,2)=0.914326D0
C
      KBF(1,3)=9.79132D-4
      KBF(2,3)=1.958264D-3
      KBF(3,3)=9.79132D-4
      KBF(4,3)=-1.910409D0
      KBF(5,3)=0.914326D0
      ENDIF                    !end of initialization
C
C READ INTEGRATING AND RATE GYRO SENSORS OUTPUT
C
      DO 1 I=1,3
         THE(I)=U(I)
 1       OME(I)=U(I+3)
C
C BEGIN CONTROL LAW CALCULATIONS
C
C  LIMIT POSITION ERROR SIGNAL
C
      DO 100 I=1,3
  100 THE(I)=DMAX1(-THELIM(I),DMIN1(THELIM(I),THE(I)))
C
C  INTEGRAL AND PROPORTIONAL PATH SIGNALS
C
      DO 101 I=1,3
      OMP(I)=KP(I)*THE(I)
  101 CI(I)=DTFC*THE(I)+CIP(I)
C
C  LIMIT THE INTEGRAL PATH SIGNAL
C
      DO 57 I=1,3
  57  CI(I)=DMAX1(-CILIM(I),DMIN1(CILIM(I),CI(I)))
      DO 102 I=1,3
      OMI(I)=KI(I)*CI(I)
  102 CIP(I)=CI(I)
C
C  LIMIT THE RATE COMMAND SIGNALS
C
      DO 56 I=1,3
  56  OME(I)=DMAX1(-OMELIM(I),DMIN1(OMELIM(I),OME(I)))
      DO 103 I=1,3
      OMR(I)=KR(I)*OME(I)
C
C COMPUTE FEED FORWARD TORQUE FROM GG TORQUE AND MANEUVER TORQUE
C ** need to include the wXh term if you have a commanded rate
CYK      TFF3(I)=OMDMC(I)*IV(I,I)-TGG(I)-TQUNLD(I)
C
C TOTAL COMMANDED TORQUE SIGNAL PRIOR TO ADDING FEED FORWARD TORQUE
C
C  103 TPC(I)=OMR(I)+OMI(I)+OMP(I)
C NEW CONTROL LAW MOD MOVING INTEGRAL PATH
  103 TPC(I)=OMR(I)+OMP(I)
CYK
      DO 565 I=1,3
 565     TFF3(I)=0.D0
C
C COMMAND TORQUE BENDING FILTER
C
      CALL PCBF(T,KBF,TPC,TCF)
C
```

```
C PROPORTIONALLY LIMIT TOTAL TORQUE COMMAND
C
      DO 104 I=1,3
  104 TCF(I)=DMAX1(-TPCLIM,DMIN1(TPCLIM,TCF(I)))
C
C ADD THE FEED FORWARD TORQUE
C
      DO 131 I=1,3
  131 TCF(I)=TCF(I)+TFF3(I)
C
C TOTAL CONTROL TORQUE AT THE C.M. OF SPACECRAFT
C THIS INCLUDES MODIFICATION TO THE CONTROLLER THAT MOVES THE INTEGRAL PATH
C
      DO 59 I=1,3
      TC(I)= TCF(I)+OMI(I)
  59  CONTINUE
C
C DISTRIBUE TOTAL CONTROL TORQUE TO SIX REACTION USING RW STEERING LAW
C THE SIGN OF RW TORQUE IS OPPOSITE TO ONE OF CONTROL TORQUE OF S/C.
C
      CALL MDM(D,TC,TCRW,6,6,3,1)
C
      DO 595 I=1,6
      R(I)= TCRW(I)
 595  CONTINUE
      RETURN
      END
C=====================================================================
      SUBROUTINE PCBF(T,KBF,TIN,TOUT)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C 2ND ORDER BENDING FILTER FOR PC COMMAND TORQUE
      DOUBLE PRECISION KBF(5,3),TIN(3),TOUT(3),S1(3),S2(3)
      IF(T.EQ.0.) THEN
      DO 1 I=1,3
      S1(I)=0.D0
    1 S2(I)=0.D0
      ENDIF
      DO 2 I=1,3
      TOUT(I)=KBF(1,I)*TIN(I)+S1(I)
      S1(I)=KBF(2,I)*TIN(I)-KBF(4,I)*TOUT(I)+S2(I)
    2 S2(I)=KBF(3,I)*TIN(I)-KBF(5,I)*TOUT(I)
      RETURN
      END
```

Appendix B
AXAF-I TREETOPS Input File AXAFI.INT

```
          TREETOPS REV 10  06/05/95

          SIM CONTROL

 1 SI   0 Title                                                 AXAF-I(1/98)
 2 SI   0 Simulation stop time                                  1000
 3 SI   0 Plot data interval                                    0.064
 4 SI   0 Integration type (R,S or U)                           R
 5 SI   0 Step size (sec)                                       0.0064
 6 SI   0 Sandia integration absolute and relative error
 7 SI   0 Linearization option  (L,Z or N)                      L
 8 SI   0 Restart option          (Y/N)                         N
 9 SI   0 Contact force computation option      (Y/N)           N
10 SI   0 Constraint force computation option  (Y/N)            N
11 SI   0 Small angle speedup option (All,Bypass,First,Nth)     A
12 SI   0 Mass matrix speedup option (All,Bypass,First,Nth)     A
13 SI   0 Non-Linear  speedup option (All,Bypass,First,Nth)     A
14 SI   0 Constraint  speedup option (All,Bypass,First,Nth)     A
15 SI   0 Constraint stabilization option  (Y/N)                N
16 SI   0 Stabilization epsilon

          BODY

17 BO   1 Body ID number                                        1
18 BO   1 Type (Rigid,Flexible,NASTRAN)                         R
19 BO   1 Number of modes
20 BO   1 Modal calculation option (0, 1 or 2)
21 BO   1 Foreshortening option (Y/N)
22 BO   1 Model reduction method (NO,MS,MC,CC,QM,CV)
23 BO   1 NASTRAN data file FORTRAN unit number (40 - 60)
24 BO   1 Number of augmented nodes (0 if none)
25 BO   1 Damping matrix option (NS,CD,HL,SD)
26 BO   1 Constant damping ratio
27 BO   1 Low frequency, High frequency ratios
28 BO   1 Mode ID number, damping ratio
29 BO   1 Conversion factors: Length,Mass,Force
30 BO   1 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
31 BO   1 Moments of inertia (kg-m2) Ixx,Iyy,Izz                4551,35830,35961
32 BO   1 Products of inertia (kg-m2) Ixy,Ixz,Iyz               94,-737,89
33 BO   1 Mass (kg)                                             310.57
34 BO   1 Number of Nodes                                       12
35 BO   1 Node ID, Node coord. (meters) x,y,z                   1,31.32,-0.02,0.09
36 BO   1 Node ID, Node coord. (meters) x,y,z                   2,0,0,0
37 BO   1 Node ID, Node coord. (meters) x,y,z                   3,40.08,2.70,-2.70
38 BO   1 Node ID, Node coord. (meters) x,y,z                   4,38.79,2.70,-2.70
39 BO   1 Node ID, Node coord. (meters) x,y,z                   5,37.51,2.70,-2.70
40 BO   1 Node ID, Node coord. (meters) x,y,z                   6,40.08,-2.70,-2.70
41 BO   1 Node ID, Node coord. (meters) x,y,z                   7,38.79,-2.70,-2.70
42 BO   1 Node ID, Node coord. (meters) x,y,z                   8,37.51,-2.70,-2.70
43 BO   1 Node ID, Node coord. (meters) x,y,z                   9,37.65,4.94,0
44 BO   1 Node ID, Node coord. (meters) x,y,z                   10,37.65,-4.94,0
45 BO   1 Node ID, Node coord. (meters) x,y,z                   11,31,2.12,2.63
46 BO   1 Node ID, Node coord. (meters) x,y,z                   12,31.28,3.28,1.98
47 BO   1 Node ID, Node structual joint ID

48 BO   2 Body ID number                                        2
49 BO   2 Type (Rigid,Flexible,NASTRAN)                         N
50 BO   2 Number of modes                                       6
51 BO   2 Modal calculation option (0, 1 or 2)                  0
52 BO   2 Foreshortening option (Y/N)                           N
53 BO   2 Model reduction method (NO,MS,MC,CC,QM,CV)            MS
54 BO   2 NASTRAN data file FORTRAN unit number (40 - 60)       41
55 BO   2 Number of augmented nodes (0 if none)                 0
```

56	BO	2	Damping matrix option (NS,CD,HL,SD)	CD
57	BO	2	Constant damping ratio	0.
58	BO	2	Low frequency, High frequency ratios	
59	BO	2	Mode ID number, damping ratio	
60	BO	2	Conversion factors: Length,Mass,Force	0.08333,12,1
61	BO	2	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	0
62	BO	2	Moments of inertia (kg-m2) Ixx,Iyy,Izz	
63	BO	2	Products of inertia (kg-m2) Ixy,Ixz,Iyz	
64	BO	2	Mass (kg)	
65	BO	2	Number of Nodes	10
66	BO	2	Node ID, Node coord. (meters) x,y,z	
67	BO	2	Node ID, Node structual joint ID	2,72
68	BO	2	Node ID, Node structual joint ID	3,50
69	BO	2	Node ID, Node structual joint ID	4,54
70	BO	2	Node ID, Node structual joint ID	5,30
71	BO	2	Node ID, Node structual joint ID	6,34
72	BO	2	Node ID, Node structual joint ID	7,10
73	BO	2	Node ID, Node structual joint ID	8,14
74	BO	2	Node ID, Node structual joint ID	9,1
75	BO	2	Node ID, Node structual joint ID	10,4
76	BO	3	Body ID number	3
77	BO	3	Type (Rigid,Flexible,NASTRAN)	N
78	BO	3	Number of modes	6
79	BO	3	Modal calculation option (0, 1 or 2)	0
80	BO	3	Foreshortening option (Y/N)	N
81	BO	3	Model reduction method (NO,MS,MC,CC,QM,CV)	MS
82	BO	3	NASTRAN data file FORTRAN unit number (40 - 60)	42
83	BO	3	Number of augmented nodes (0 if none)	0
84	BO	3	Damping matrix option (NS,CD,HL,SD)	CD
85	BO	3	Constant damping ratio	0
86	BO	3	Low frequency, High frequency ratios	
87	BO	3	Mode ID number, damping ratio	
88	BO	3	Conversion factors: Length,Mass,Force	0.08333,12,1
89	BO	3	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	0
90	BO	3	Moments of inertia (kg-m2) Ixx,Iyy,Izz	
91	BO	3	Products of inertia (kg-m2) Ixy,Ixz,Iyz	
92	BO	3	Mass (kg)	
93	BO	3	Number of Nodes	10
94	BO	3	Node ID, Node coord. (meters) x,y,z	
95	BO	3	Node ID, Node structual joint ID	2,72
96	BO	3	Node ID, Node structual joint ID	3,50
97	BO	3	Node ID, Node structual joint ID	4,54
98	BO	3	Node ID, Node structual joint ID	5,30
99	BO	3	Node ID, Node structual joint ID	6,34
100	BO	3	Node ID, Node structual joint ID	7,10
101	BO	3	Node ID, Node structual joint ID	8,14
102	BO	3	Node ID, Node structual joint ID	9,1
103	BO	3	Node ID, Node structual joint ID	10,4
104	BO	11	Body ID number	11
105	BO	11	Type (Rigid,Flexible,NASTRAN)	R
106	BO	11	Number of modes	
107	BO	11	Modal calculation option (0, 1 or 2)	
108	BO	11	Foreshortening option (Y/N)	
109	BO	11	Model reduction method (NO,MS,MC,CC,QM,CV)	
110	BO	11	NASTRAN data file FORTRAN unit number (40 - 60)	
111	BO	11	Number of augmented nodes (0 if none)	
112	BO	11	Damping matrix option (NS,CD,HL,SD)	
113	BO	11	Constant damping ratio	
114	BO	11	Low frequency, High frequency ratios	
115	BO	11	Mode ID number, damping ratio	
116	BO	11	Conversion factors: Length,Mass,Force	
117	BO	11	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
118	BO	11	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.54E-2,1.54E-2,2.36E-2
119	BO	11	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
120	BO	11	Mass (kg)	0.23
121	BO	11	Number of Nodes	2
122	BO	11	Node ID, Node coord. (meters) x,y,z	1,0,0,0
123	BO	11	Node ID, Node coord. (meters) x,y,z	2,0,0,0
124	BO	11	Node ID, Node structual joint ID	
125	BO	12	Body ID number	12
126	BO	12	Type (Rigid,Flexible,NASTRAN)	R
127	BO	12	Number of modes	

```
128 BO  12 Modal calculation option (0, 1 or 2)
129 BO  12 Foreshortening option (Y/N)
130 BO  12 Model reduction method (NO,MS,MC,CC,QM,CV)
131 BO  12 NASTRAN data file FORTRAN unit number (40 - 60)
132 BO  12 Number of augmented nodes (0 if none)
133 BO  12 Damping matrix option (NS,CD,HL,SD)
134 BO  12 Constant damping ratio
135 BO  12 Low frequency, High frequency ratios
136 BO  12 Mode ID number, damping ratio
137 BO  12 Conversion factors: Length,Mass,Force
138 BO  12 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
139 BO  12 Moments of inertia (kg-m2) Ixx,Iyy,Izz             1.475E-2,1.475E-2,2.2125E-2
140 BO  12 Products of inertia (kg-m2) Ixy,Ixz,Iyz            0,0,0
141 BO  12 Mass (kg)                                          0.1823
142 BO  12 Number of Nodes                                    2
143 BO  12 Node ID, Node coord. (meters) x,y,z                1,0,0,0.1936
144 BO  12 Node ID, Node coord. (meters) x,y,z                2,0,0,0
145 BO  12 Node ID, Node structual joint ID

146 BO  13 Body ID number                                     13
147 BO  13 Type (Rigid,Flexible,NASTRAN)                      R
148 BO  13 Number of modes
149 BO  13 Modal calculation option (0, 1 or 2)
150 BO  13 Foreshortening option (Y/N)
151 BO  13 Model reduction method (NO,MS,MC,CC,QM,CV)
152 BO  13 NASTRAN data file FORTRAN unit number (40 - 60)
153 BO  13 Number of augmented nodes (0 if none)
154 BO  13 Damping matrix option (NS,CD,HL,SD)
155 BO  13 Constant damping ratio
156 BO  13 Low frequency, High frequency ratios
157 BO  13 Mode ID number, damping ratio
158 BO  13 Conversion factors: Length,Mass,Force
159 BO  13 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
160 BO  13 Moments of inertia (kg-m2) Ixx,Iyy,Izz             0.03961,0.03961,0.07921
161 BO  13 Products of inertia (kg-m2) Ixy,Ixz,Iyz            0,0,-1E-6
162 BO  13 Mass (kg)                                          0.3659
163 BO  13 Number of Nodes                                    2
164 BO  13 Node ID, Node coord. (meters) x,y,z                1,0,-5E-6,0
165 BO  13 Node ID, Node coord. (meters) x,y,z                2,0,0,0
166 BO  13 Node ID, Node structual joint ID

167 BO  21 Body ID number                                     21
168 BO  21 Type (Rigid,Flexible,NASTRAN)                      R
169 BO  21 Number of modes
170 BO  21 Modal calculation option (0, 1 or 2)
171 BO  21 Foreshortening option (Y/N)
172 BO  21 Model reduction method (NO,MS,MC,CC,QM,CV)
173 BO  21 NASTRAN data file FORTRAN unit number (40 - 60)
174 BO  21 Number of augmented nodes (0 if none)
175 BO  21 Damping matrix option (NS,CD,HL,SD)
176 BO  21 Constant damping ratio
177 BO  21 Low frequency, High frequency ratios
178 BO  21 Mode ID number, damping ratio
179 BO  21 Conversion factors: Length,Mass,Force
180 BO  21 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
181 BO  21 Moments of inertia (kg-m2) Ixx,Iyy,Izz             1.54E-2,1.54E-2,2.36E-2
182 BO  21 Products of inertia (kg-m2) Ixy,Ixz,Iyz            0,0,0
183 BO  21 Mass (kg)                                          0.23
184 BO  21 Number of Nodes                                    2
185 BO  21 Node ID, Node coord. (meters) x,y,z                1,0,0,0
186 BO  21 Node ID, Node coord. (meters) x,y,z                2,0,0,0
187 BO  21 Node ID, Node structual joint ID

188 BO  22 Body ID number                                     22
189 BO  22 Type (Rigid,Flexible,NASTRAN)                      R
190 BO  22 Number of modes
191 BO  22 Modal calculation option (0, 1 or 2)
192 BO  22 Foreshortening option (Y/N)
193 BO  22 Model reduction method (NO,MS,MC,CC,QM,CV)
194 BO  22 NASTRAN data file FORTRAN unit number (40 - 60)
195 BO  22 Number of augmented nodes (0 if none)
196 BO  22 Damping matrix option (NS,CD,HL,SD)
197 BO  22 Constant damping ratio
198 BO  22 Low frequency, High frequency ratios
199 BO  22 Mode ID number, damping ratio
```

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200 BO  22 Conversion factors: Length,Mass,Force
201 BO  22 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
202 BO  22 Moments of inertia (kg-m2) Ixx,Iyy,Izz              1.475E-2,1.475E-2,2.2125E-2
203 BO  22 Products of inertia (kg-m2) Ixy,Ixz,Iyz             0,0,0
204 BO  22 Mass (kg)                                            0.1823
205 BO  22 Number of Nodes                                      2
206 BO  22 Node ID, Node coord. (meters) x,y,z                  1,0,0,0.1936
207 BO  22 Node ID, Node coord. (meters) x,y,z                  2,0,0,0
208 BO  22 Node ID, Node structual joint ID

209 BO  23 Body ID number                                       23
210 BO  23 Type (Rigid,Flexible,NASTRAN)                        R
211 BO  23 Number of modes
212 BO  23 Modal calculation option (0, 1 or 2)
213 BO  23 Foreshortening option (Y/N)
214 BO  23 Model reduction method (NO,MS,MC,CC,QM,CV)
215 BO  23 NASTRAN data file FORTRAN unit number (40 - 60)
216 BO  23 Number of augmented nodes (0 if none)
217 BO  23 Damping matrix option (NS,CD,HL,SD)
218 BO  23 Constant damping ratio
219 BO  23 Low frequency, High frequency ratios
220 BO  23 Mode ID number, damping ratio
221 BO  23 Conversion factors: Length,Mass,Force
222 BO  23 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
223 BO  23 Moments of inertia (kg-m2) Ixx,Iyy,Izz              0.03961,0.03961,0.07921
224 BO  23 Products of inertia (kg-m2) Ixy,Ixz,Iyz             0,0,-1E-6
225 BO  23 Mass (kg)                                            0.3659
226 BO  23 Number of Nodes                                      2
227 BO  23 Node ID, Node coord. (meters) x,y,z                  1,0,-5E-6,0
228 BO  23 Node ID, Node coord. (meters) x,y,z                  2,0,0,0
229 BO  23 Node ID, Node structual joint ID

230 BO  31 Body ID number                                       31
231 BO  31 Type (Rigid,Flexible,NASTRAN)                        R
232 BO  31 Number of modes
233 BO  31 Modal calculation option (0, 1 or 2)
234 BO  31 Foreshortening option (Y/N)
235 BO  31 Model reduction method (NO,MS,MC,CC,QM,CV)
236 BO  31 NASTRAN data file FORTRAN unit number (40 - 60)
237 BO  31 Number of augmented nodes (0 if none)
238 BO  31 Damping matrix option (NS,CD,HL,SD)
239 BO  31 Constant damping ratio
240 BO  31 Low frequency, High frequency ratios
241 BO  31 Mode ID number, damping ratio
242 BO  31 Conversion factors: Length,Mass,Force
243 BO  31 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
244 BO  31 Moments of inertia (kg-m2) Ixx,Iyy,Izz              1.54E-2,1.54E-2,2.36E-2
245 BO  31 Products of inertia (kg-m2) Ixy,Ixz,Iyz             0,0,0
246 BO  31 Mass (kg)                                            0.23
247 BO  31 Number of Nodes                                      2
248 BO  31 Node ID, Node coord. (meters) x,y,z                  1,0,0,0
249 BO  31 Node ID, Node coord. (meters) x,y,z                  2,0,0,0
250 BO  31 Node ID, Node structual joint ID

251 BO  32 Body ID number                                       32
252 BO  32 Type (Rigid,Flexible,NASTRAN)                        R
253 BO  32 Number of modes
254 BO  32 Modal calculation option (0, 1 or 2)
255 BO  32 Foreshortening option (Y/N)
256 BO  32 Model reduction method (NO,MS,MC,CC,QM,CV)
257 BO  32 NASTRAN data file FORTRAN unit number (40 - 60)
258 BO  32 Number of augmented nodes (0 if none)
259 BO  32 Damping matrix option (NS,CD,HL,SD)
260 BO  32 Constant damping ratio
261 BO  32 Low frequency, High frequency ratios
262 BO  32 Mode ID number, damping ratio
263 BO  32 Conversion factors: Length,Mass,Force
264 BO  32 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
265 BO  32 Moments of inertia (kg-m2) Ixx,Iyy,Izz              1.475E-2,1.475E-2,2.2125E-2
266 BO  32 Products of inertia (kg-m2) Ixy,Ixz,Iyz             0,0,0
267 BO  32 Mass (kg)                                            0.1823
268 BO  32 Number of Nodes                                      2
269 BO  32 Node ID, Node coord. (meters) x,y,z                  1,0,0,0.1936
270 BO  32 Node ID, Node coord. (meters) x,y,z                  2,0,0,0
271 BO  32 Node ID, Node structual joint ID
```

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272 BO  33 Body ID number                                          33
273 BO  33 Type (Rigid,Flexible,NASTRAN)                           R
274 BO  33 Number of modes
275 BO  33 Modal calculation option (0, 1 or 2)
276 BO  33 Foreshortening option (Y/N)
277 BO  33 Model reduction method (NO,MS,MC,CC,QM,CV)
278 BO  33 NASTRAN data file FORTRAN unit number (40 - 60)
279 BO  33 Number of augmented nodes (0 if none)
280 BO  33 Damping matrix option (NS,CD,HL,SD)
281 BO  33 Constant damping ratio
282 BO  33 Low frequency, High frequency ratios
283 BO  33 Mode ID number, damping ratio
284 BO  33 Conversion factors: Length,Mass,Force
285 BO  33 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
286 BO  33 Moments of inertia (kg-m2) Ixx,Iyy,Izz              0.03961,0.03961,0.07921
287 BO  33 Products of inertia (kg-m2) Ixy,Ixz,Iyz             0,0,-1E-6
288 BO  33 Mass (kg)                                           0.3659
289 BO  33 Number of Nodes                                     2
290 BO  33 Node ID, Node coord. (meters) x,y,z                 1,0,-5E-6,0
291 BO  33 Node ID, Node coord. (meters) x,y,z                 2,0,0,0
292 BO  33 Node ID, Node structual joint ID

293 BO  41 Body ID number                                      41
294 BO  41 Type (Rigid,Flexible,NASTRAN)                       R
295 BO  41 Number of modes
296 BO  41 Modal calculation option (0, 1 or 2)
297 BO  41 Foreshortening option (Y/N)
298 BO  41 Model reduction method (NO,MS,MC,CC,QM,CV)
299 BO  41 NASTRAN data file FORTRAN unit number (40 - 60)
300 BO  41 Number of augmented nodes (0 if none)
301 BO  41 Damping matrix option (NS,CD,HL,SD)
302 BO  41 Constant damping ratio
303 BO  41 Low frequency, High frequency ratios
304 BO  41 Mode ID number, damping ratio
305 BO  41 Conversion factors: Length,Mass,Force
306 BO  41 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
307 BO  41 Moments of inertia (kg-m2) Ixx,Iyy,Izz              1.54E-2,1.54E-2,2.36E-2
308 BO  41 Products of inertia (kg-m2) Ixy,Ixz,Iyz             0,0,0
309 BO  41 Mass (kg)                                           0.23
310 BO  41 Number of Nodes                                     2
311 BO  41 Node ID, Node coord. (meters) x,y,z                 1,0,0,0
312 BO  41 Node ID, Node coord. (meters) x,y,z                 2,0,0,0
313 BO  41 Node ID, Node structual joint ID

314 BO  42 Body ID number                                      42
315 BO  42 Type (Rigid,Flexible,NASTRAN)                       R
316 BO  42 Number of modes
317 BO  42 Modal calculation option (0, 1 or 2)
318 BO  42 Foreshortening option (Y/N)
319 BO  42 Model reduction method (NO,MS,MC,CC,QM,CV)
320 BO  42 NASTRAN data file FORTRAN unit number (40 - 60)
321 BO  42 Number of augmented nodes (0 if none)
322 BO  42 Damping matrix option (NS,CD,HL,SD)
323 BO  42 Constant damping ratio
324 BO  42 Low frequency, High frequency ratios
325 BO  42 Mode ID number, damping ratio
326 BO  42 Conversion factors: Length,Mass,Force
327 BO  42 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
328 BO  42 Moments of inertia (kg-m2) Ixx,Iyy,Izz              1.475E-2,1.475E-2,2.2125E-2
329 BO  42 Products of inertia (kg-m2) Ixy,Ixz,Iyz             0,0,0
330 BO  42 Mass (kg)                                           0.1823
331 BO  42 Number of Nodes                                     2
332 BO  42 Node ID, Node coord. (meters) x,y,z                 1,0,0,0.1936
333 BO  42 Node ID, Node coord. (meters) x,y,z                 2,0,0,0
334 BO  42 Node ID, Node structual joint ID

335 BO  43 Body ID number                                      43
336 BO  43 Type (Rigid,Flexible,NASTRAN)                       R
337 BO  43 Number of modes
338 BO  43 Modal calculation option (0, 1 or 2)
339 BO  43 Foreshortening option (Y/N)
340 BO  43 Model reduction method (NO,MS,MC,CC,QM,CV)
341 BO  43 NASTRAN data file FORTRAN unit number (40 - 60)
342 BO  43 Number of augmented nodes (0 if none)
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343 BO  43 Damping matrix option (NS,CD,HL,SD)
344 BO  43 Constant damping ratio
345 BO  43 Low frequency, High frequency ratios
346 BO  43 Mode ID number, damping ratio
347 BO  43 Conversion factors: Length,Mass,Force
348 BO  43 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
349 BO  43 Moments of inertia (kg-m2) Ixx,Iyy,Izz            0.03961,0.03961,0.07921
350 BO  43 Products of inertia (kg-m2) Ixy,Ixz,Iyz           0,0,-1E-6
351 BO  43 Mass (kg)                                         0.3659
352 BO  43 Number of Nodes                                   2
353 BO  43 Node ID, Node coord. (meters) x,y,z               1,0,-5E-6,0
354 BO  43 Node ID, Node coord. (meters) x,y,z               2,0,0,0
355 BO  43 Node ID, Node structual joint ID

356 BO  51 Body ID number                                    51
357 BO  51 Type (Rigid,Flexible,NASTRAN)                     R
358 BO  51 Number of modes
359 BO  51 Modal calculation option (0, 1 or 2)
360 BO  51 Foreshortening option (Y/N)
361 BO  51 Model reduction method (NO,MS,MC,CC,QM,CV)
362 BO  51 NASTRAN data file FORTRAN unit number (40 - 60)
363 BO  51 Number of augmented nodes (0 if none)
364 BO  51 Damping matrix option (NS,CD,HL,SD)
365 BO  51 Constant damping ratio
366 BO  51 Low frequency, High frequency ratios
367 BO  51 Mode ID number, damping ratio
368 BO  51 Conversion factors: Length,Mass,Force
369 BO  51 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
370 BO  51 Moments of inertia (kg-m2) Ixx,Iyy,Izz            1.54E-2,1.54E-2,2.36E-2
371 BO  51 Products of inertia (kg-m2) Ixy,Ixz,Iyz           0,0,0
372 BO  51 Mass (kg)                                         0.23
373 BO  51 Number of Nodes                                   2
374 BO  51 Node ID, Node coord. (meters) x,y,z               1,0,0,0
375 BO  51 Node ID, Node coord. (meters) x,y,z               2,0,0,0
376 BO  51 Node ID, Node structual joint ID

377 BO  52 Body ID number                                    52
378 BO  52 Type (Rigid,Flexible,NASTRAN)                     R
379 BO  52 Number of modes
380 BO  52 Modal calculation option (0, 1 or 2)
381 BO  52 Foreshortening option (Y/N)
382 BO  52 Model reduction method (NO,MS,MC,CC,QM,CV)
383 BO  52 NASTRAN data file FORTRAN unit number (40 - 60)
384 BO  52 Number of augmented nodes (0 if none)
385 BO  52 Damping matrix option (NS,CD,HL,SD)
386 BO  52 Constant damping ratio
387 BO  52 Low frequency, High frequency ratios
388 BO  52 Mode ID number, damping ratio
389 BO  52 Conversion factors: Length,Mass,Force
390 BO  52 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
391 BO  52 Moments of inertia (kg-m2) Ixx,Iyy,Izz            1.475E-2,1.475E-2,2.2125E-2
392 BO  52 Products of inertia (kg-m2) Ixy,Ixz,Iyz           0,0,0
393 BO  52 Mass (kg)                                         0.1823
394 BO  52 Number of Nodes                                   2
395 BO  52 Node ID, Node coord. (meters) x,y,z               1,0,0,0.1936
396 BO  52 Node ID, Node coord. (meters) x,y,z               2,0,0,0
397 BO  52 Node ID, Node structual joint ID

398 BO  53 Body ID number                                    53
399 BO  53 Type (Rigid,Flexible,NASTRAN)                     R
400 BO  53 Number of modes
401 BO  53 Modal calculation option (0, 1 or 2)
402 BO  53 Foreshortening option (Y/N)
403 BO  53 Model reduction method (NO,MS,MC,CC,QM,CV)
404 BO  53 NASTRAN data file FORTRAN unit number (40 - 60)
405 BO  53 Number of augmented nodes (0 if none)
406 BO  53 Damping matrix option (NS,CD,HL,SD)
407 BO  53 Constant damping ratio
408 BO  53 Low frequency, High frequency ratios
409 BO  53 Mode ID number, damping ratio
410 BO  53 Conversion factors: Length,Mass,Force
411 BO  53 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
412 BO  53 Moments of inertia (kg-m2) Ixx,Iyy,Izz            0.03961,0.03961,0.07921
413 BO  53 Products of inertia (kg-m2) Ixy,Ixz,Iyz           0,0,-1E-6
414 BO  53 Mass (kg)                                         0.3659
```

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415 BO  53 Node ID, Number of Nodes                                 2
416 BO  53 Node ID, Node coord. (meters) x,y,z                      1,0,-5E-6,0
417 BO  53 Node ID, Node coord. (meters) x,y,z                      2,0,0,0
418 BO  53 Node ID, Node structual joint ID

419 BO  61 Body ID number                                           61
420 BO  61 Type (Rigid,Flexible,NASTRAN)                            R
421 BO  61 Number of modes
422 BO  61 Modal calculation option (0, 1 or 2)
423 BO  61 Foreshortening option (Y/N)
424 BO  61 Model reduction method (NO,MS,MC,CC,QM,CV)
425 BO  61 NASTRAN data file FORTRAN unit number (40 - 60)
426 BO  61 Number of augmented nodes (0 if none)
427 BO  61 Damping matrix option (NS,CD,HL,SD)
428 BO  61 Constant damping ratio
429 BO  61 Low frequency, High frequency ratios
430 BO  61 Mode ID number, damping ratio
431 BO  61 Conversion factors: Length,Mass,Force
432 BO  61 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
433 BO  61 Moments of inertia (kg-m2) Ixx,Iyy,Izz                 1.54E-2,1.54E-2,2.36E-2
434 BO  61 Products of inertia (kg-m2) Ixy,Ixz,Iyz                0,0,0
435 BO  61 Mass (kg)                                               0.23
436 BO  61 Number of Nodes                                         2
437 BO  61 Node ID, Node coord. (meters) x,y,z                     1,0,0,0
438 BO  61 Node ID, Node coord. (meters) x,y,z                     2,0,0,0
439 BO  61 Node ID, Node structual joint ID

440 BO  62 Body ID number                                          62
441 BO  62 Type (Rigid,Flexible,NASTRAN)                           R
442 BO  62 Number of modes
443 BO  62 Modal calculation option (0, 1 or 2)
444 BO  62 Foreshortening option (Y/N)
445 BO  62 Model reduction method (NO,MS,MC,CC,QM,CV)
446 BO  62 NASTRAN data file FORTRAN unit number (40 - 60)
447 BO  62 Number of augmented nodes (0 if none)
448 BO  62 Damping matrix option (NS,CD,HL,SD)
449 BO  62 Constant damping ratio
450 BO  62 Low frequency, High frequency ratios
451 BO  62 Mode ID number, damping ratio
452 BO  62 Conversion factors: Length,Mass,Force
453 BO  62 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
454 BO  62 Moments of inertia (kg-m2) Ixx,Iyy,Izz                 1.475E-2,1.475E-2,2.2125E-2
455 BO  62 Products of inertia (kg-m2) Ixy,Ixz,Iyz                0,0,0
456 BO  62 Mass (kg)                                               0.1823
457 BO  62 Number of Nodes                                         2
458 BO  62 Node ID, Node coord. (meters) x,y,z                     1,0,0,0.1936
459 BO  62 Node ID, Node coord. (meters) x,y,z                     2,0,0,0
460 BO  62 Node ID, Node structual joint ID

461 BO  63 Body ID number                                          63
462 BO  63 Type (Rigid,Flexible,NASTRAN)                           R
463 BO  63 Number of modes
464 BO  63 Modal calculation option (0, 1 or 2)
465 BO  63 Foreshortening option (Y/N)
466 BO  63 Model reduction method (NO,MS,MC,CC,QM,CV)
467 BO  63 NASTRAN data file FORTRAN unit number (40 - 60)
468 BO  63 Number of augmented nodes (0 if none)
469 BO  63 Damping matrix option (NS,CD,HL,SD)
470 BO  63 Constant damping ratio
471 BO  63 Low frequency, High frequency ratios
472 BO  63 Mode ID number, damping ratio
473 BO  63 Conversion factors: Length,Mass,Force
474 BO  63 Inertia reference node (0=Bdy Ref Frm; 1=mass cen) 1
475 BO  63 Moments of inertia (kg-m2) Ixx,Iyy,Izz                 0.03961,0.03961,0.07921
476 BO  63 Products of inertia (kg-m2) Ixy,Ixz,Iyz                0,0,-1E-6
477 BO  63 Mass (kg)                                               0.3659
478 BO  63 Number of Nodes                                         2
479 BO  63 Node ID, Node coord. (meters) x,y,z                     1,0,-5E-6,0
480 BO  63 Node ID, Node coord. (meters) x,y,z                     2,0,0,0
481 BO  63 Node ID, Node structual joint ID

           HINGE

482 HI   1 Hinge ID number                                         1
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483 HI   1 Inboard body ID, Outboard body ID                 0,1
484 HI   1 "p" node ID, "q" node ID                          0,1
485 HI   1 Number of rotation DOFs, Rotation option (F or G)  3,G
486 HI   1 L1 unit vector in inboard body coord. x,y,z       1,0,0
487 HI   1 L1 unit vector in outboard body coord. x,y,z      1,0,0
488 HI   1 L2 unit vector in inboard body coord. x,y,z
489 HI   1 L2 unit vector in outboard body coord. x,y,z
490 HI   1 L3 unit vector in inboard body coord. x,y,z       0,0,1
491 HI   1 L3 unit vector in outboard body coord. x,y,z      0,0,1
492 HI   1 Initial rotation angles (deg)                     0,2.77778E-2,2.77778E-2
493 HI   1 Initial rotation rates (deg/sec)                  0,8.E-4,8.E-4
494 HI   1 Rotation stiffness (newton-meters/rad)            0 0 0
495 HI   1 Rotation damping (newton-meters/rad/sec)          0 0 0
496 HI   1 Null torque angles (deg)                          0 0 0
497 HI   1 Number of translation DOFs                        0
498 HI   1 First translation unit vector    g1               1 0 0
499 HI   1 Second translation unit vector   g2               0 1 0
500 HI   1 Third translation unit vector    g3               0 0 1
501 HI   1 Initial translation (meters)                      0 0 0
502 HI   1 Initial translation velocity (meters/sec)
503 HI   1 Translation stiffness (newtons/meters)
504 HI   1 Translation damping (newtons/meter/sec)
505 HI   1 Null force translations

506 HI   2 Hinge ID number                                   2
507 HI   2 Inboard body ID, Outboard body ID                 1,2
508 HI   2 "p" node ID, "q" node ID                          9,2
509 HI   2  No of rotation DOFs, Hinge 1 rotation option(F/G) 0
510 HI   2 L1 unit vector in inboard body coord. x,y,z       0 1 0
511 HI   2 L1 unit vector in outboard body coord. x,y,z      0 1 0
512 HI   2 L2 unit vector in inboard body coord. x,y,z
513 HI   2 L2 unit vector in outboard body coord. x,y,z
514 HI   2 L3 unit vector in inboard body coord. x,y,z       1 0 0
515 HI   2 L3 unit vector in outboard body coord. x,y,z      1 0 0
516 HI   2 Initial rotation angles (deg)                     0 0 0
517 HI   2 Initial rotation rates (deg/sec)
518 HI   2 Rotation stiffness (newton-meters/rad)
519 HI   2 Rotation damping (newton-meters/rad/sec)
520 HI   2 Null torque angles (deg)
521 HI   2 Number of translation DOFs                        0
522 HI   2 First translation unit vector    g1               1 0 0
523 HI   2 Second translation unit vector   g2               0 1 0
524 HI   2 Third translation unit vector    g3               0 0 1
525 HI   2 Initial translation (meters)                      0 0 0
526 HI   2 Initial translation velocity (meters/sec)
527 HI   2 Translation stiffness (newtons/meters)
528 HI   2 Translation damping (newtons/meter/sec)
529 HI   2 Null force translations

530 HI   3 Hinge ID number                                   3
531 HI   3 Inboard body ID, Outboard body ID                 1,3
532 HI   3 "p" node ID, "q" node ID                          10,2
533 HI   3 Number of rotation DOFs, Rotation option (F or G)  0
534 HI   3 L1 unit vector in inboard body coord. x,y,z       0,-1,0
535 HI   3 L1 unit vector in outboard body coord. x,y,z      0,1,0
536 HI   3 L2 unit vector in inboard body coord. x,y,z
537 HI   3 L2 unit vector in outboard body coord. x,y,z
538 HI   3 L3 unit vector in inboard body coord. x,y,z       1,0,0
539 HI   3 L3 unit vector in outboard body coord. x,y,z      1,0,0
540 HI   3 Initial rotation angles (deg)                     0 0 0
541 HI   3 Initial rotation rates (deg/sec)
542 HI   3 Rotation stiffness (newton-meters/rad)
543 HI   3 Rotation damping (newton-meters/rad/sec)
544 HI   3 Null torque angles (deg)
545 HI   3 Number of translation DOFs                        0
546 HI   3 First translation unit vector    g1               1 0 0
547 HI   3 Second translation unit vector   g2               0 1 0
548 HI   3 Third translation unit vector    g3               0 0 1
549 HI   3 Initial translation (meters)                      0 0 0
550 HI   3 Initial translation velocity (meters/sec)
551 HI   3 Translation stiffness (newtons/meters)
552 HI   3 Translation damping (newtons/meter/sec)
553 HI   3 Null force translations

554 HI  11 Hinge ID number                                   11
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555 HI  11 Inboard body ID, Outboard body ID                       1,11
556 HI  11 "p" node ID, "q" node ID                                3,1
557 HI  11 Number of rotation DOFs, Rotation option (F or G)       3
558 HI  11 L1 unit vector in inboard body coord. x,y,z             0.5,0.75,0.4330127
559 HI  11 L1 unit vector in outboard body coord. x,y,z            0,0,1
560 HI  11 L2 unit vector in inboard body coord. x,y,z
561 HI  11 L2 unit vector in outboard body coord. x,y,z
562 HI  11 L3 unit vector in inboard body coord. x,y,z             0.8660254,-0.4330127,-0.25
563 HI  11 L3 unit vector in outboard body coord. x,y,z            0,1,0
564 HI  11 Initial rotation angles (deg)                           0 0 0
565 HI  11 Initial rotation rates (deg/sec)                        0 0 0
566 HI  11 Rotation stiffness (newton-meters/rad)                  204.7 204.7 204.7
567 HI  11 Rotation damping (newton-meters/rad/sec)                0.362 0.362 0.362
568 HI  11 Null torque angles (deg)                                0 0 0
569 HI  11 Number of translation DOFs                              3
570 HI  11 First translation unit vector   g1                      1 0 0
571 HI  11 Second translation unit vector  g2                      0 1 0
572 HI  11 Third translation unit vector   g3                      0 0 1
573 HI  11 Initial translation (meters)                            0 0 0
574 HI  11 Initial translation velocity (meters/sec)               0 0 0
575 HI  11 Translation stiffness (newtons/meters)                  2121.3 2121.3 2121.3
576 HI  11 Translation damping (newtons/meter/sec)                 3.75 3.75 3.75
577 HI  11 Null force translations                                 0 0 0

578 HI  12 Hinge ID number                                         12
579 HI  12 Inboard body ID, Outboard body ID                       11,12
580 HI  12 "p" node ID, "q" node ID                                2,2
581 HI  12  Number of rotation DOFs                                0
582 HI  12 L1 unit vector in inboard body coord. x,y,z             0,0,1
583 HI  12 L1 unit vector in outboard body coord. x,y,z            0,0,1
584 HI  12 L2 unit vector in inboard body coord. x,y,z
585 HI  12 L2 unit vector in outboard body coord. x,y,z
586 HI  12 L3 unit vector in inboard body coord. x,y,z             0,1,0
587 HI  12 L3 unit vector in outboard body coord. x,y,z            0,1,0
588 HI  12 Initial rotation angles (deg)                           0 0 0
589 HI  12 Initial rotation rates (deg/sec)
590 HI  12 Rotation stiffness (newton-meters/rad)
591 HI  12 Rotation damping (newton-meters/rad/sec)
592 HI  12 Null torque angles (deg)
593 HI  12 Number of translation DOFs                              0
594 HI  12 First translation unit vector   g1                      1 0 0
595 HI  12 Second translation unit vector  g2                      0 1 0
596 HI  12 Third translation unit vector   g3                      0 0 1
597 HI  12 Initial translation (meters)                            0 0 0
598 HI  12 Initial translation velocity (meters/sec)
599 HI  12 Translation stiffness (newtons/meters)
600 HI  12 Translation damping (newtons/meter/sec)
601 HI  12 Null force translations

602 HI  13 Hinge ID number                                         13
603 HI  13 Inboard body ID, Outboard body ID                       12,13
604 HI  13 "p" node ID, "q" node ID                                1,1
605 HI  13  Number of rotation DOFs                                1
606 HI  13 L1 unit vector in inboard body coord. x,y,z             0,0,1
607 HI  13 L1 unit vector in outboard body coord. x,y,z            0,0,1
608 HI  13 L2 unit vector in inboard body coord. x,y,z
609 HI  13 L2 unit vector in outboard body coord. x,y,z
610 HI  13 L3 unit vector in inboard body coord. x,y,z             0,1,0
611 HI  13 L3 unit vector in outboard body coord. x,y,z            0,1,0
612 HI  13 Initial rotation angles (deg)                           0 0 0
613 HI  13 Initial rotation rates (deg/sec)                        13500
614 HI  13 Rotation stiffness (newton-meters/rad)                  0
615 HI  13 Rotation damping (newton-meters/rad/sec)                0
616 HI  13 Null torque angles (deg)                                0
617 HI  13 Number of translation DOFs                              0
618 HI  13 First translation unit vector   g1                      1 0 0
619 HI  13 Second translation unit vector  g2                      0 1 0
620 HI  13 Third translation unit vector   g3                      0 0 1
621 HI  13 Initial translation (meters)                            0 0 0
622 HI  13 Initial translation velocity (meters/sec)
623 HI  13 Translation stiffness (newtons/meters)
624 HI  13 Translation damping (newtons/meter/sec)
625 HI  13 Null force translations

626 HI  21 Hinge ID number                                         21
```

627	HI	21	Inboard body ID, Outboard body ID	1,21
628	HI	21	"p" node ID, "q" node ID	4,1
629	HI	21	Number of rotation DOFs, Rotation option (F or G)	3
630	HI	21	L1 unit vector in inboard body coord. x,y,z	0.5,0,0.8660254
631	HI	21	L1 unit vector in outboard body coord. x,y,z	0,0,1
632	HI	21	L2 unit vector in inboard body coord. x,y,z	
633	HI	21	L2 unit vector in outboard body coord. x,y,z	
634	HI	21	L3 unit vector in inboard body coord. x,y,z	0.8660254,0,-0.5
635	HI	21	L3 unit vector in outboard body coord. x,y,z	0,1,0
636	HI	21	Initial rotation angles (deg)	0 0 0
637	HI	21	Initial rotation rates (deg/sec)	0 0 0
638	HI	21	Rotation stiffness (newton-meters/rad)	204.7 204.7 204.7
639	HI	21	Rotation damping (newton-meters/rad/sec)	0.362 0.362 0.362
640	HI	21	Null torque angles (deg)	0 0 0
641	HI	21	Number of translation DOFs	3
642	HI	21	First translation unit vector g1	1 0 0
643	HI	21	Second translation unit vector g2	0 1 0
644	HI	21	Third translation unit vector g3	0 0 1
645	HI	21	Initial translation (meters)	0 0 0
646	HI	21	Initial translation velocity (meters/sec)	0 0 0
647	HI	21	Translation stiffness (newtons/meters)	2121.3 2121.3 2121.3
648	HI	21	Translation damping (newtons/meter/sec)	3.75 3.75 3.75
649	HI	21	Null force translations	0 0 0
650	HI	22	Hinge ID number	22
651	HI	22	Inboard body ID, Outboard body ID	21,22
652	HI	22	"p" node ID, "q" node ID	2,2
653	HI	22	Number of rotation DOFs	0
654	HI	22	L1 unit vector in inboard body coord. x,y,z	0,0,1
655	HI	22	L1 unit vector in outboard body coord. x,y,z	0,0,1
656	HI	22	L2 unit vector in inboard body coord. x,y,z	
657	HI	22	L2 unit vector in outboard body coord. x,y,z	
658	HI	22	L3 unit vector in inboard body coord. x,y,z	0,1,0
659	HI	22	L3 unit vector in outboard body coord. x,y,z	0,1,0
660	HI	22	Initial rotation angles (deg)	0 0 0
661	HI	22	Initial rotation rates (deg/sec)	
662	HI	22	Rotation stiffness (newton-meters/rad)	
663	HI	22	Rotation damping (newton-meters/rad/sec)	
664	HI	22	Null torque angles (deg)	
665	HI	22	Number of translation DOFs	0
666	HI	22	First translation unit vector g1	1 0 0
667	HI	22	Second translation unit vector g2	0 1 0
668	HI	22	Third translation unit vector g3	0 0 1
669	HI	22	Initial translation (meters)	0 0 0
670	HI	22	Initial translation velocity (meters/sec)	
671	HI	22	Translation stiffness (newtons/meters)	
672	HI	22	Translation damping (newtons/meter/sec)	
673	HI	22	Null force translations	
674	HI	23	Hinge ID number	23
675	HI	23	Inboard body ID, Outboard body ID	22,23
676	HI	23	"p" node ID, "q" node ID	1,1
677	HI	23	Number of rotation DOFs	1
678	HI	23	L1 unit vector in inboard body coord. x,y,z	0,0,1
679	HI	23	L1 unit vector in outboard body coord. x,y,z	0,0,1
680	HI	23	L2 unit vector in inboard body coord. x,y,z	
681	HI	23	L2 unit vector in outboard body coord. x,y,z	
682	HI	23	L3 unit vector in inboard body coord. x,y,z	0,1,0
683	HI	23	L3 unit vector in outboard body coord. x,y,z	0,1,0
684	HI	23	Initial rotation angles (deg)	0 0 0
685	HI	23	Initial rotation rates (deg/sec)	-13500
686	HI	23	Rotation stiffness (newton-meters/rad)	0
687	HI	23	Rotation damping (newton-meters/rad/sec)	0
688	HI	23	Null torque angles (deg)	0
689	HI	23	Number of translation DOFs	0
690	HI	23	First translation unit vector g1	1 0 0
691	HI	23	Second translation unit vector g2	0 1 0
692	HI	23	Third translation unit vector g3	0 0 1
693	HI	23	Initial translation (meters)	0 0 0
694	HI	23	Initial translation velocity (meters/sec)	
695	HI	23	Translation stiffness (newtons/meters)	
696	HI	23	Translation damping (newtons/meter/sec)	
697	HI	23	Null force translations	
698	HI	31	Hinge ID number	31

```
699 HI  31 Inboard body ID, Outboard body ID                  1,31
700 HI  31 "p" node ID, "q" node ID                           5,1
701 HI  31 Number of rotation DOFs, Rotation option (F or G)  3
702 HI  31 L1 unit vector in inboard body coord. x,y,z        0.5,-0.75,0.4330127
703 HI  31 L1 unit vector in outboard body coord. x,y,z       0,0,1
704 HI  31 L2 unit vector in inboard body coord. x,y,z
705 HI  31 L2 unit vector in outboard body coord. x,y,z
706 HI  31 L3 unit vector in inboard body coord. x,y,z        0.8660254,0.4330127,-0.25
707 HI  31 L3 unit vector in outboard body coord. x,y,z       0,1,0
708 HI  31 Initial rotation angles (deg)                      0 0 0
709 HI  31 Initial rotation rates (deg/sec)                   0 0 0
710 HI  31 Rotation stiffness (newton-meters/rad)             204.7 204.7 204.7
711 HI  31 Rotation damping (newton-meters/rad/sec)           0.362 0.362 0.362
712 HI  31 Null torque angles (deg)                           0 0 0
713 HI  31 Number of translation DOFs                         3
714 HI  31 First translation unit vector   g1                 1 0 0
715 HI  31 Second translation unit vector  g2                 0 1 0
716 HI  31 Third translation unit vector   g3                 0 0 1
717 HI  31 Initial translation (meters)                       0 0 0
718 HI  31 Initial translation velocity (meters/sec)          0 0 0
719 HI  31 Translation stiffness (newtons/meters)             2121.3 2121.3 2121.3
720 HI  31 Translation damping (newtons/meter/sec)            3.75 3.75 3.75
721 HI  31 Null force translations                            0 0 0

722 HI  32 Hinge ID number                                    32
723 HI  32 Inboard body ID, Outboard body ID                  31,32
724 HI  32 "p" node ID, "q" node ID                           2,2
725 HI  32  Number of rotation DOFs                           0
726 HI  32 L1 unit vector in inboard body coord. x,y,z        0,0,1
727 HI  32 L1 unit vector in outboard body coord. x,y,z       0,0,1
728 HI  32 L2 unit vector in inboard body coord. x,y,z
729 HI  32 L2 unit vector in outboard body coord. x,y,z
730 HI  32 L3 unit vector in inboard body coord. x,y,z        0,1,0
731 HI  32 L3 unit vector in outboard body coord. x,y,z       0,1,0
732 HI  32 Initial rotation angles (deg)                      0 0 0
733 HI  32 Initial rotation rates (deg/sec)
734 HI  32 Rotation stiffness (newton-meters/rad)
735 HI  32 Rotation damping (newton-meters/rad/sec)
736 HI  32 Null torque angles (deg)
737 HI  32 Number of translation DOFs                         0
738 HI  32 First translation unit vector   g1                 1 0 0
739 HI  32 Second translation unit vector  g2                 0 1 0
740 HI  32 Third translation unit vector   g3                 0 0 1
741 HI  32 Initial translation (meters)                       0 0 0
742 HI  32 Initial translation velocity (meters/sec)
743 HI  32 Translation stiffness (newtons/meters)
744 HI  32 Translation damping (newtons/meter/sec)
745 HI  32 Null force translations

746 HI  33 Hinge ID number                                    33
747 HI  33 Inboard body ID, Outboard body ID                  32,33
748 HI  33 "p" node ID, "q" node ID                           1,1
749 HI  33  Number of rotation DOFs                           1
750 HI  33 L1 unit vector in inboard body coord. x,y,z        0,0,1
751 HI  33 L1 unit vector in outboard body coord. x,y,z       0,0,1
752 HI  33 L2 unit vector in inboard body coord. x,y,z
753 HI  33 L2 unit vector in outboard body coord. x,y,z
754 HI  33 L3 unit vector in inboard body coord. x,y,z        0,1,0
755 HI  33 L3 unit vector in outboard body coord. x,y,z       0,1,0
756 HI  33 Initial rotation angles (deg)                      0 0 0
757 HI  33 Initial rotation rates (deg/sec)                   13500
758 HI  33 Rotation stiffness (newton-meters/rad)             0
759 HI  33 Rotation damping (newton-meters/rad/sec)           0
760 HI  33 Null torque angles (deg)                           0
761 HI  33 Number of translation DOFs                         0
762 HI  33 First translation unit vector   g1                 1 0 0
763 HI  33 Second translation unit vector  g2                 0 1 0
764 HI  33 Third translation unit vector   g3                 0 0 1
765 HI  33 Initial translation (meters)                       0 0 0
766 HI  33 Initial translation velocity (meters/sec)
767 HI  33 Translation stiffness (newtons/meters)
768 HI  33 Translation damping (newtons/meter/sec)
769 HI  33 Null force translations

770 HI  41 Hinge ID number                                    41
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771	HI	41	Inboard body ID, Outboard body ID	1,41
772	HI	41	"p" node ID, "q" node ID	6,1
773	HI	41	Number of rotation DOFs, Rotation option (F or G)	3
774	HI	41	L1 unit vector in inboard body coord. x,y,z	0.5,-0.75,-0.4330127
775	HI	41	L1 unit vector in outboard body coord. x,y,z	0,0,1
776	HI	41	L2 unit vector in inboard body coord. x,y,z	
777	HI	41	L2 unit vector in outboard body coord. x,y,z	
778	HI	41	L3 unit vector in inboard body coord. x,y,z	0.8660254,0.4330127,0.25
779	HI	41	L3 unit vector in outboard body coord. x,y,z	0,1,0
780	HI	41	Initial rotation angles (deg)	0 0 0
781	HI	41	Initial rotation rates (deg/sec)	0 0 0
782	HI	41	Rotation stiffness (newton-meters/rad)	204.7 204.7 204.7
783	HI	41	Rotation damping (newton-meters/rad/sec)	0.362 0.362 0.362
784	HI	41	Null torque angles (deg)	0 0 0
785	HI	41	Number of translation DOFs	3
786	HI	41	First translation unit vector g1	1 0 0
787	HI	41	Second translation unit vector g2	0 1 0
788	HI	41	Third translation unit vector g3	0 0 1
789	HI	41	Initial translation (meters)	0 0 0
790	HI	41	Initial translation velocity (meters/sec)	0 0 0
791	HI	41	Translation stiffness (newtons/meters)	2121.3 2121.3 2121.3
792	HI	41	Translation damping (newtons/meter/sec)	3.75 3.75 3.75
793	HI	41	Null force translations	0 0 0
794	HI	42	Hinge ID number	42
795	HI	42	Inboard body ID, Outboard body ID	41,42
796	HI	42	"p" node ID, "q" node ID	2,2
797	HI	42	Number of rotation DOFs	0
798	HI	42	L1 unit vector in inboard body coord. x,y,z	0,0,1
799	HI	42	L1 unit vector in outboard body coord. x,y,z	0,0,1
800	HI	42	L2 unit vector in inboard body coord. x,y,z	
801	HI	42	L2 unit vector in outboard body coord. x,y,z	
802	HI	42	L3 unit vector in inboard body coord. x,y,z	0,1,0
803	HI	42	L3 unit vector in outboard body coord. x,y,z	0,1,0
804	HI	42	Initial rotation angles (deg)	0 0 0
805	HI	42	Initial rotation rates (deg/sec)	
806	HI	42	Rotation stiffness (newton-meters/rad)	
807	HI	42	Rotation damping (newton-meters/rad/sec)	
808	HI	42	Null torque angles (deg)	
809	HI	42	Number of translation DOFs	0
810	HI	42	First translation unit vector g1	1 0 0
811	HI	42	Second translation unit vector g2	0 1 0
812	HI	42	Third translation unit vector g3	0 0 1
813	HI	42	Initial translation (meters)	0 0 0
814	HI	42	Initial translation velocity (meters/sec)	
815	HI	42	Translation stiffness (newtons/meters)	
816	HI	42	Translation damping (newtons/meter/sec)	
817	HI	42	Null force translations	
818	HI	43	Hinge ID number	43
819	HI	43	Inboard body ID, Outboard body ID	42,43
820	HI	43	"p" node ID, "q" node ID	1,1
821	HI	43	Number of rotation DOFs	1
822	HI	43	L1 unit vector in inboard body coord. x,y,z	0,0,1
823	HI	43	L1 unit vector in outboard body coord. x,y,z	0,0,1
824	HI	43	L2 unit vector in inboard body coord. x,y,z	
825	HI	43	L2 unit vector in outboard body coord. x,y,z	
826	HI	43	L3 unit vector in inboard body coord. x,y,z	0,1,0
827	HI	43	L3 unit vector in outboard body coord. x,y,z	0,1,0
828	HI	43	Initial rotation angles (deg)	0 0 0
829	HI	43	Initial rotation rates (deg/sec)	-13500
830	HI	43	Rotation stiffness (newton-meters/rad)	0
831	HI	43	Rotation damping (newton-meters/rad/sec)	0
832	HI	43	Null torque angles (deg)	0
833	HI	43	Number of translation DOFs	0
834	HI	43	First translation unit vector g1	1 0 0
835	HI	43	Second translation unit vector g2	0 1 0
836	HI	43	Third translation unit vector g3	0 0 1
837	HI	43	Initial translation (meters)	0 0 0
838	HI	43	Initial translation velocity (meters/sec)	
839	HI	43	Translation stiffness (newtons/meters)	
840	HI	43	Translation damping (newtons/meter/sec)	
841	HI	43	Null force translations	
842	HI	51	Hinge ID number	51

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843 HI  51 Inboard body ID, Outboard body ID                  1,51
844 HI  51 "p" node ID, "q" node ID                           7,1
845 HI  51 Number of rotation DOFs, Rotation option (F or G)  3
846 HI  51 L1 unit vector in inboard body coord. x,y,z        0.5,0,-0.8660254
847 HI  51 L1 unit vector in outboard body coord. x,y,z       0,0,1
848 HI  51 L2 unit vector in inboard body coord. x,y,z
849 HI  51 L2 unit vector in outboard body coord. x,y,z
850 HI  51 L3 unit vector in inboard body coord. x,y,z        0.8660254,0,0.5
851 HI  51 L3 unit vector in outboard body coord. x,y,z       0,1,0
852 HI  51 Initial rotation angles (deg)                      0 0 0
853 HI  51 Initial rotation rates (deg/sec)                   0 0 0
854 HI  51 Rotation stiffness (newton-meters/rad)             204.7 204.7 204.7
855 HI  51 Rotation damping (newton-meters/rad/sec)           0.362 0.362 0.362
856 HI  51 Null torque angles (deg)                           0 0 0
857 HI  51 Number of translation DOFs                         3
858 HI  51 First translation unit vector   g1                 1 0 0
859 HI  51 Second translation unit vector  g2                 0 1 0
860 HI  51 Third translation unit vector   g3                 0 0 1
861 HI  51 Initial translation (meters)                       0 0 0
862 HI  51 Initial translation velocity (meters/sec)          0 0 0
863 HI  51 Translation stiffness (newtons/meters)             2121.3 2121.3 2121.3
864 HI  51 Translation damping (newtons/meter/sec)            3.75 3.75 3.75
865 HI  51 Null force translations                            0 0 0

866 HI  52 Hinge ID number                                    52
867 HI  52 Inboard body ID, Outboard body ID                  51,52
868 HI  52 "p" node ID, "q" node ID                           2,2
869 HI  52  Number of rotation DOFs                           0
870 HI  52 L1 unit vector in inboard body coord. x,y,z        0,0,1
871 HI  52 L1 unit vector in outboard body coord. x,y,z       0,0,1
872 HI  52 L2 unit vector in inboard body coord. x,y,z
873 HI  52 L2 unit vector in outboard body coord. x,y,z
874 HI  52 L3 unit vector in inboard body coord. x,y,z        0,1,0
875 HI  52 L3 unit vector in outboard body coord. x,y,z       0,1,0
876 HI  52 Initial rotation angles (deg)                      0 0 0
877 HI  52 Initial rotation rates (deg/sec)
878 HI  52 Rotation stiffness (newton-meters/rad)
879 HI  52 Rotation damping (newton-meters/rad/sec)
880 HI  52 Null torque angles (deg)
881 HI  52 Number of translation DOFs                         0
882 HI  52 First translation unit vector   g1                 1 0 0
883 HI  52 Second translation unit vector  g2                 0 1 0
884 HI  52 Third translation unit vector   g3                 0 0 1
885 HI  52 Initial translation (meters)                       0 0 0
886 HI  52 Initial translation velocity (meters/sec)
887 HI  52 Translation stiffness (newtons/meters)
888 HI  52 Translation damping (newtons/meter/sec)
889 HI  52 Null force translations

890 HI  53 Hinge ID number                                    53
891 HI  53 Inboard body ID, Outboard body ID                  52,53
892 HI  53 "p" node ID, "q" node ID                           1,1
893 HI  53  Number of rotation DOFs                           1
894 HI  53 L1 unit vector in inboard body coord. x,y,z        0,0,1
895 HI  53 L1 unit vector in outboard body coord. x,y,z       0,0,1
896 HI  53 L2 unit vector in inboard body coord. x,y,z
897 HI  53 L2 unit vector in outboard body coord. x,y,z
898 HI  53 L3 unit vector in inboard body coord. x,y,z        0,1,0
899 HI  53 L3 unit vector in outboard body coord. x,y,z       0,1,0
900 HI  53 Initial rotation angles (deg)                      0 0 0
901 HI  53 Initial rotation rates (deg/sec)                   13500
902 HI  53 Rotation stiffness (newton-meters/rad)             0
903 HI  53 Rotation damping (newton-meters/rad/sec)           0
904 HI  53 Null torque angles (deg)                           0
905 HI  53 Number of translation DOFs                         0
906 HI  53 First translation unit vector   g1                 1 0 0
907 HI  53 Second translation unit vector  g2                 0 1 0
908 HI  53 Third translation unit vector   g3                 0 0 1
909 HI  53 Initial translation (meters)                       0 0 0
910 HI  53 Initial translation velocity (meters/sec)
911 HI  53 Translation stiffness (newtons/meters)
912 HI  53 Translation damping (newtons/meter/sec)
913 HI  53 Null force translations

914 HI  61 Hinge ID number                                    61
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915 HI  61 Inboard body ID, Outboard body ID                     1,61
916 HI  61 "p" node ID, "q" node ID                              8,1
917 HI  61 Number of rotation DOFs, Rotation option (F or G)     3
918 HI  61 L1 unit vector in inboard body coord. x,y,z           0.5,0.75,-0.4330127
919 HI  61 L1 unit vector in outboard body coord. x,y,z          0,0,1
920 HI  61 L2 unit vector in inboard body coord. x,y,z
921 HI  61 L2 unit vector in outboard body coord. x,y,z
922 HI  61 L3 unit vector in inboard body coord. x,y,z           0.8660254,-0.4330127,0.25
923 HI  61 L3 unit vector in outboard body coord. x,y,z          0,1,0
924 HI  61 Initial rotation angles (deg)                         0 0 0
925 HI  61 Initial rotation rates (deg/sec)                      0 0 0
926 HI  61 Rotation stiffness (newton-meters/rad)                204.7 204.7 204.7
927 HI  61 Rotation damping (newton-meters/rad/sec)              0.362 0.362 0.362
928 HI  61 Null torque angles (deg)                              0 0 0
929 HI  61 Number of translation DOFs                            3
930 HI  61 First translation unit vector   g1                    1 0 0
931 HI  61 Second translation unit vector  g2                    0 1 0
932 HI  61 Third translation unit vector   g3                    0 0 1
933 HI  61 Initial translation (meters)                          0 0 0
934 HI  61 Initial translation velocity (meters/sec)             0 0 0
935 HI  61 Translation stiffness (newtons/meters)                2121.3 2121.3 2121.3
936 HI  61 Translation damping (newtons/meter/sec)               3.75 3.75 3.75
937 HI  61 Null force translations                               0 0 0

938 HI  62 Hinge ID number                                       62
939 HI  62 Inboard body ID, Outboard body ID                     61,62
940 HI  62 "p" node ID, "q" node ID                              2,2
941 HI  62  Number of rotation DOFs                              0
942 HI  62 L1 unit vector in inboard body coord. x,y,z           0,0,1
943 HI  62 L1 unit vector in outboard body coord. x,y,z          0,0,1
944 HI  62 L2 unit vector in inboard body coord. x,y,z
945 HI  62 L2 unit vector in outboard body coord. x,y,z
946 HI  62 L3 unit vector in inboard body coord. x,y,z           0,1,0
947 HI  62 L3 unit vector in outboard body coord. x,y,z          0,1,0
948 HI  62 Initial rotation angles (deg)                         0 0 0
949 HI  62 Initial rotation rates (deg/sec)
950 HI  62 Rotation stiffness (newton-meters/rad)
951 HI  62 Rotation damping (newton-meters/rad/sec)
952 HI  62 Null torque angles (deg)
953 HI  62 Number of translation DOFs                            0
954 HI  62 First translation unit vector   g1                    1 0 0
955 HI  62 Second translation unit vector  g2                    0 1 0
956 HI  62 Third translation unit vector   g3                    0 0 1
957 HI  62 Initial translation (meters)                          0 0 0
958 HI  62 Initial translation velocity (meters/sec)
959 HI  62 Translation stiffness (newtons/meters)
960 HI  62 Translation damping (newtons/meter/sec)
961 HI  62 Null force translations

962 HI  63 Hinge ID number                                       63
963 HI  63 Inboard body ID, Outboard body ID                     62,63
964 HI  63 "p" node ID, "q" node ID                              1,1
965 HI  63  Number of rotation DOFs                              1
966 HI  63 L1 unit vector in inboard body coord. x,y,z           0,0,1
967 HI  63 L1 unit vector in outboard body coord. x,y,z          0,0,1
968 HI  63 L2 unit vector in inboard body coord. x,y,z
969 HI  63 L2 unit vector in outboard body coord. x,y,z
970 HI  63 L3 unit vector in inboard body coord. x,y,z           0,1,0
971 HI  63 L3 unit vector in outboard body coord. x,y,z          0,1,0
972 HI  63 Initial rotation angles (deg)                         0 0 0
973 HI  63 Initial rotation rates (deg/sec)                      -13500
974 HI  63 Rotation stiffness (newton-meters/rad)                0
975 HI  63 Rotation damping (newton-meters/rad/sec)              0
976 HI  63 Null torque angles (deg)                              0
977 HI  63 Number of translation DOFs                            0
978 HI  63 First translation unit vector   g1                    1 0 0
979 HI  63 Second translation unit vector  g2                    0 1 0
980 HI  63 Third translation unit vector   g3                    0 0 1
981 HI  63 Initial translation (meters)                          0 0 0
982 HI  63 Initial translation velocity (meters/sec)
983 HI  63 Translation stiffness (newtons/meters)
984 HI  63 Translation damping (newtons/meter/sec)
985 HI  63 Null force translations

           SENSOR
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986	SE	11	Sensor ID number	11
987	SE	11	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	I
988	SE	11	Mounting point body ID, Mounting point node ID	1,1
989	SE	11	Second mounting point body ID, Second node ID	
990	SE	11	Input axis unit vector (IA) x,y,z	1,0,0
991	SE	11	Mounting point Hinge index, Axis index	
992	SE	11	First focal plane unit vector (Fp1) x,y,z	
993	SE	11	Second focal plane unit vector (Fp2) x,y,z	
994	SE	11	Sun/Star unit vector (Us) x,y,z	
995	SE	11	Euler Angle Sequence (1-6)	
996	SE	11	CMG ID number and Gimbal number	
997	SE	12	Sensor ID number	12
998	SE	12	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	I
999	SE	12	Mounting point body ID, Mounting point node ID	1,1
1000	SE	12	Second mounting point body ID, Second node ID	
1001	SE	12	Input axis unit vector (IA) x,y,z	0,1,0
1002	SE	12	Mounting point Hinge index, Axis index	
1003	SE	12	First focal plane unit vector (Fp1) x,y,z	
1004	SE	12	Second focal plane unit vector (Fp2) x,y,z	
1005	SE	12	Sun/Star unit vector (Us) x,y,z	
1006	SE	12	Euler Angle Sequence (1-6)	
1007	SE	12	CMG ID number and Gimbal number	
1008	SE	13	Sensor ID number	13
1009	SE	13	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	I
1010	SE	13	Mounting point body ID, Mounting point node ID	1,1
1011	SE	13	Second mounting point body ID, Second node ID	
1012	SE	13	Input axis unit vector (IA) x,y,z	0,0,1
1013	SE	13	Mounting point Hinge index, Axis index	
1014	SE	13	First focal plane unit vector (Fp1) x,y,z	
1015	SE	13	Second focal plane unit vector (Fp2) x,y,z	
1016	SE	13	Sun/Star unit vector (Us) x,y,z	
1017	SE	13	Euler Angle Sequence (1-6)	
1018	SE	13	CMG ID number and Gimbal number	
1019	SE	14	Sensor ID number	14
1020	SE	14	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	G
1021	SE	14	Mounting point body ID, Mounting point node ID	1,1
1022	SE	14	Second mounting point body ID, Second node ID	
1023	SE	14	Input axis unit vector (IA) x,y,z	1,0,0
1024	SE	14	Mounting point Hinge index, Axis index	
1025	SE	14	First focal plane unit vector (Fp1) x,y,z	
1026	SE	14	Second focal plane unit vector (Fp2) x,y,z	
1027	SE	14	Sun/Star unit vector (Us) x,y,z	
1028	SE	14	Euler Angle Sequence (1-6)	
1029	SE	14	CMG ID number and Gimbal number	
1030	SE	15	Sensor ID number	15
1031	SE	15	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	G
1032	SE	15	Mounting point body ID, Mounting point node ID	1,1
1033	SE	15	Second mounting point body ID, Second node ID	
1034	SE	15	Input axis unit vector (IA) x,y,z	0,1,0
1035	SE	15	Mounting point Hinge index, Axis index	
1036	SE	15	First focal plane unit vector (Fp1) x,y,z	
1037	SE	15	Second focal plane unit vector (Fp2) x,y,z	
1038	SE	15	Sun/Star unit vector (Us) x,y,z	
1039	SE	15	Euler Angle Sequence (1-6)	
1040	SE	15	CMG ID number and Gimbal number	
1041	SE	16	Sensor ID number	16
1042	SE	16	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	G
1043	SE	16	Mounting point body ID, Mounting point node ID	1,1
1044	SE	16	Second mounting point body ID, Second node ID	
1045	SE	16	Input axis unit vector (IA) x,y,z	0,0,1
1046	SE	16	Mounting point Hinge index, Axis index	
1047	SE	16	First focal plane unit vector (Fp1) x,y,z	
1048	SE	16	Second focal plane unit vector (Fp2) x,y,z	
1049	SE	16	Sun/Star unit vector (Us) x,y,z	
1050	SE	16	Euler Angle Sequence (1-6)	
1051	SE	16	CMG ID number and Gimbal number	
1052	SE	1	Sensor ID number	1

```
1053 SE   1 Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)      IM
1054 SE   1 Mounting point body ID, Mounting point node ID     1,1
1055 SE   1 Second mounting point body ID, Second node ID
1056 SE   1 Input axis unit vector (IA) x,y,z
1057 SE   1 Mounting point Hinge index, Axis index
1058 SE   1 First focal plane unit vector  (Fp1) x,y,z
1059 SE   1 Second focal plane unit vector (Fp2) x,y,z
1060 SE   1 Sun/Star unit vector (Us) x,y,z
1061 SE   1 Euler Angle Sequence (1-6)                         1
1062 SE   1 CMG ID number and Gimbal number

            ACTR

1063 AC  13 Actuator ID number                                 13
1064 AC  13 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)                T
1065 AC  13 Actuator location; Node or Hinge (N or H)
1066 AC  13 Mounting point body ID number, node ID number
1067 AC  13 Second mounting point body ID, second node ID
1068 AC  13 Output axis unit vector x,y,z
1069 AC  13 Mounting point Hinge index, Axis index             13,1
1070 AC  13 Rotor spin axis unit vector x,y,z
1071 AC  13 Initial rotor momentum, H
1072 AC  13 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)
1073 AC  13 Outer gimbal axis unit vector x,y,z
1074 AC  13 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1075 AC  13 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)
1076 AC  13 Inner gimbal axis unit vector x,y,z
1077 AC  13 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1078 AC  13 Initial length and rate, y(to) and ydot(to)
1079 AC  13 Constants; K1 or wo, n or zeta, Kg, Jm
1080 AC  13 Non-linearities; TLim, Tco, Dz

1081 AC  23 Actuator ID number                                 23
1082 AC  23 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)                T
1083 AC  23 Actuator location; Node or Hinge (N or H)
1084 AC  23 Mounting point body ID number, node ID number
1085 AC  23 Second mounting point body ID, second node ID
1086 AC  23 Output axis unit vector x,y,z
1087 AC  23 Mounting point Hinge index, Axis index             23,1
1088 AC  23 Rotor spin axis unit vector x,y,z
1089 AC  23 Initial rotor momentum, H
1090 AC  23 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)
1091 AC  23 Outer gimbal axis unit vector x,y,z
1092 AC  23 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1093 AC  23 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)
1094 AC  23 Inner gimbal axis unit vector x,y,z
1095 AC  23 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1096 AC  23 Initial length and rate, y(to) and ydot(to)
1097 AC  23 Constants; K1 or wo, n or zeta, Kg, Jm
1098 AC  23 Non-linearities; TLim, Tco, Dz

1099 AC  33 Actuator ID number                                 33
1100 AC  33 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)                T
1101 AC  33 Actuator location; Node or Hinge (N or H)
1102 AC  33 Mounting point body ID number, node ID number
1103 AC  33 Second mounting point body ID, second node ID
1104 AC  33 Output axis unit vector x,y,z
1105 AC  33 Mounting point Hinge index, Axis index             33,1
1106 AC  33 Rotor spin axis unit vector x,y,z
1107 AC  33 Initial rotor momentum, H
1108 AC  33 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)
1109 AC  33 Outer gimbal axis unit vector x,y,z
1110 AC  33 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1111 AC  33 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)
1112 AC  33 Inner gimbal axis unit vector x,y,z
1113 AC  33 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1114 AC  33 Initial length and rate, y(to) and ydot(to)
1115 AC  33 Constants; K1 or wo, n or zeta, Kg, Jm
1116 AC  33 Non-linearities; TLim, Tco, Dz

1117 AC  43 Actuator ID number                                 43
1118 AC  43 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)                T
1119 AC  43 Actuator location; Node or Hinge (N or H)
1120 AC  43 Mounting point body ID number, node ID number
```

```
1121 AC  43 Second mounting point body ID, second node ID
1122 AC  43 Output axis unit vector x,y,z
1123 AC  43 Mounting point Hinge index, Axis index              43,1
1124 AC  43 Rotor spin axis unit vector x,y,z
1125 AC  43 Initial rotor momentum, H
1126 AC  43 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)
1127 AC  43 Outer gimbal axis unit vector x,y,z
1128 AC  43 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1129 AC  43 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)
1130 AC  43 Inner gimbal axis unit vector x,y,z
1131 AC  43 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1132 AC  43 Initial length and rate, y(to) and ydot(to)
1133 AC  43 Constants; K1 or wo, n or zeta, Kg, Jm
1134 AC  43 Non-linearities; TLim, Tco, Dz

1135 AC  53 Actuator ID number                                  53
1136 AC  53 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)                 T
1137 AC  53 Actuator location; Node or Hinge (N or H)
1138 AC  53 Mounting point body ID number, node ID number
1139 AC  53 Second mounting point body ID, second node ID
1140 AC  53 Output axis unit vector x,y,z
1141 AC  53 Mounting point Hinge index, Axis index              53,1
1142 AC  53 Rotor spin axis unit vector x,y,z
1143 AC  53 Initial rotor momentum, H
1144 AC  53 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)
1145 AC  53 Outer gimbal axis unit vector x,y,z
1146 AC  53 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1147 AC  53 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)
1148 AC  53 Inner gimbal axis unit vector x,y,z
1149 AC  53 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1150 AC  53 Initial length and rate, y(to) and ydot(to)
1151 AC  53 Constants; K1 or wo, n or zeta, Kg, Jm
1152 AC  53 Non-linearities; TLim, Tco, Dz

1153 AC  63 Actuator ID number                                  63
1154 AC  63 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)                 T
1155 AC  63 Actuator location; Node or Hinge (N or H)
1156 AC  63 Mounting point body ID number, node ID number
1157 AC  63 Second mounting point body ID, second node ID
1158 AC  63 Output axis unit vector x,y,z
1159 AC  63 Mounting point Hinge index, Axis index              63,1
1160 AC  63 Rotor spin axis unit vector x,y,z
1161 AC  63 Initial rotor momentum, H
1162 AC  63 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)
1163 AC  63 Outer gimbal axis unit vector x,y,z
1164 AC  63 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1165 AC  63 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)
1166 AC  63 Inner gimbal axis unit vector x,y,z
1167 AC  63 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)
1168 AC  63 Initial length and rate, y(to) and ydot(to)
1169 AC  63 Constants; K1 or wo, n or zeta, Kg, Jm
1170 AC  63 Non-linearities; TLim, Tco, Dz

            CONTROLLER

1171 CO   1 Controller ID number                                1
1172 CO   1 Controller type (CB,CM,DB,DM,UC,UD)                 UD
1173 CO   1 Sample time (sec)                                   0.064
1174 CO   1 Number of inputs, Number of outputs                 6,6
1175 CO   1 Number of states
1176 CO   1 Output No., Input type (I,S,T), Input ID, Gain

            INTERCONNECT

1177 IN  13 Interconnect ID number                              13
1178 IN  13 Source type(S,C, or F),Source ID,Source row #       C,1,1
1179 IN  13 Destination type(A or C),Dest ID,Dest row #         A,13,1
1180 IN  13 Gain                                                1

1181 IN  23 Interconnect ID number                              23
1182 IN  23 Source type(S,C, or F),Source ID,Source row #       C,1,2
1183 IN  23 Destination type(A or C),Dest ID,Dest row #         A,23,1
1184 IN  23 Gain                                                1
```

```
1185 IN  33 Interconnect ID number                            33
1186 IN  33 Source type(S,C, or F),Source ID,Source row #     C,1,3
1187 IN  33 Destination type(A or C),Dest ID,Dest row #       A,33,1
1188 IN  33 Gain                                              1

1189 IN  43 Interconnect ID number                            43
1190 IN  43 Source type(S,C, or F),Source ID,Source row #     C,1,4
1191 IN  43 Destination type(A or C),Dest ID,Dest row #       A,43,1
1192 IN  43 Gain                                              1

1193 IN  53 Interconnect ID number                            53
1194 IN  53 Source type(S,C, or F),Source ID,Source row #     C,1,5
1195 IN  53 Destination type(A or C),Dest ID,Dest row #       A,53,1
1196 IN  53 Gain                                              1

1197 IN  63 Interconnect ID number                            63
1198 IN  63 Source type(S,C, or F),Source ID,Source row #     C,1,6
1199 IN  63 Destination type(A or C),Dest ID,Dest row #       A,63,1
1200 IN  63 Gain                                              1

1201 IN   1 Interconnect ID number                            1
1202 IN   1 Source type(S,C, or F),Source ID,Source row #     S,1,1
1203 IN   1 Destination type(A or C),Dest ID,Dest row #       C,1,1
1204 IN   1 Gain                                              -1

1205 IN   2 Interconnect ID number                            2
1206 IN   2 Source type(S,C, or F),Source ID,Source row #     S,1,2
1207 IN   2 Destination type(A or C),Dest ID,Dest row #       C,1,2
1208 IN   2 Gain                                              -1

1209 IN   3 Interconnect ID number                            3
1210 IN   3 Source type(S,C, or F),Source ID,Source row #     S,1,3
1211 IN   3 Destination type(A or C),Dest ID,Dest row #       C,1,3
1212 IN   3 Gain                                              -1

1213 IN   4 Interconnect ID number                            4
1214 IN   4 Source type(S,C, or F),Source ID,Source row #     S,14,1
1215 IN   4 Destination type(A or C),Dest ID,Dest row #       C,1,4
1216 IN   4 Gain                                              -1

1217 IN   5 Interconnect ID number                            5
1218 IN   5 Source type(S,C, or F),Source ID,Source row #     S,15,1
1219 IN   5 Destination type(A or C),Dest ID,Dest row #       C,1,5
1220 IN   5 Gain                                              -1

1221 IN   6 Interconnect ID number                            6
1222 IN   6 Source type(S,C, or F),Source ID,Source row #     S,16,1
1223 IN   6 Destination type(A or C),Dest ID,Dest row #       C,1,6
1224 IN   6 Gain                                              -1

            CNTDTA

1225 CN   1 CNTDTA : ID Number                                1
1226 CN   1 CNTDTA : Number of data values (max = 150)         19
1227 CN   1 CNTDTA : Array value                              6.506
1228 CN   1 CNTDTA : Array value                              68.382
1229 CN   1 CNTDTA : Array value                              72.908
1230 CN   1 CNTDTA : Array value                              6.506E-3
1231 CN   1 CNTDTA : Array value                              3.419E-2
1232 CN   1 CNTDTA : Array value                              3.6454E-2
1233 CN   1 CNTDTA : Array value                              325.30
1234 CN   1 CNTDTA : Array value                              3419.10
1235 CN   1 CNTDTA : Array value                              3645.40
1236 CN   1 CNTDTA : Array value                              0.05695
1237 CN   1 CNTDTA : Array value                              6.98E-4
1238 CN   1 CNTDTA : Array value                              6.98E-4
1239 CN   1 CNTDTA : Array value                              0.06
1240 CN   1 CNTDTA : Array value                              0.011
1241 CN   1 CNTDTA : Array value                              0.01
1242 CN   1 CNTDTA : Array value                              1.E6
1243 CN   1 CNTDTA : Array value                              1.E6
1244 CN   1 CNTDTA : Array value                              1.E6
1245 CN   1 CNTDTA : Array value                              0.25
```

Appendix C
AXAF-I TREETOPS Input File AXAFI.FLN

```
FLAG, REVISION NUMBER
XXXXXX         1
 BODY ID
      2
 MODES, NODES, MODAL OPTIONS
      6      10       2       0       0       0       0       0
      0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0
      0       0       0       0       0       0       0       0
 NODAL LOCATION VECTORS
-0.25659736E-16 0.14245523E+02 0.50299722E-01 0.00000000E+00-0.98421063E-02
 0.00000000E+00 0.33627405E+01 0.46979787E+01 0.55389451E-01-0.33627405E+01
 0.46979787E+01 0.55389451E-01 0.33627405E+01 0.12000853E+02 0.55389451E-01
-0.33627405E+01 0.12000853E+02 0.55389451E-01 0.33627405E+01 0.19303728E+02
 0.55389451E-01-0.33627405E+01 0.19303728E+02 0.55389451E-01 0.33627405E+01
 0.26258866E+02 0.55389451E-01-0.33627405E+01 0.26258866E+02 0.55389451E-01
 MASS, Ixx, Iyy, Izz, Ixy, Ixz, Iyz
 0.25688829E+01 0.66230670E+03 0.11668189E+02 0.67396022E+03 0.12951566E-15
-0.13009385E-17-0.20111547E+01
 PHI for node #           2
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00
 PHI PRIME for node #           2
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00
 PHI for node #           3
 0.34267600E-05 0.25275900E-02-0.16523000E+00-0.61755500E+00-0.44938300E+00
 0.10990500E-01 0.16425400E-01 0.20560500E-03 0.71447400E+00 0.10187200E-04
-0.13720400E-01 0.91569600E+00-0.34107300E-01 0.15257800E-01-0.23861700E+01
 0.73277400E-04-0.31646000E-01 0.21297000E+01
 PHI PRIME for node #           3
-0.13447378E+00 0.39621025E-02-0.32939518E-03 0.10671847E-02 0.33307452E-02
 0.12957398E+00 0.23957638E+00 0.21752910E+00 0.48884555E-03 0.35746910E+00
 0.11949118E-01-0.96766111E-03-0.42796952E+00-0.72856474E+00-0.60992800E-02
 0.12530541E+00 0.71339854E-01-0.70710548E-02
 PHI for node #           4
 0.31104200E-03 0.80964200E-02-0.15086300E+00-0.59198200E+00-0.25163000E+00
 0.57645100E-02 0.25899100E-01-0.59342500E-02 0.37661600E+00 0.91971400E-03
-0.30644700E-01 0.84088200E+00-0.67191500E-01 0.20576800E-01-0.12850500E+01
 0.63790800E-02-0.45259300E-01 0.19886400E+01
 PHI PRIME for node #           4
-0.98232809E-01 0.34850594E-02 0.89734909E-03 0.45555262E-02 0.11058862E-02
 0.14805712E+00 0.10755706E+00 0.19197648E+00-0.48632905E-02 0.32308772E+00
 0.10336061E-01 0.26260770E-02-0.22925957E+00-0.65433337E+00 0.84705268E-02
 0.34299412E+00 0.69890076E-01 0.19916117E-01
 PHI for node #           5
 0.10511700E-07 0.32662700E-02-0.14734100E+01-0.17949400E+01-0.25219900E+00
 0.11283000E-01 0.17730500E-01 0.49816100E-03 0.16398500E+01-0.16279500E-06
-0.39222100E-02 0.28983700E+01-0.97617700E-03 0.58804400E-03-0.22196500E+01
 0.63338200E-06-0.16895500E-01 0.71811900E+00
 PHI PRIME for node #           5
-0.18535821E+00-0.60430577E-03 0.00000000E+00 0.13411016E-02 0.59774271E-02
 0.00000000E+00 0.12438258E+00 0.86916597E+00 0.00000000E+00-0.20764791E+00
```

```
-0.71677067E-02 0.00000000E+00 0.31649226E+00-0.11764203E+01 0.00000000E+00
-0.86076083E+00-0.10873251E-01 0.00000000E+00
 PHI for node #          6
 0.87398000E-04-0.53788900E-02-0.11734000E+01-0.15731800E+01 0.25203600E+00
-0.87900100E-02-0.20435600E-01-0.73059300E-02-0.14277700E+01 0.10382600E-02
-0.64987400E-02 0.31714000E+01 0.67738700E-01-0.87174900E-02 0.26612100E+01
 0.12932500E-02-0.49710700E-01 0.20578400E+01
 PHI PRIME for node #          6
-0.16690028E+00-0.17600384E-02 0.82568823E-04-0.79495980E-03 0.47446058E-02
 0.14613825E+00-0.14191768E+00 0.75653786E+00 0.13886355E-02 0.47158166E-01
-0.20923077E-01-0.63428297E-03-0.83953918E-01-0.14036001E+01-0.15471379E-02
-0.51644426E+00-0.26030481E-01 0.43785551E-02
 PHI for node #          7
-0.57220400E-07 0.30484500E-02-0.25807200E+01-0.25783200E+01 0.45007500E+00
-0.32329300E-01 0.18981800E-01 0.56736800E-03-0.41307700E+01-0.10577800E-05
-0.11027800E-01 0.11219900E+01-0.24070800E-03-0.28698600E-02-0.86849600E-02
-0.39767100E-06 0.14442900E-01-0.34620400E+01
 PHI PRIME for node #          7
-0.20274931E+00-0.37891396E-03 0.79006480E-05-0.35959918E-03 0.96274811E-02
 0.13160566E+00-0.11730541E+00 0.12347534E+01 0.23840994E-03-0.70301572E+00
-0.15140406E-01 0.13899316E-03-0.79412216E+00 0.30577703E-01-0.88140406E-03
 0.90810872E+00 0.88912637E-01 0.10373575E-03
 PHI for node #          8
 0.58516100E-07 0.30484500E-02-0.25807200E+01-0.25783200E+01-0.45007500E+00
 0.32329300E-01 0.18981800E-01-0.56736800E-03 0.41307700E+01 0.10578700E-05
-0.11027800E-01 0.11219900E+01-0.24070800E-03 0.28698600E-02 0.86849600E-02
 0.39762000E-06 0.14442900E-01-0.34620400E+01
 PHI PRIME for node #          8
-0.20274931E+00 0.37891396E-03-0.79007200E-05 0.35959918E-03 0.96274811E-02
 0.13160566E+00 0.11730541E+00 0.12347534E+01 0.23840994E-03-0.70301572E+00
 0.15140406E-01-0.13899316E-03 0.79412216E+00 0.30577703E-01-0.88140406E-03
 0.90810872E+00-0.88912637E-01-0.10373575E-03
 PHI for node #          9
 0.35819300E-08 0.30484700E-02-0.39931300E+01-0.35094500E+01 0.45004300E+00
-0.34790800E-01 0.17810200E-01 0.56774400E-03-0.48784100E+01 0.69938800E-07
-0.11027400E-01-0.38676400E+01 0.57003100E-02-0.28693600E-02-0.54549700E+01
-0.16194100E-06 0.14442800E-01 0.34909800E+01
 PHI PRIME for node #          9
-0.20356174E+00-0.55587904E-04-0.13330613E-07-0.31879515E-03 0.10342194E-01
 0.13387375E+00-0.91133805E-01 0.14489500E+01 0.16844714E-03-0.73649346E+00
-0.15171367E-02-0.38039722E-06-0.71005040E+00 0.16115445E+01-0.85416297E-03
 0.11085167E+01 0.43101644E-02 0.11149274E-05
 PHI for node #         10
-0.18157300E-08 0.30484700E-02-0.39931300E+01-0.35094500E+01-0.45004300E+00
 0.34790800E-01 0.17810200E-01-0.56774400E-03 0.48784100E+01-0.69819200E-07
-0.11027400E-01-0.38676400E+01 0.57003100E-02 0.28693600E-02 0.54549700E+01
 0.16186900E-06 0.14442800E-01 0.34909800E+01
 PHI PRIME for node #         10
-0.20356174E+00 0.55588984E-04 0.13263051E-07 0.31879515E-03 0.10342194E-01
 0.13387375E+00 0.91133805E-01 0.14489500E+01 0.16844714E-03-0.73649346E+00
 0.15171367E-02 0.38039362E-06 0.71005040E+00 0.16115445E+01-0.85416297E-03
 0.11085167E+01-0.43101644E-02-0.11149238E-05
 MASS MATRIX
 0.12000000E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.12000000E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.12000000E+02
 DAMPING MATRIX
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
```

```
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00
 STIFFNESS MATRIX
 0.22020840E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.20798280E+03 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.31780320E+03
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.10440012E+04 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.34207440E+04 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.77901960E+04
         *** MODAL COUPLING TERMS ***

 INTEGRAL PHI DM
-0.16740209E-04 0.29528532E-02-0.16005450E+01-0.17375877E+01 0.24947556E-01
 0.22243362E-03 0.16911117E-01 0.20343733E-03 0.10254551E+00 0.94073675E-06
-0.85373781E-02 0.72221416E+00-0.79137993E-02-0.26541078E-02 0.15777214E+00
-0.24108060E-03-0.99455802E-02 0.62734730E+00
 H PARAMETER
-0.83054904E+02 0.35595343E+00-0.16330605E-02 0.17008809E-01-0.22477178E+00
 0.84318187E+02 0.43996190E+01 0.28534870E+01-0.69978860E+00 0.10266543E+02
 0.48335086E+00 0.23832211E-02 0.40227323E+01 0.46717960E+01 0.12234931E+00
 0.14205193E+02 0.13555315E+01 0.12820144E-01
 S1
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 FLAG, REVISION NUMBER
XXXXXX          1
 BODY ID
       3
 MODES, NODES, MODAL OPTIONS
       6      10       2       0       0       0       0       0
       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0
       0       0       0       0       0       0       0       0
 NODAL LOCATION VECTORS
-0.25659736E-16 0.14245523E+02 0.50299722E-01 0.00000000E+00-0.98421063E-02
 0.00000000E+00 0.33627405E+01 0.46979787E+01 0.55389451E-01-0.33627405E+01
 0.46979787E+01 0.55389451E-01 0.33627405E+01 0.12000853E+02 0.55389451E-01
-0.33627405E+01 0.12000853E+02 0.55389451E-01 0.33627405E+01 0.19303728E+02
 0.55389451E-01-0.33627405E+01 0.19303728E+02 0.55389451E-01 0.33627405E+01
 0.26258866E+02 0.55389451E-01-0.33627405E+01 0.26258866E+02 0.55389451E-01
 MASS, Ixx, Iyy, Izz, Ixy, Ixz, Iyz
 0.25688829E+01 0.66230670E+03 0.11668189E+02 0.67396022E+03 0.12951566E-15
-0.13009385E-17-0.20111547E+01
 PHI for node #          2
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00
 PHI PRIME for node #          2
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00
 PHI for node #          3
 0.34267600E-05 0.25275900E-02-0.16523000E+00-0.61755500E+00-0.44938300E+00
```

```
 0.10990500E-01 0.16425400E-01 0.20560500E-03 0.71447400E+00 0.10187200E-04
-0.13720400E-01 0.91569600E+00-0.34107300E-01 0.15257800E-01-0.23861700E+01
 0.73277400E-04-0.31646000E-01 0.21297000E+01
 PHI PRIME for node #          3
-0.13447378E+00 0.39621025E-02-0.32939518E-03 0.10671847E-02 0.33307452E-02
 0.12957398E+00 0.23957638E+00 0.21752910E+00 0.48884555E-03 0.35746910E+00
 0.11949118E-01-0.96766111E-03-0.42796952E+00-0.72856474E+00-0.60992800E-02
 0.12530541E+00 0.71339854E-01-0.70710548E-02
 PHI for node #          4
 0.31104200E-03 0.80964200E-02-0.15086300E+00-0.59198200E+00-0.25163000E+00
 0.57645100E-02 0.25899100E-01-0.59342500E-02 0.37661600E+00 0.91971400E-03
-0.30644700E-01 0.84088200E+00-0.67191500E-01 0.20576800E-01-0.12850500E+01
 0.63790800E-02-0.45259300E-01 0.19886400E+01
 PHI PRIME for node #          4
-0.98232809E-01 0.34850594E-02 0.89734909E-03 0.45555262E-02 0.11058862E-02
 0.14805712E+00 0.10755706E+00 0.19197648E+00-0.48632905E-02 0.32308772E+00
 0.10336061E-01 0.26260770E-02-0.22925957E+00-0.65433337E+00 0.84705268E-02
 0.34299412E+00 0.69890076E-01 0.19916117E-01
 PHI for node #          5
 0.10511700E-07 0.32662700E-02-0.14734100E+01-0.17949400E+01-0.25219900E+00
 0.11283000E-01 0.17730500E-01 0.49816100E-03 0.16398500E+01-0.16279500E-06
-0.39222100E-02 0.28983700E+01-0.97617700E-03 0.58804400E-03-0.22196500E+01
 0.63338200E-06-0.16895500E-01 0.71811900E+00
 PHI PRIME for node #          5
-0.18535821E+00-0.60430577E-03 0.00000000E+00 0.13411016E-02 0.59774271E-02
 0.00000000E+00 0.12438258E+00 0.86916597E+00 0.00000000E+00-0.20764791E+00
-0.71677067E-02 0.00000000E+00 0.31649226E+00-0.11764203E+01 0.00000000E+00
-0.86076083E+00-0.10873251E-01 0.00000000E+00
 PHI for node #          6
 0.87398000E-04-0.53788900E-02-0.11734000E+01-0.15731800E+01 0.25203600E+00
-0.87900100E-02-0.20435600E-01-0.73059300E-02-0.14277700E+01 0.10382600E-02
-0.64987400E-02 0.31714000E+01 0.67738700E-01-0.87174900E-02 0.26612100E+01
 0.12932500E-02-0.49710700E-01 0.20578400E+01
 PHI PRIME for node #          6
-0.16690028E+00-0.17600384E-02 0.82568823E-04-0.79495980E-03 0.47446058E-02
 0.14613825E+00-0.14191768E+00 0.75653786E+00 0.13886355E-02 0.47158166E-01
-0.20923077E-01-0.63428297E-03-0.83953918E-01-0.14036001E+01-0.15471379E-02
-0.51644426E+00-0.26030481E-01 0.43785551E-02
 PHI for node #          7
-0.57220400E-07 0.30484500E-02-0.25807200E+01-0.25783200E+01 0.45007500E+00
-0.32329300E-01 0.18981800E-01 0.56736800E-03-0.41307700E+01-0.10577800E-05
-0.11027800E-01 0.11219900E+01-0.24070800E-03-0.28698600E-02-0.86849600E-02
-0.39767100E-06 0.14442900E-01-0.34620400E+01
 PHI PRIME for node #          7
-0.20274931E+00-0.37891396E-03 0.79006480E-05-0.35959918E-03 0.96274811E-02
 0.13160566E+00-0.11730541E+00 0.12347534E+01 0.23840994E-03-0.70301572E+00
-0.15140406E-01 0.13899316E-03-0.79412216E+00 0.30577703E-01-0.88140406E-03
 0.90810872E+00 0.88912637E-01 0.10373575E-03
 PHI for node #          8
 0.58516100E-07 0.30484500E-02-0.25807200E+01-0.25783200E+01-0.45007500E+00
 0.32329300E-01 0.18981800E-01-0.56736800E-03 0.41307700E+01 0.10578700E-05
-0.11027800E-01 0.11219900E+01-0.24070800E-03 0.28698600E-02 0.86849600E-02
 0.39762000E-06 0.14442900E-01-0.34620400E+01
 PHI PRIME for node #          8
-0.20274931E+00 0.37891396E-03-0.79007200E-05 0.35959918E-03 0.96274811E-02
 0.13160566E+00 0.11730541E+00 0.12347534E+01 0.23840994E-03-0.70301572E+00
 0.15140406E-01-0.13899316E-03 0.79412216E+00 0.30577703E-01-0.88140406E-03
 0.90810872E+00-0.88912637E-01-0.10373575E-03
 PHI for node #          9
 0.35819300E-08 0.30484700E-02-0.39931300E+01-0.35094500E+01 0.45004300E+00
-0.34790800E-01 0.17810200E-01 0.56774400E-03-0.48784100E+01 0.69938800E-07
-0.11027400E-01-0.38676400E+01 0.57003100E-02-0.28693600E-02-0.54549700E+01
-0.16194100E-06 0.14442800E-01 0.34909800E+01
 PHI PRIME for node #          9
-0.20356174E+00-0.55587904E-04-0.13330613E-07-0.31879515E-03 0.10342194E-01
 0.13387375E+00-0.91133805E-01 0.14489500E+01 0.16844714E-03-0.73649346E+00
-0.15171367E-02-0.38039722E-06-0.71005040E+00 0.16115445E+01-0.85416297E-03
```

```
 0.11085167E+01 0.43101644E-02 0.11149274E-05
 PHI for node #         10
-0.18157300E-08 0.30484700E-02-0.39931300E+01-0.35094500E+01-0.45004300E+00
 0.34790800E-01 0.17810200E-01-0.56774400E-03 0.48784100E+01-0.69819200E-07
-0.11027400E-01-0.38676400E+01 0.57003100E-02 0.28693600E-02 0.54549700E+01
 0.16186900E-06 0.14442800E-01 0.34909800E+01
 PHI PRIME for node #         10
-0.20356174E+00 0.55588984E-04 0.13263051E-07 0.31879515E-03 0.10342194E-01
 0.13387375E+00 0.91133805E-01 0.14489500E+01 0.16844714E-03-0.73649346E+00
 0.15171367E-02 0.38039362E-06 0.71005040E+00 0.16115445E+01-0.85416297E-03
 0.11085167E+01-0.43101644E-02-0.11149238E-05
 MASS MATRIX
 0.12000000E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.12000000E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.12000000E+02
 DAMPING MATRIX
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00
 STIFFNESS MATRIX
 0.22020840E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.20798280E+03 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.31780320E+03
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.10440012E+04 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.34207440E+04 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.77901960E+04
          *** MODAL COUPLING TERMS ***

 INTEGRAL PHI DM
-0.16740209E-04 0.29528532E-02-0.16005450E+01-0.17375877E+01 0.24947556E-01
 0.22243362E-03 0.16911117E-01 0.20343733E-03 0.10254551E+00 0.94073675E-06
-0.85373781E-02 0.72221416E+00-0.79137993E-02-0.26541078E-02 0.15777214E+00
-0.24108060E-03-0.99455802E-02 0.62734730E+00
 H PARAMETER
-0.83054904E+02 0.35595343E+00-0.16330605E-02 0.17008809E-01-0.22477178E+00
 0.84318187E+02 0.43996190E+01 0.28534870E+01-0.69978860E+00 0.10266543E+02
 0.48335086E+00 0.23832211E-02 0.40227323E+01 0.46717960E+01 0.12234931E+00
 0.14205193E+02 0.13555315E+01 0.12820144E-01
 S1
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
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 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
```

Appendix D
AXAF-I TREETOPS Input File AXAFI.RET

```
2 6
1 2 3 4 5 6
3 6
1 2 3 4 5 6
```

Appendix E
NASTRAN Model of AXAF-I Solar Array

```
NASTRAN TITLEOPT=-1
ID AXAF,DEPLOYED ED12
$SOL 103
SOL 3
TIME 200
$$YK DIAG 8,9,13,14
diag 8,9
readfile ALTERS
$$$$$$$$$$$$ by YK
$ALTER 105 $ FOR '91 CSA NASTRAN
$ALTER 106 $ FOR '93 CSA NASTRAN
RFINSERT READ $ FOR '94 CSA NASTRAN
TABPT EQEXIN// $
GKAM ,,PHIA,MI,LAMA,DIT,,,,CASECC/MMASS,MDAMP,MSTIFF,PHIDH/-1/
     0/0.0/1.E+30/-1/-1/-1/V,N,NONCUP/V,N,FMODE/ $
VECPLOT, ,BGPDT,EQEXIN,CSTM,,/RBMAT1///4 $
TRNSP RBMAT1/RBMAT $
MATGEN ,/ZEROG/7/LUSET/1 $
VECPLOT ZEROG,BGPDT,EQEXIN,CSTM,CASECC,/COORD///3 $
MATGEN ,/PVECX/4/1/LUSET/0/1/6/1 $
MATGEN ,/PVECY/4/1/LUSET/0/1/6/2 $
MATGEN ,/PVECZ/4/1/LUSET/0/1/6/3 $
MATGEN ,/PVECXY/6/2/1/1 $
MATGEN ,/PVECXYZ/6/3/2/1 $
PARTN COORD,,PVECX/,XGEOM,,/1 $
PARTN COORD,,PVECY/,YGEOM,,/1 $
PARTN COORD,,PVECZ/,ZGEOM,,/1 $
MERGE XGEOM,,YGEOM,,PVECXY,/XYGEOM/1 $
MERGE XYGEOM,,ZGEOM,,PVECXYZ,/XYZGEO/1 $
UMERGE USET,PHIA,/PHIAJB/C,Y,MAJOR=N/C,Y,SUB0=A/C,Y,SUB1=SB $
OUTPUT5 MGG,PHIAJB,MMASS,MSTIFF,XYZGEO//C,N,-1/C,N,11/C,N,DYNACSJB/1 $   $
OUTPUT5 ,,,,//C,N,-9/C,N,11/C,N,DYNACSJB/C,N,1 $
ENDALTER $
$$$$$$$$$$$$$$$$$
CEND
$
$
$  RECIEVED FROM TRW/ZIGGY JAB 3/2/93
$
$---------------------------------------------------------------------
$ necessary alter for Lanczos with sol 3
$COMPILE SOL3 SOUIN=MSCSOU
$RFALTER RF3D83
$---------------------------------------------------------------------
LINE=48
TITLE = AXAF-I Solar Array Modes
SUBTITLE = Normal Modal Analysis
$LABEL = FREE-FREE
$$YK DISPLACEMENT = ALL
disp (plot) = all   $ YK
$
$$YK ECHO = SORT
echo = none   $ YK
SPC=100
$MPC=10
METHOD = 1000
$SET 1 = ALL
```

```
$SET 1 = 63001,60000,60003,60400,60403,60800,60803,61100,61103
$DISP = 1
$
$
$
$PLOTID = SEND PLOTS TO J. A. BRUNTY BIN 196
OUTPUT(PLOT)
$PLOTTER NAST
$SET 1 = 1 THRU 1000000
SET 1 = ALL
$SET 1 = 63001,60000,60003,60400,60403,60800,60803,61100,61103
$MAXIMUM DEFORMATION 100.
CSCALE=2
AXES X,Y,Z
VIEW 5.,35.,10.
FIND SCALE, ORIGIN 1, SET 1
PLOT SET 1, ORIGIN 1
PLOT SET 1, ORIGIN 1, LABEL GRID POINTS
$PLOT SET 1, ORIGIN 1, LABEL ELEMENTS
PLOT MODAL DEFORMATION, SET 1, ORIGIN 1
$-----------------------------------------------------------------------
BEGIN BULK
param   autospc yes
PARAM   GRDPNT  0
PARAM   WTMASS  .002588
PARAM   TINY    1.0
$PARAM   K6ROT   0.25
$  FOR OUTPUT USED IN MSC/NASTRAN EXCEL
$PARAM   POST    0
$  FOR OUTPUT USED IN PATRAN
PARAM,POST,-1
$  PARAM DEFAULT IS 1
$PARAM,POST,1
$-------2-------3-------4-------5-------6-------7-------8-------9-------
$EIGRL  1000    -1.0    100.
$$YK EIGR    1000    BLAN    -1.     100.
EIGR    1000    BLAN    -1.     20.
$-----------------------------------------------------------------------
$INCLUDE sa+yscif.osas
$
$      SADA REPRESENTED WITH A RIGID TEPEE TO PROVIDE INTERFACE
$      AT THE PROPER LOCATION AND CELAS TO PROVIDE FOR SADA
$      FLEXIBILITIES.          HRG 3/30/94
$
$      Material properties of tipee CBARS.  OSAS. (Uncomment only if the wing
is to be run alone.)
$
$$$PBAR    872     809     100.    1000.   1000.   2000.
$$$MAT1    809     10.0E06         .33
$
$$$CBAR    87201   872     84023   84501   0.      0.      1.
+C942219
$$$CBAR    87202   872     84024   84501   0.      0.      1.
+C942220
$$$CBAR    87203   872     84027   84501   0.      0.      1.
+C942419
$$$CBAR    87204   872     84028   84501   0.      0.      1.
+C942420
$$$CBAR    87205   872     84031   84501   0.      0.      1.
+C942619
$$$CBAR    87206   872     84032   84501   0.      0.      1.
+C942620
$
$  COINCIDENT GRIDS TO MODEL SADA FLEXIBILITY FOR +Y SA
$
$**************************************************************************
***
```

```
$     Uncomment cordinate system 810 if this panel is to be run alone.  OSAS.
$
CORD2R  810     0       0.0     0.0     0.0     0.0     0.0     1.
        1.      0.0     0.0
$***********************************************************************
***
$
$$$GRID    84501   810     445.88  68.025  -9.53
$$$GRID    84502   810     445.88  68.025  -9.53
$$$$GRID    84503   810     445.88  68.025  -9.53 COMMENTED OUT PER R.H. .
OSAS. 5/24/94.
$GRID    84504   810     445.88  68.025  -9.53
$
$  SADA STIFFNESS (TDRS VALUES)
$
$$$CELAS2  89235   50.00E3 84501   1       84502   1
$$$CELAS2  89236   50.00E3 84501   2       84502   2
$$$CELAS2  89237   50.00E3 84501   3       84502   3
$$$CELAS2  89238    8.00E5 84501   4       84502   4
$$$CELAS2  89239    8.00E4 84501   5       84502   5
$$$CELAS2  89240    8.00E5 84501   6       84502   6
$
$!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
$     Include rigid elements for free-free run only
$
$RBE2    80000      87064   123456  87060   87036    87040  87037  87039
$     84504
$!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
$
$      Bottom grids of tepee
$
$$$GRID    84023   810     450.113 60.25   -4.53
$$$GRID    84024   810     440.113 60.25   -4.53
$$$GRID    84027   810     450.113 60.25   -9.53
$$$GRID    84028   810     440.113 60.25   -9.53
$$$GRID    84031   810     450.113 60.25   -14.53
$$$GRID    84032   810     440.113 60.25   -14.53
$
$INCLUDE sa+y.osas
$
$$$ BASIC COORDINATE SYSTEM of S/A (600) FOR MODEL
$
$
$     Attachement of +y wing to tepee (corner grid of yoke to outboard grid of
SADA)
$
$$$RBAR      60001  84502  63001  123456             123456
spc1,100,12346,63001
$
$      Modify Location of I/F per IOC M533.2.94-073
$      RH    5/94
GRID    63001   600     0.      -.11811 0.0     600
$$$GRID    63001   810     445.88  68.025  -9.53
$
RBE2    63051   63001   123456  63002
GRID    63002   600     0.      .94488  0.0     600
GRID    63003   600     0.      .94488  0.0     600
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$       BAPTA & SADM Hinge
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
RBE2    63052   63002   123     63003
CELAS2  63061   2.3454+563002   4       63003   4
CELAS2  63062   5.8414+463002   5       63003   5
CELAS2  63063   1.6374+663002   6       63003   6
$
```

```
CONM2   63071   63003   600     2.82368
$
$
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$     Inboard Panel
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$        Edge Beams
CBAR    60151   611     60000   60001   0.      0.      1.
CBAR    60152   611     60001   60002   0.      0.      1.
CBAR    60153   611     60002   60003   0.      0.      1.
CBAR    60154   611     60300   60301   0.      0.      1.
CBAR    60155   611     60301   60302   0.      0.      1.
CBAR    60156   611     60302   60303   0.      0.      1.
$        Panel Wt
CONM2   60161   60001   601     0.12346
CONM2   60162   60002   601     0.12346
CONM2   60163   60301   601     0.12346
CONM2   60164   60302   601     0.12346
CONM2   60165   60101   601     0.1411
CONM2   60166   60102   601     0.1411
CONM2   60167   60201   601     0.1411
CONM2   60168   60202   601     0.1411
$       Quad's
CQUAD4  60101   601     60000   60001   60101   60100
CQUAD4  60102   602     60001   60002   60102   60101
CQUAD4  60103   601     60002   60003   60103   60102
CQUAD4  60104   601     60100   60101   60201   60200
CQUAD4  60105   602     60101   60102   60202   60201
CQUAD4  60106   601     60102   60103   60203   60202
CQUAD4  60107   601     60200   60201   60301   60300
CQUAD4  60108   602     60201   60202   60302   60301
CQUAD4  60109   601     60202   60203   60303   60302
$       Grids
GRID    60000   601     40.3545 0.0     0.0     601
GRID    60001   601     22.6379 0.0     0.0     601
GRID    60002   601     -22.63790.0     0.0     601
GRID    60003   601     -40.35450.0     0.0     601
GRID    60100   601     40.3545 20.8466 0.0     601
GRID    60101   601     22.6379 20.8466 0.0     601
GRID    60102   601     -22.637920.8466 0.0     601
GRID    60103   601     -40.354520.8466 0.0     601
GRID    60200   601     40.3545 65.8271 0.0     601
GRID    60201   601     22.6379 65.8271 0.0     601
GRID    60202   601     -22.637965.8271 0.0     601
GRID    60203   601     -40.354565.8271 0.0     601
GRID    60300   601     40.3545 83.465  0.0     601
GRID    60301   601     22.6379 83.465  0.0     601
GRID    60302   601     -22.637983.465  0.0     601
GRID    60303   601     -40.354583.465  0.0     601
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$     Mid Panel
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$        Edge Beams
CBAR    60251   611     60400   60401   0.      0.      1.
CBAR    60252   611     60401   60402   0.      0.      1.
CBAR    60253   611     60402   60403   0.      0.      1.
CBAR    60254   611     60700   60701   0.      0.      1.
CBAR    60255   611     60701   60702   0.      0.      1.
CBAR    60256   611     60702   60703   0.      0.      1.
$        Panel Wt
CONM2   60261   60401   602     0.12346
CONM2   60262   60402   602     0.12346
CONM2   60263   60701   602     0.12346
CONM2   60264   60702   602     0.12346
```

```
CONM2   60265   60501   602     0.1411
CONM2   60266   60502   602     0.1411
CONM2   60267   60601   602     0.1411
CONM2   60268   60602   602     0.1411
$        Quads
CQUAD4  60201   601     60400   60401   60501   60500
CQUAD4  60202   602     60401   60402   60502   60501
CQUAD4  60203   601     60402   60403   60503   60502
CQUAD4  60204   601     60500   60501   60601   60600
CQUAD4  60205   602     60501   60502   60602   60601
CQUAD4  60206   601     60502   60503   60603   60602
CQUAD4  60207   601     60600   60601   60701   60700
CQUAD4  60208   602     60601   60602   60702   60701
CQUAD4  60209   601     60602   60603   60703   60702
$        Grids
GRID    60400   602     40.3545 0.0     0.0     602
GRID    60401   602     22.6379 0.0     0.0     602
GRID    60402   602     -22.63790.0     0.0     602
GRID    60403   602     -40.35450.0     0.0     602
GRID    60500   602     40.3545 17.6379 0.0     602
GRID    60501   602     22.6379 17.6379 0.0     602
GRID    60502   602     -22.637917.6379 0.0     602
GRID    60503   602     -40.354517.6379 0.0     602
GRID    60600   602     40.3545 62.6184 0.0     602
GRID    60601   602     22.6379 62.6184 0.0     602
GRID    60602   602     -22.637962.6184 0.0     602
GRID    60603   602     -40.354562.6184 0.0     602
GRID    60700   602     40.3545 83.465  0.0     602
GRID    60701   602     22.6379 83.465  0.0     602
GRID    60702   602     -22.637983.465  0.0     602
GRID    60703   602     -40.354583.465  0.0     602
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$     Outboard Panel
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$       Edge Beams
CBAR    60351   611     60800   60801   0.      0.      1.
CBAR    60352   611     60801   60802   0.      0.      1.
CBAR    60353   611     60802   60803   0.      0.      1.
CBAR    60354   611     61100   61101   0.      0.      1.
CBAR    60355   611     61101   61102   0.      0.      1.
CBAR    60356   611     61102   61103   0.      0.      1.
$        Panel Wt
CONM2   60361   60801   603     0.12346
CONM2   60362   60802   603     0.12346
CONM2   60363   61101   603     0.12346
CONM2   60364   61102   603     0.12346
CONM2   60365   60901   603     0.54586
CONM2   60366   60902   603     0.54586
CONM2   60367   61001   603     0.54586
CONM2   60368   61002   603     0.54586
$         Tip Masses for Outboiard Panel
CONM2   60369   61100   603     0.26
CONM2   60370   61103   603     0.26
$        Quads
CQUAD4  60301   601     60800   60801   60901   60900
CQUAD4  60302   602     60801   60802   60902   60901
CQUAD4  60303   601     60802   60803   60903   60902
CQUAD4  60304   601     60900   60901   61001   61000
CQUAD4  60305   602     60901   60902   61002   61001
CQUAD4  60306   601     60902   60903   61003   61002
CQUAD4  60307   601     61000   61001   61101   61100
CQUAD4  60308   602     61001   61002   61102   61101
CQUAD4  60309   601     61002   61003   61103   61102
$         Grids
GRID    60800   603     40.3545 0.0     0.0     603
```

```
GRID    60801   603     22.6379 0.0     0.0     603
GRID    60802   603     -22.63790.0     0.0     603
GRID    60803   603     -40.35450.0     0.0     603
GRID    60900   603     40.3545 20.8466 0.0     603
GRID    60901   603     22.6379 20.8466 0.0     603
GRID    60902   603     -22.637920.8466 0.0     603
GRID    60903   603     -40.354520.8466 0.0     603
GRID    61000   603     40.3545 65.8271 0.0     603
GRID    61001   603     22.6379 65.8271 0.0     603
GRID    61002   603     -22.637965.8271 0.0     603
GRID    61003   603     -40.354565.8271 0.0     603
GRID    61100   603     40.3545 83.465  0.0     603
GRID    61101   603     22.6379 83.465  0.0     603
GRID    61102   603     -22.637983.465  0.0     603
GRID    61103   603     -40.354583.465  0.0     603
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$       Yoke
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
GRID    63004   600     -6.715  16.1516 0.0     600
GRID    63005   600     -13.430731.358270.0     600
GRID    63006   600     -18.033541.7815 0.0     600
GRID    63007   600     -22.637852.2047 0.0     600
GRID    63008   600     6.715   16.1516 0.0     600
GRID    63009   600     13.4307 31.358270.0     600
GRID    63010   600     18.0335 41.7815 0.0     600
GRID    63011   600     22.6378 52.2047 0.0     600
$         Yoke Cross Bar
GRID    63012   600     -11.318952.2047 0.0     600
GRID    63013   600     0.      52.2047 0.0     600
GRID    63014   600     11.3189 52.2047 0.0     600
$
CBAR    63001   612     63003   63004   0.      0.      1.
63002   612     63004   63005   0.      0.      1.
CBAR    63003   612     63005   63006   0.      0.      1.
CBAR    63004   612     63006   63007   0.      0.      1.
CBAR    63005   612     63003   63008   0.      0.      1.
CBAR    63006   612     63008   63009   0.      0.      1.
CBAR    63007   612     63009   63010   0.      0.      1.
CBAR    63008   612     63010   63011   0.      0.      1.
$       Yoke Cross Bar
CBAR    63009   613     63007   63012   0.      0.      1.
CBAR    63010   613     63012   63013   0.      0.      1.
CBAR    63011   613     63013   63014   0.      0.      1.
CBAR    63012   613     63014   63011   0.      0.      1.
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$       Hinge Lines
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$           Yoke to Wing I/F
$
CBAR    63101   614     63007   63101   1.      0.      0.
CBAR    63102   615     63102   60002   1.      0.      0.
CBAR    63103   614     63011   63103   1.      0.      0.
CBAR    63104   615     63104   60001   1.      0.      0.
GRID    63101   601     -22.6378-2.0866 0.5953  601
GRID    63102   601     -22.6378-2.0866 0.5953  601
GRID    63103   601     22.6378 -2.0866 0.5953  601
GRID    63104   601     22.6378 -2.0866 0.5953  601
RBE2    63105   63101   123456  63102
RBE2    63106   63103   123456  63104
$           Inbd to Mid
CBAR    63111   615     60302   63111   1.      0.      0.
CBAR    63112   615     63112   60402   1.      0.      0.
CBAR    63113   615     60301   63113   1.      0.      0.
CBAR    63114   615     63114   60401   1.      0.      0.
```

```
GRID    63111   602     -22.6378-2.0866 -.5953  602
GRID    63112   602     -22.6378-2.0866 -.5953  602
GRID    63113   602     22.6378 -2.0866 -.5953  602
GRID    63114   602     22.6378 -2.0866 -.5953  602
RBE2    63115   63111   123456  63112
RBE2    63116   63113   123456  63114
$           Outbd to Mid
CBAR    63121   615     60702   63121   1.      0.      0.
CBAR    63122   615     63122   60802   1.      0.      0.
CBAR    63123   615     60701   63123   1.      0.      0.
CBAR    63124   615     63124   60801   1.      0.      0.
GRID    63121   603     -22.6378-2.0866 0.5953  603
GRID    63122   603     -22.6378-2.0866 0.5953  603
GRID    63123   603     22.6378 -2.0866 0.5953  603
GRID    63124   603     22.6378 -2.0866 0.5953  603
RBE2    63125   63121   123456  63122
RBE2    63126   63123   123456  63124
$
$
$
$
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$       Coordinate Systems
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
CORD2R  600             0.      0.      0.      0.      0.      1.      +C600
+C600   1.      0.      0.
$$$CORD2R  600             445.88  68.025  -9.53   445.88  68.025  -8.53
+C600
$$$+C600   446.88  68.025  -9.53
CORD2R  601     600     0.      56.378  0.6647  0.      56.378  1.      +C601
+C601   1.      56.378  0.6647
CORD2R  602     601     0.      87.6382 0.      0.      87.6382 1.      +C602
+C602   1.      87.6382 0.
CORD2R  603     602     0.      87.6382 0.      0.      87.6382 1.      +C603
+C603   1.      87.6382 0.
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$       Materials and Properties
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
MAT1    614     8.238+6 3.133+6
MAT1    615     8.238+6 3.133+6
MAT1    623             1.218+4
MAT1    631     2.2336+77.542+6
MAT1    632     1.3779+74.6412+6
MAT1    633     2.64+7  1.0153+6
MAT2    621     2.226+7 3.168+5 0.      2.226+7 0.      5.802+5 0.      +MT2A
+MT2A   .324-6  .324-6  0.      68.
MAT2    622     1.8710+74.6593+50.      2.5824+70.      5.802+5 0.      +MT2B
+MT2B   .324-6  .324-6  0.      68.
PBAR    611     631     7.44-3  1.2013-21.3935-34.5648-3
PBAR    612     632     .2294   8.1188-28.1188-2.121694 3.3246-2
PBAR    613     633     6.8045-21.2978-2.130878 1.1396-62.824-2
PBAR    614     614     .15655  1.946-3 5.237-3 7.616-3 .11759
PBAR    615     615     .15655  1.946-3 6.979-3 7.616-3 .13236
PSHELL  601     621     9.449-3 621     25484.  623     91.67   2.8702-3+PS601
+PS601  .4378   -.4378
PSHELL  602     622     1.1811-2622     16354.1 623     73.33   3.587-3 +PS602
+PS602  .438976 -.438976
$
$
ENDDATA
```

Appendix F
NASTRAN Normal Modal Analysis Output of AXAF-I Solar Array

```
NORMAL MODAL ANALYSIS

O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
REFERENCE POINT =        0


MO - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM
***                                                                                  ***
*  8.271776E+01  0.000000E+00  0.000000E+00  0.000000E+00  4.993016E+01 -1.414086E+04 *
*  0.000000E+00  8.271776E+01  0.000000E+00 -4.993016E+01  0.000000E+00  6.863821E-13 *
*  0.000000E+00  0.000000E+00  8.271776E+01  1.414086E+04 -2.745528E-12  0.000000E+00 *
*  0.000000E+00 -4.993016E+01  1.414086E+04  3.071223E+06 -7.028553E-10 -1.029573E-12 *
*  4.993016E+01  0.000000E+00 -6.863821E-13 -3.514276E-10  5.410720E+04 -9.326042E+03 *
* -1.414086E+04  6.863821E-13  0.000000E+00 -2.745528E-12 -9.326042E+03  3.125262E+06 *
***                                                                                  ***


S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION
***                                            ***
*  1.000000E+00  0.000000E+00  0.000000E+00 *
*  0.000000E+00  1.000000E+00  0.000000E+00 *
*  0.000000E+00  0.000000E+00  1.000000E+00 *
***                                            ***


     DIRECTION
MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
        X             8.271776E+01      0.000000E+00  1.709532E+02  6.036208E-01
        Y             8.271776E+01      8.297881E-15  0.000000E+00  6.036208E-01
        Z             8.271776E+01      3.319152E-14  1.709532E+02  0.000000E+00


     I(S) - INERTIAS RELATIVE TO C.G.
***                                            ***
*  6.537670E+05  2.334984E-10  6.152586E-13 *
*  2.334984E-10  5.407706E+04  7.903221E+02 *
*  6.152586E-13  7.903221E+02  7.078363E+05 *
***                                            ***


      I(Q) - PRINCIPAL INERTIAS
***                                            ***
*  6.537670E+05                             *
*                7.078372E+05               *
*                              5.407610E+04 *
***                                            ***


      Q - TRANSFORMATION MATRIX
      I(Q) = QT*IBAR(S)*Q
***                                            ***
*  1.000000E+00  0.000000E+00  0.000000E+00 *
*  0.000000E+00  1.208886E-03  9.999993E-01 *
*  0.000000E+00 -9.999993E-01  1.208886E-03 *
***                                            ***
```

AXAF-I SOLAR ARRAY
NORMAL MODAL ANALYSIS

R E A L   E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIAN FREQUENCY	CYCLIC FREQUENCY	GENERALIZ MASS	GENERALIZED STIFFNESS
1	1	1.835065E+00	1.354646E+00	2.155986E-01	1.000000E+00	1.835065E+00
2	2	1.733193E+01	4.163164E+00	6.625881E-01	1.000000E+00	1.733193E+01
3	3	2.648359E+01	5.146221E+00	8.190466E-01	1.000000E+00	2.648359E+01
4	4	8.700010E+01	9.327385E+00	1.484499E+00	1.000000E+00	8.700010E+01
5	5	2.850619E+02	1.688378E+01	2.687136E+00	1.000000E+00	2.850619E+02
6	6	6.491830E+02	2.547907E+01	4.055120E+00	1.000000E+00	6.491830E+02
7	7	1.019662E+03	3.193215E+01	5.082160E+00	1.000000E+00	1.019662E+03
8	8	2.025334E+03	4.500371E+01	7.162563E+00	1.000000E+00	2.025334E+03
9	9	2.203281E+03	4.693912E+01	7.470593E+00	1.000000E+00	2.203281E+03
10	10	1.468234E+04	1.211707E+02	1.928492E+01	1.000000E+00	1.468234E+04

Appendix G
SSE MACOS Input File

```
ChfRayDir=  0.000000000D+00  0.000000000D+00  1.000000000D+00
ChfRayPos=  0.000000000D+00  0.000000000D+00 -1.000000000D+01
 zSource=   1.000000000D+22
  IndRef=   1.000000000D+00
  Extinc=   0.000000000D+00
 Wavelen=   2.834700000D-05
    Flux=   1.000000000D+00
GridType=   Circular
Aperture=   17.2
Obscratn=   0.000000000D+00
nGridpts=   100
   xGrid=   1.000000000D+00  0.000000000D+00  0.000000000D+00
   yGrid=   0.000000000D+00  1.000000000D+00  0.000000000D+00
    nElt=     9

    iElt=     1
 EltName= ring_front
 Element= Refractor
 Surface= Flat
   KrElt=  -1.000000000D+22
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00  0.000000000D+00 -1.000000000D+00
  VptElt=   0.000000000D+00  0.000000000D+00 -1.377730000D+00
  RptElt=   0.000000000D+00  0.000000000D+00 -1.377730000D+00
  IndRef=   1.595059000D+00
  Extinc=   0.000000000D+00
    nObs=     1
 ObsType=   Circle
  ObsVec=   7.190000000D+00  0.000000000D+00  0.000000000D+00
    xObs=   1.000000000D+00  0.000000000D+00  0.000000000D+00
  ApType=   Circular
   ApVec=   7.590000000D+00  0.000000000D+00  0.000000000D+00
    zElt=   1.000000000D+22
PropType=   Geometric
 nECoord=   -6

    iElt=     2
 EltName= ring_back
 Element= Refractor
 Surface= Aspheric
   KrElt=   1.337423000D+01
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00  0.000000000D+00 -1.000000000D+00
  VptElt=   0.000000000D+00  0.000000000D+00 -1.374730000D+00
  RptElt=   0.000000000D+00  0.000000000D+00 -1.374730000D+00
  IndRef=   1.000000000D+00
  Extinc=   0.000000000D+00
AsphCoef=   4.145520000D-04 -3.444760000D-06  1.990750000D-08  0.000000000D+00
    nObs=     1
 ObsType=   Circle
  ObsVec=   7.190000000D+00  0.000000000D+00  0.000000000D+00
    xObs=   1.000000000D+00  0.000000000D+00  0.000000000D+00
  ApType=   Circular
   ApVec=   7.590000000D+00  0.000000000D+00  0.000000000D+00
    zElt=   1.337423000D+01
PropType=   Geometric
 nECoord=   -6

    iElt=     3
```

```
 EltName= NDfilter_front
 Element= Refractor
 Surface= Flat
   KrElt=  -1.000000000D+22
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt=   0.000000000D+00  1.901096200D+01  7.336785300D+01
  RptElt=   0.000000000D+00  1.901096200D+01  7.336785300D+01
  IndRef=   1.454853000D+00
  Extinc=   0.000000000D+00
    nObs=    0
  ApType=   Circular
   ApVec=   3.000000000D+00  0.000000000D+00  0.000000000D+00
    zElt=   1.000000000D+22
PropType=   Geometric
 nECoord=   -6

    iElt=    4
 EltName= NDfilter_back
 Element= Refractor
 Surface= Flat
   KrElt=  -1.000000000D+22
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt=   0.000000000D+00  1.905007100D+01  7.361477500D+01
  RptElt=   0.000000000D+00  1.905007100D+01  7.361477500D+01
  IndRef=   1.000000000D+00
  Extinc=   0.000000000D+00
    nObs=    0
  ApType=   Circular
   ApVec=   3.000000000D+00  0.000000000D+00  0.000000000D+00
    zElt=   1.000000000D+22
PropType=   Geometric
 nECoord=   -6

    iElt=    5
 EltName= Cylinder_front
 Element= Refractor
 EltName= Cylinder
 Element= Refractor
 Surface= Conic
    fElt=   4.803140000D+00
    eElt=   0.000000000D+00
   KrElt=   4.803140000D+00
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00  -1.564298529D-01 -9.876890711D-01
  VptElt=   0.000000000D+00  1.996007600D+01  7.357189100D+01
  RptElt=   0.000000000D+00  1.996007600D+01  7.357189100D+01
  IndRef=   1.512549000D+00
  Extinc=   0.000000000D+00
    nObs=    0
  ApType=   Rectangular
   ApVec=  -1.250000000D+00  1.250000000D+00 -3.250000000D+00  3.250000000D+00
    zElt=   4.803140000D+00
PropType=   Geometric
 nECoord=   -6

    iElt=    6
 EltName= Cylinder_back
 Element= Refractor
 Surface= Flat
   KrElt=  -1.000000000D+22
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt=   0.000000000D+00  2.018179300D+01  7.497176100D+01
  RptElt=   0.000000000D+00  2.018179300D+01  7.497176100D+01
  IndRef=   1.000000000D+00
```

```
  Extinc=   0.000000000D+00
    nObs=    0
  ApType=   Rectangular
   ApVec=  -1.250000000D+00  1.250000000D+00 -3.250000000D+00  3.250000000D+00
    zElt=   1.000000000D+22
PropType=   Geometric
 nECoord=   -6

    iElt=    7
 EltName= NBPfilter_front
 Element= Refractor
 Surface= Flat
   KrElt=  -1.000000000D+22
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt=   0.000000000D+00  2.065109600D+01  7.793482000D+01
  RptElt=   0.000000000D+00  2.065109600D+01  7.793482000D+01
  IndRef=   1.454853000D+00
  Extinc=   0.000000000D+00
    nObs=    0
  ApType=   Circular
   ApVec=   2.000000000D+00  0.000000000D+00  0.000000000D+00
    zElt=   1.000000000D+22
PropType=   Geometric
 nECoord=   -6

    iElt=    8
 EltName= NBPfilter_back
 Element= Refractor
 Surface= Flat
   KrElt=  -1.000000000D+22
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt=   0.000000000D+00  2.068238300D+01  7.813235800D+01
  RptElt=   0.000000000D+00  2.068238300D+01  7.813235800D+01
  IndRef=   1.000000000D+00
  Extinc=   0.000000000D+00
    nObs=    0
  ApType=   Circular
   ApVec=   2.000000000D+00  0.000000000D+00  0.000000000D+00
    zElt=   1.000000000D+22
PropType=   Geometric
 nECoord=   -6

    iElt=    9
 EltName= Focal_plane
 Element= FocalPlane
 Surface= Flat
   KrElt=  -1.000000000D+22
   KcElt=   0.000000000D+00
  psiElt=   0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt=   0.000000000D+00  2.101021800D+01  8.020223000D+01
  RptElt=   0.000000000D+00  2.101021800D+01  8.020223000D+01
  IndRef=   1.000000000D+00
  Extinc=   0.000000000D+00
    nObs=    0
  ApType=   Rectangular
   ApVec=  -1.250000000D-01  1.250000000D-01 -5.900000000D-01  5.900000000D-01
    zElt=   1.000000000D+22
PropType=   Geometric
 nECoord=   -6

nOutCord=    5
    Tout=   1.000000000D+00  0.000000000D+00  0.000000000D+00  0.000000000D+00
0.000000000D+00  0.000000000D+00  0.000000000D+00
            0.000000000D+00  1.000000000D+00  0.000000000D+00  0.000000000D+00
0.000000000D+00  0.000000000D+00  0.000000000D+00
```

```
            0.000000000D+00  0.000000000D+00  0.000000000D+00  1.000000000D+00
0.000000000D+00  0.000000000D+00  0.000000000D+00
            0.000000000D+00  0.000000000D+00  0.000000000D+00  0.000000000D+00
1.000000000D+00  0.000000000D+00  0.000000000D+00
            0.000000000D+00  0.000000000D+00  0.000000000D+00  0.000000000D+00
0.000000000D+00  0.000000000D+00  1.000000000D+00
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16. Abstract

The computer simulation tool, TREETOPS, has been upgraded and used at NASA/MSFC to model various complicated mechanical systems and to perform their dynamics and control analysis with pointing control systems. A TREETOPS model of Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) dynamics and control system was developed to evaluate the AXAF-I pointing performance for Normal Pointing Mode. An optical model of Shooting Star Experiment (SSE) was also developed and its optical performance analysis was done using the MACOS software.

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