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EMULATING A FLEXIBLE SPACE STRUCTURE: MODELING

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16. ABSTRACT

Control Dynamics, in conjunction with Marshall Space Flight Center, has participated in the modeling and testing of Flexible Space Structures for the past several years. Through the series of configurations tested and the many techniques used for collecting, analyzing, and modeling the data; many valuable insights have been gained and important lessons learned. This paper discusses the background of the Large Space Structure program, Control Dynamics' involvement in testing and modeling of the configurations (especially the ACES configuration), the results from these two processes, and insights gained from this work.

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INTRODUCTION

Control Dynamics, in conjunction with Marshall Space Flight Center (MSFC), has participated in the modeling and testing of Flexible Space Structures for the past several years. Many valuable insights have been gained and important lessons learned through the many configurations tested and the many techniques used for collecting, analyzing, and modeling the data. The following sections discuss the background of the Large Space Structure program, Control Dynamics' involvement in testing and modeling, and the results from these two processes.

STRUCTURAL BACKGROUND

MSFC has developed a facility in which dynamic behavior and closed-loop control of Large Space Structures (LSSs) can be demonstrated and verified. Figure 1 depicts the evolution of the test configurations since the conception of the facility.

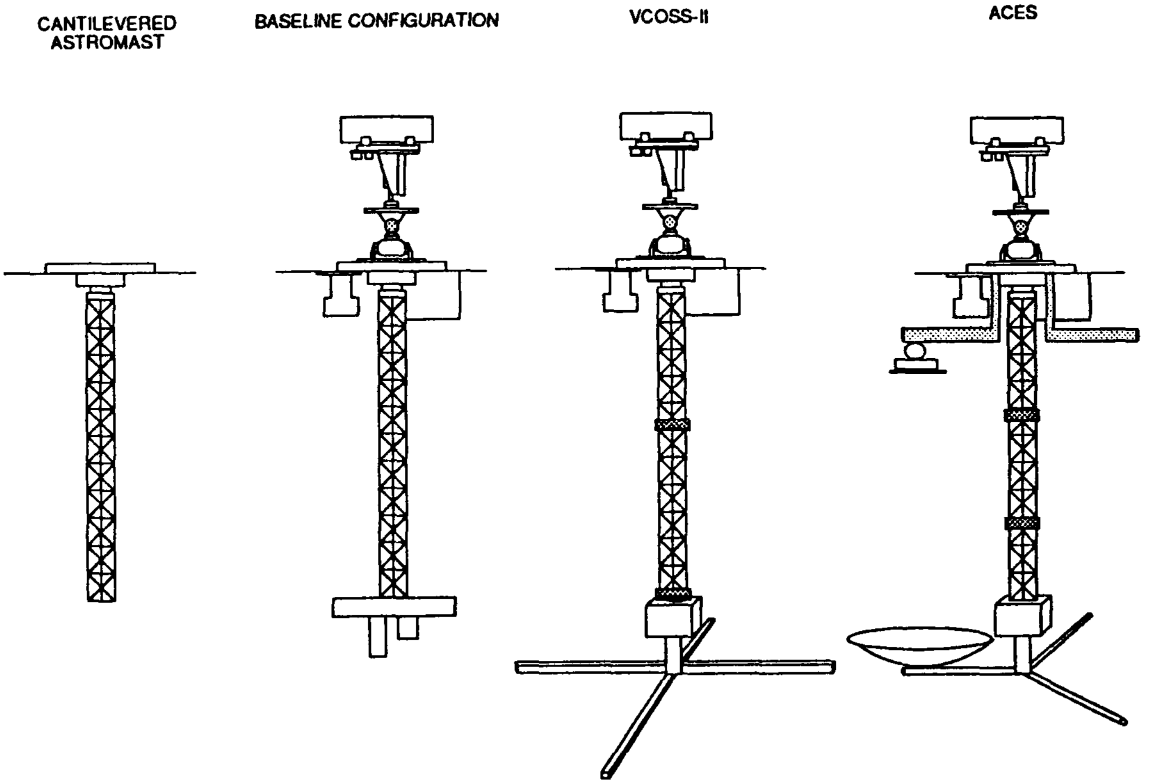

Figure 1. Configuration history.

In 1983, the first set of modal tests was initiated, by MSFC, on the spare 13-meter Voyager Magnetometer Boom (ASTROMAST) hung in the cantilevered state. The structure was excited using impact testing techniques. Frequencies and modeshapes were obtained and an analytical model was tuned to correspond to the test data. The beam's stiffness values were the main variables to be adjusted as they were not initially well known. After tuning the model, analytical frequencies within 10 percent of experimental values were obtained and the mode shapes agreed well. The testing revealed that the ASTROMAST behaved as a linear beam. This enabled the analytical model to be fairly simple, four consistent beam elements which would minimize the number of Degrees of Freedom (DOFs). The beam itself did not exhibit a typical LSS characteristic such as densely packed modes.

In 1984, a baseline set of sensors and actuators was incorporated into the LSS laboratory. The baseline set of sensors and actuators included the Base Excitation Table (BET) for two-axis translational disturbance at the base of the structure, the augmented Advanced Gimbal System (AGS) at the base for control in the three rotational axes, and a three axis set of gyros and accelerometers at both the base and the tip of the mast for measurements. These hardware components were modeled using their mass properties and were assumed to be rigid. Gravity effects were accounted for in the model by adding in geometric stiffness elements. Each of these elements is a function of the load seen at the point of interest. The analytical model yielded frequencies within 20 percent of experimental values and good mode shape agreement. It was not realized at this time that the load on the mast changes the beam's inherent stiffness values. The model and the structure showed that the structural differences in each axis (shake table masses, tip and base inertias, rotational moment arms for each gimbal) tended to separate the bending pair frequencies. This second configuration also did not exhibit densely packed modes.

In 1986, the VCOSS-II configuration was obtained by adding a cruciform and additional pairs of sensors/actuators. This configuration produced the desired LSS characteristics with the addition of an unsymmetric cruciform attached to the tip instrument package. The ASTROMAST retained its basic properties and the addition of the four "legs" induced some structural interaction between the components to introduce more modes at the lower frequency range. The sensor/ actuator pairs introduced were the Linear Momentum Exchange Devices (LMEDs) produced under the VCOSS (Vibration Control of Space Structures) program; these were later modified by Control Dynamics to diminish the stiction and hysteresis effects. The VCOSS-II configuration was the first structure to have independent transfer function testing beyond the modal testing conducted by MSFC personnel. The LMEDs were not utilized during the transfer function testing as they were in the process of being modified. Dummy masses were attached to the structure to represent the LMEDs.

The model for the VCOSS-II configuration compared well with the modal test data except for one pair of modes. One of these pair was later determined to contain some invalid data and was eliminated from the modal data set. Transfer function testing was then performed to further quantify the amount of difference between the model and experimental results. This led to recalculations of the tip package and roll gimbal inertias, as well as a change in the beam's stiffness characteristics. Thus, it was realized that the ASTROMAST's stiffness values vary under different load conditions. An increased load starts to untwist the mast causing its structural characteristics to change. With these modifications, model frequencies within 12 percent of the experimental values were generated. And again, there was good modeshape correspondence.

These previous configurations have evolved into the ACES-I (Active Control Technique Evaluation for Spacecraft) configuration which is the main configuration examined in this report. Using everything which has been learned from the previous configurations, MSFC and Control Dynamics have produced an extensive amount of accurate experimental data and a valid analytical model which was used in control design.

ACES TESTING: MODAL AND TRANSFER FUNCTION TESTS

The ACES configuration (Fig. 2) underwent the most rigorous testing of any configuration. Modal testing of the structure was conducted over a series of frequency ranges. In addition, a full complement of sensor/actuator transfer functions were generated to aid in final model development and control system design and analysis.

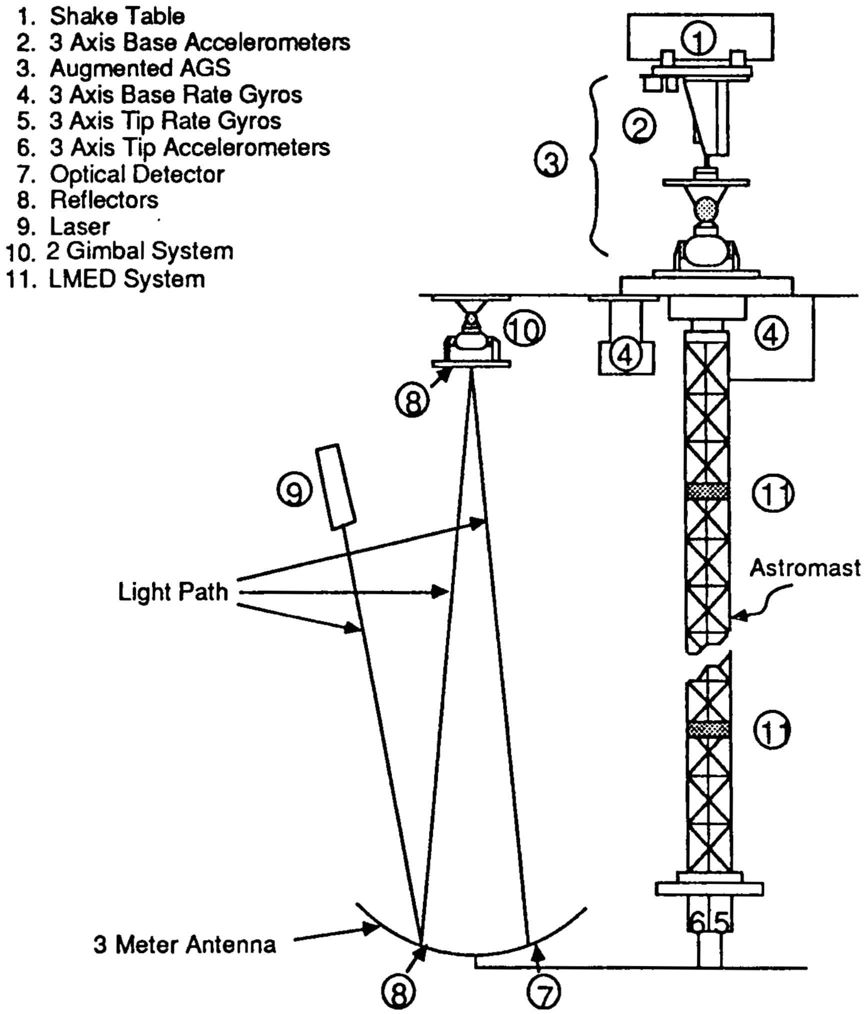

Figure 2. ACES configuration.

MSFC has conducted extensive modal tests on the preliminary ACES configuration in order to obtain a reliable set of test data. The preliminary ACES structure had the BET and augmented AGS turned off, the LMEDs locked in place, and dummy masses for the Image Motion Compensation (IMC) equipment. Single and multi-point random techniques were used to obtain the modal data. This data was stored and manipulated on a GenRad 2515 Structural Dynamics Analyzer from which frequencies, modeshapes, and damping values were obtained. From these tests, the frequencies and modeshape descriptions given in Table 1 were obtained. For a detailed report on the modal testing, contact ET53 at MSFC and reference report number TCF DEV-ET86-040.

TABLE 1. SUMMARY OF MODAL TEST RESULTS

TEST NO.	FREQUENCY (HZ)	DAMPING (%)	DESCRIPTION
TSS-002	0.637	1.13	2nd Bnd Y
	0.752	1.07	2nd Bnd X
	0.826	1.03	3rd Bnd Y
	1.04	0.65	3rd Bnd X
	1.405	0.68	Antenna Torsion, Upper Balance Arms Bnd
	1.702	0.36	Antenna Rocking About X, Lower Balance Arms Bnd X, Mast Bnd Y
	1.752	0.41	Antenna Torsion, and Rocking About Y, Mast Bnd X, Upper Balance Arms Bnd X, Power Balance Arms B Z
	1.92	0.51	Antenna Torsion and Rocking About X, Mast Bnd Y, Upper Balance Arms Bnd XZ, Lower Balance Arms Bnd XZ
TSS-003	2.0	0.37	Antenna Torsion, Mast Bnd XY, Upper Balance Arms Bnd X, Lower Balance Arms BndX
	2.356	0.76	Antenna Torsion, Mast Bnd XY, Upper Balance Arms Bnd X, Lower Balance Arms Bnd X)Same Motion A 2.0Hz Mode but out of Phase)
	2.494	0.63	Mast Bnd Y, Upper Balance Arms and AGS Plate Bnd Z, Antenna Rolling About Y
TSS-004	4.196	0.54	Mast Bnd XY (3rd Bnd), Antenna Rolling About Y, Lower Balance Arms Bnd Z
	7.023	1.44	AGS Adapter Plate and Upper Balance Arms Torsion
	7.261	0.91	Mast Bnd XY
TSS-005	1.36	0.2	Lower Balance Arms Bnd Z
	1.47	0.56	Antenna Torsion

NOTE: Three system modes, a first bending pair at approximately 0.14Hz and a first torsion at approximately 0.03Hz were observed in the FRF's but mode shapes were not obtainable.

A second means of verifying the model was through the use of transfer function tests which were effected by Control Dynamics personnel. Dummy masses were still on the structure representing the pointing gimbals, mirrors, and detector. These tests had the roll gimbal and LMEDs operational. A set of tests was also run with the LMEDs locked in order to readily compare with the modal test data.

All control actuators and sensors were stabilized in the transfer function tests. Tables 2 and 3 list the possible excitation and response locations. The blocks which do not contain an "X" had a minimal response for the associated input-output combination. The transfer functions for the boxes with an "X" were saved on tape, plotted, and used to compare with those transfer functions from the analytical model.

TABLE 2. TRANSFER FUNCTIONS WITH LMEDs LOCKED

OUTPUT INPUT	BASE ACCEL x	BASE ACCEL y	BASE GYRO x	BASE GYRO y	BASE GYRO z	LMED1 x	LMED1 y	LMED2 x	LMED2 y	TIP ACCEL x	TIP ACCEL y	TIP ACCEL z	TIP GYRO x	TIP GYRO y	TIP GYRO z	ANTENNA BASE x	ANTENNA BASE y	ANTENNA BASE z	GIMBAL ARM x	GIMBAL ARM y	GIMBAL ARM z
BET x																					
BET y																					
AGS x			X	X		X		X	X			X	X				X			X	X
AGS y			X	X		X	X	X	X			X	X			X			X		X
ROLL z																					

TABLE 3. TRANSFER FUNCTIONS WITH LMEDs UNLOCKED

OUTPUT INPUT	BASE ACCEL x	BASE ACCEL y	BASE GYRO x	BASE GYRO y	BASE GYRO z	LMED1 x	LMED1 y	LMED2 x	LMED2 y	TIP ACCEL x	TIP ACCEL y	TIP ACCEL z	TIP GYRO x	TIP GYRO y	TIP GYRO z	ANTENNA BASE x	ANTENNA BASE y	ANTENNA BASE z	GIMBAL ARM x	GIMBAL ARM y	GIMBAL ARM z
BET x																					
BET y																					
AGS x			X	X		X	X	X	X				X	X							
AGS y			X	X		X	X	X					X	X							
ROLL z					X																
LMED1 x				X		X															
LMED1 y			X						X				X	X							
LMED2 x						X		X					X	X							
LMED2 y									X				X	X							

The transfer functions were generated utilizing the control actuators and sensors. An input excitation was applied to the structure through each control actuator. Each output response was measured by each of the control sensors. The actuator input signal and the sensor output signal were transmitted to the HP5423 structural analyzer to calculate the transfer function.

Judicious selection of the input excitation improves the accuracy of the transfer function over the frequency range of interest. The coherence function was examined to determine the reliability of each transfer function. Figure 3 illustrates the input excitation chosen to generate the transfer functions. The protracted pulse is of length 5 times the sample period, where the length is chosen such that its frequency response zero does not interfere with the transfer function. The amplitude of the input is maximized; this maximization is limited by sensor saturation. Ten averages were collected for each final transfer function. An 8 Hz bandwidth was used as it accommodates the significant modes and corresponds to an analyzer sampling time of close to 20 msec. An exponential window was applied to force the response to zero.

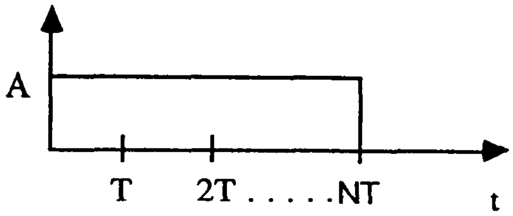

Figure 3. Transfer function excitation.

ACES MODEL

The ACES model was the most complex model developed. It was developed in stages as the actual hardware became available. A pre-test model was developed to aid the modal test team in determining the testing ranges. As the modal test data and transfer function data became available, this model became the preliminary model. With all the data correlated, the control model evolved from the preliminary model. The control model is the one provided to the control designers working on Positivity, FAMESS, and HAC/LAC designs.

PROCESS

The present configuration is the ACES configuration, which has undergone the most extensive testing and analysis of any configuration. The cruciform was removed from the tip of the VCOSS-II model and a tri-element figure was added. The one "leg" contains an antenna structure with a mirror and detector at its center. There was originally a covering on the antenna frame, but this produced an extensive amount of damping in the tip movement and was removed. There are also two counterbalance "legs" at the tip of the structure to keep the center of mass along the vertical axis. Near the base of the structure two "arms" were also added. One "arm" reaches over the antenna and has attached to its end a two-axis gimballed mirror; the second "arm" functions as a counterweight to the first "arm." The gimbals on the "arm" provide a new actuating location and the detector provides a new sensing location. All in all, the simple cantilevered ASTROMAST has become a very complex control structure. The new appendages have succeeded in making this configuration conform to the definition of LSSs; lightly damped, densely packed, coupled low frequency modes.

COMPARISON WITH TEST RESULTS

A comparison of the preliminary analytical model with the modal test data shows that the antenna model contributed a significant number of frequencies in the 0 to 8 Hz range. These modes were not measured in the modal tests. It was decided to simplify the antenna model by eliminating many localized modes of the antenna and to become more consistent with the actual structure. The original antenna model was fairly complex with more detail than was required. The antenna modes still did not correspond well with the measured antenna behavior, but since these modes do not effect any sensor/actuator behavior it was decided that it was more important to tune the behavior of the ASTROMAST, "arms," and "legs" than the local antenna motion.

During the transfer function testing it became apparent that the roll gimbal and the BET could move even when turned off. At this point it was decided to unlock the DOFs corresponding to the X and Y translations of the BET and the rotation about Z of the roll gimbal. For modeling purposes only, stiffness values were implemented to model the break-away friction for the equipment. This was done in an attempt to better match the modal test conditions. Stiffness values were chosen so that key modal frequencies matched. In the control model, these DOFs are freed (no associated stiffness values) in order to agree with the ACES configuration which has the equipment fully operational.

The problems matching the measured torsional modes with the preliminary model were alleviated through the utilization of the torsion spring. Freeing the roll gimbal DOF and inserting the torsional spring helped immensely, as the modes could not occur with the roll gimbal locked. This allowed the shapes to match, but the frequencies were still not within an allowable range. The E (Young's Modulus) value for the "arms" was then adjusted for stiffness purposes. It could not be adjusted dramatically as the "arm" behavior for the bending modes would be effected. It was adjusted in coordination with the torsional spring and the ASTROMAST G (torsional modulus) value to match the torsional frequencies and to not disrupt the bending frequencies.

The modal testing and transfer function testing revealed a great deal more cross coupling than seen in the model. Actual location measurements were then made on the structure and it was observed that the components were not lined up as assumed. When the misalignments were added to the model the coupling did increase, but the magnitude of the cross coupling was still below the measured behavior.

Based upon the results of the modal and transfer function testing, a tuned model was developed incorporating the updates previously discussed. The results from this tuned model and its comparison with the modal data is given in Table 4. The analytical frequencies are all within 20 percent except for the first torsional mode. Looking at this frequency numerically, it is only off by 0.04 Hz. In the testing, this mode could be seen but is difficult to measure due to its extremely low frequency; the transfer function testing located this mode at 0.045 Hz.

TABLE 4. TUNED PRELIMINARY MODEL MODE DESCRIPTIONS

Model Frequency (Hz)	Experimental Freq. (Hz)	Percent Error	Description
.07	0.03	-133%	Torsion
.14	0.14	-	X-Bending
.14	0.14	-	Y-Bending
.53	0.637	17%	Y-Bending
.59			X + Antenna
.59			Y + Antenna
.60			Torsion + Antenna
.70			X + Legs + Ant.
.71			X + Legs + Ant.
.73	0.752	3%	X + Ant. + Arms
.95			Antenna
.95			Antenna
.95	0.826	-15%	Y + Legs + Ant.
1.00	1.042	4%	X + Legs + Ant. + Arms
1.20	1.405	15%	Torsion + Arms
1.34			Arms
	1.357		Legs
	1.466		Antenna Torsion
1.70	1.702	-	X + Y + Legs
1.73	1.752	1%	X + Y + Legs + Arms
1.84			Y + Legs + Ant.
1.92			Antenna
1.92			Antenna
2.12	1.920	-10%	Y + Antenna
2.20	2.000	-10%	X + Arms
2.53	2.356	-7%	X + Legs + Ant.
2.55	2.494	-2%	Y + Ant. + Arms
3.31			Antenna
3.31			Antenna
3.80			Torsion
4.29	4.196	-2%	X + Legs + Ant.
4.71			Antenna
4.71			Antenna
5.35			Antenna
5.45			Y + Legs + Ant.
6.73			Y + Z + Legs
6.87	7.023	2%	Torsion + Arms
6.97	7.261	4%	Torsion

There are also two modes obtained in the modal testing which do not appear in the model. They were both obtained during the torsion testing, which had its own difficulties. As neither mode appeared in the transfer function tests and these modes did not appear from the modal testing to have a great deal of action at the sensor/actuator complement, it was decided not to try and force the model to yield these behaviors.

The remaining experimental and analytical modeshapes agreed well. The basic characteristics which appeared in the modal testing appeared in the model. Figures 4 and 5 give examples of modeshape comparisons. Since the model is linear and the structure is not, discrepancies are bound to occur. These differences involve "arm" motion and some "leg" motion. Some of the non-linearities include non-rigid joint connections, friction, and damping.

While the modal testing helped in matching frequencies and modeshapes, the transfer function testing aided in matching the system coupling and mode dominance. Because the torsional measurements were limited by equipment and measurement locations, the transfer function results are only useful for transverse vibrations. Figures 6 and 7 depict two comparisons of the measured and modeled behavior. The analytical transfer functions basically have the same behavior as the experimental ones. Discrepancies between the two sets do exist however; the major differences involve the magnitudes of the peaks, the model peaks are generally lower than their experimental counterparts. The phases are difficult to compare as the experimental plots contain lags due to the computational delays in the computer system.

The control model has utilized all that has been learned in the previous configurations, especially from the results of the preliminary model. The modal testing and transfer function testing have contributed a significant amount of knowledge about the structure which previously was not available. The following changes have been made to update the preliminary model to the control model form. The characteristics of the actual equipment have been implemented: pointing gimbal assembly, mirrors, detector, and any counterweight updates. The stiffness values for the BET and roll gimbal have been removed as the equipment is operational for control and disturbance purposes. Table 5 gives the frequencies and modeshape descriptions for the control model.

Line-Of-Sight (LOS) errors were calculated, for each mode, for the two mirrors and the detector. The LOS errors were calculated utilizing the structure's geometry (Fig. 8) and the modal gains for each frequency. The geometry relating the laser source, mirrors, and detector for a static condition is input and transformed from the laboratory reference frame to local detector and mirror frames. For the static case, this produces a 0.0 LOS error in the plane of the mirrors and detector. When the modal gains are included in the LOS equations, an X and Y error are calculated for each mirror and the detector. The detector local coordinate system is calculated to be parallel to the global system as the detector was originally in the horizontal plane and there are only small angle perturbations at the detector location in the analytical model. Again, these are the two LOS error components in the plane of a mirror or detector, and the values are the distance of the laser beam from the center point in meters.

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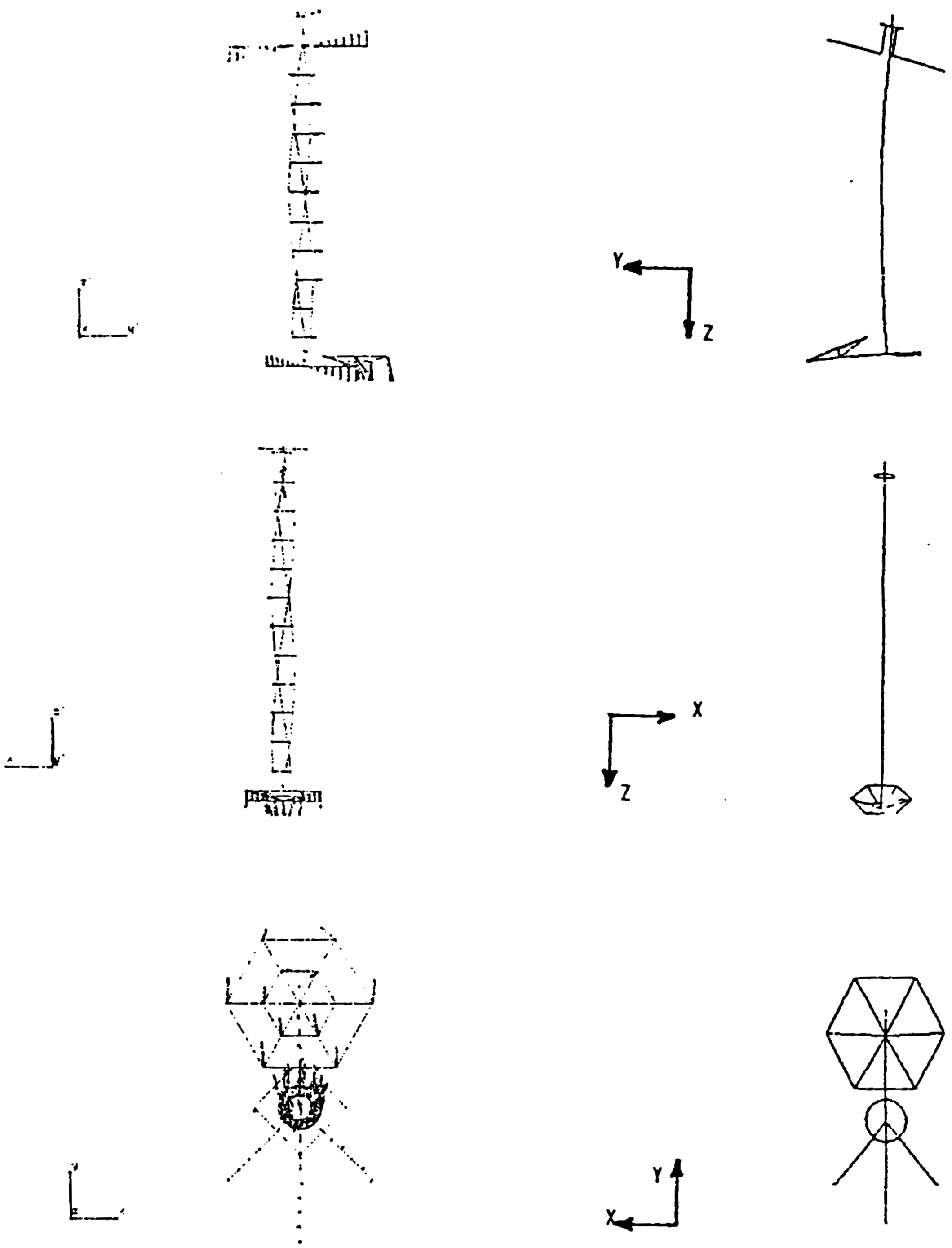


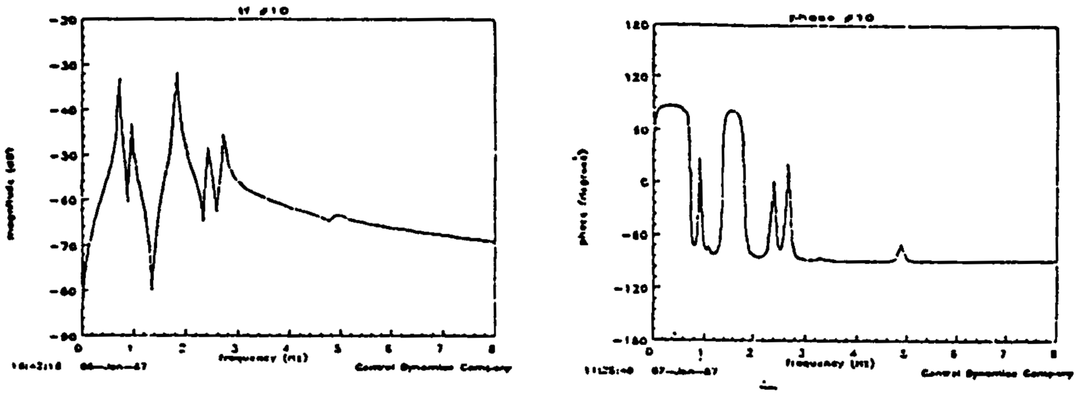
Experimental Mode, 0.637 Hz

Analytical Mode #4, 0.53 Hz

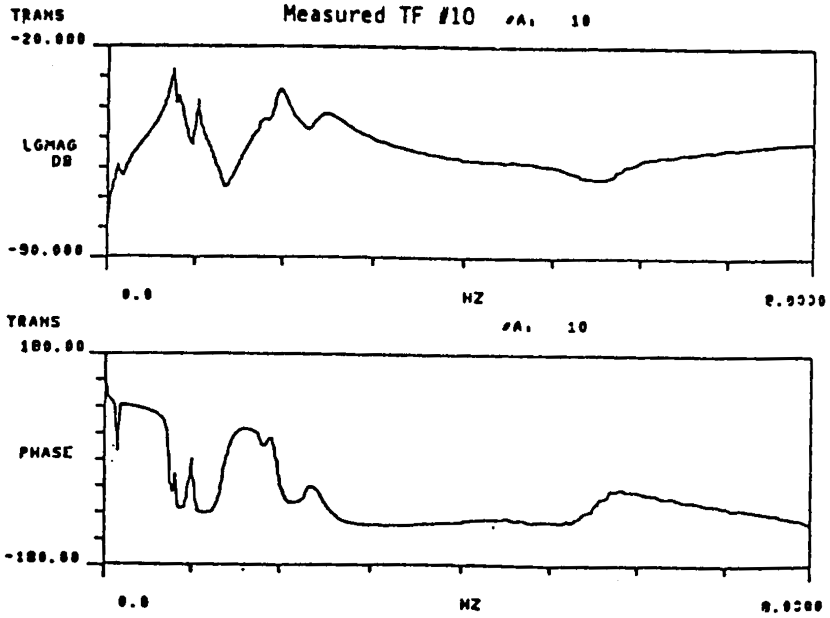
Figure 4. Y-bending.

AGS-Y to BASE GYRO-Y

Model TF #10



Measured TF #10



	Analytical	Experimental
.75Hz	-33dB	-28dB
.83Hz		-35dB
1.0 Hz	-44dB	-38dB
1.8 Hz	-32dB	-42dB
2.0 Hz	-48dB	-32dB
2.5 Hz	-45dB	-40dB

Figure 6. Transfer function.

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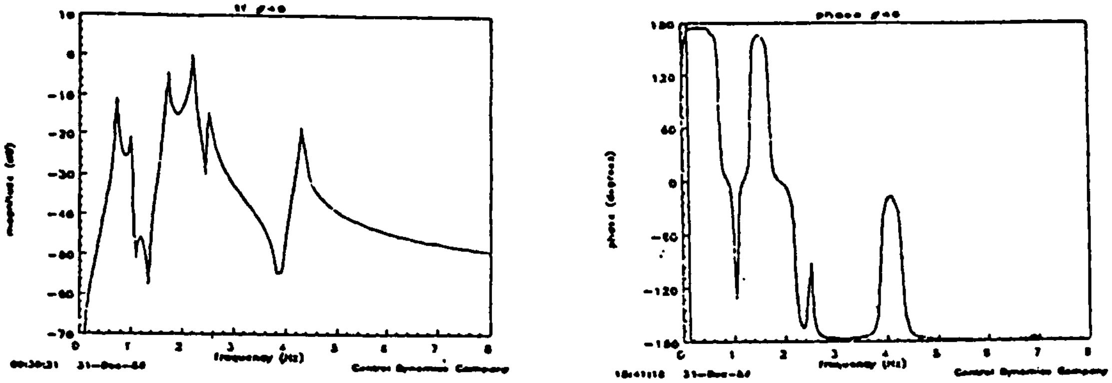
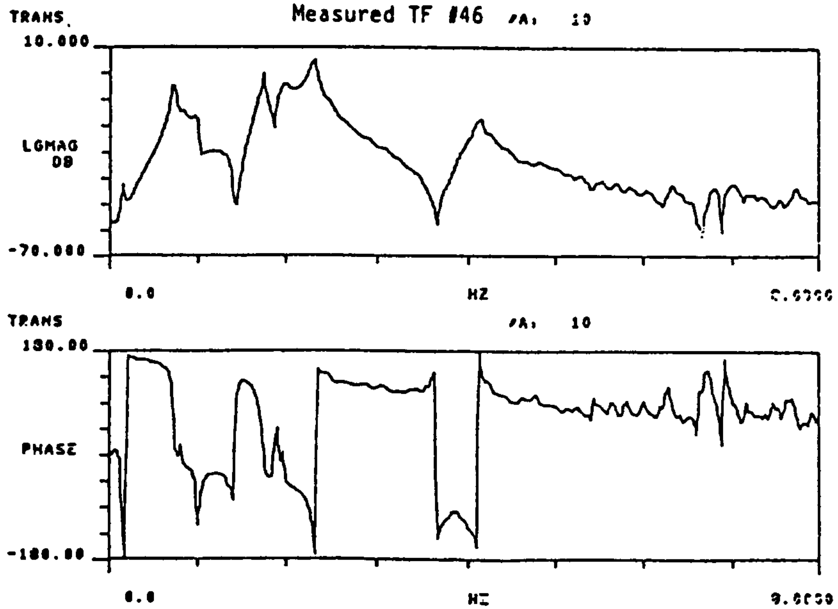
AGS-Y to LMED1-X

Model TF #46



Measured TF #46



	Analytical	Experimental
.75Hz	-10dB	-5dB
1.0 Hz	-21dB	-15dB
1.75Hz	-4dB	0dB
2.0 Hz	0dB	-5dB
2.3 Hz	-15dB	5dB
4.2 Hz	-18dB	-20dB

Figure 7. Transfer function.

TABLE 5. FINAL ACES MODEL

Final ACES Model	
Mode	Frequency (Hz)
Rigid Body, Torsion + X-Bending	0.00
Rigid Body, Torsion + X-Bending	0.00
Rigid Body, Y-Bending	0.00
Torsion + Legs + Antenna + Arms + Gimbals	0.09
Y-Bending + Antenna + Gimbals + LMEDs	0.50
X-Bending + Antenna	0.59
Antenna	0.59
Torsion + Antenna	0.60
X-Bending + Legs + Antenna + Arms + Gimbals + LMEDs	0.69
X-Bending + Y Bending + Legs + Antenna	0.70
X-Bending + Legs + Antenna + LMEDs	0.71
Y-Bending + Legs + Antenna + LMEDs	0.92
Antenna	0.95
Antenna	0.95
X-Bending + Legs + Arms + Gimbals + LMEDs	0.96
X-Bending + Y-Bending + LMEDs	1.17
X-Bending + Y-Bending + LMEDs	1.18
X-Bending + Y-Bending + Legs + LMEDs	1.23
X-Bending + Y-Bending + Legs + LMEDs	1.24
Arms + Gimbals	1.25
Gimbals	1.51
X-Bending + Arms + Gimbals + LMEDs	1.67
Y-Bending + Legs + Antenna + Gimbals + LMEDs	1.76
Y-Bending + Legs + Antenna + Gimbals	1.85
Antenna	1.92
Antenna	1.93
X-Bending + Gimbals	2.08
Y-Bending + Antenna + Arms + Gimbals + LMEDs	2.18
X-Bending + Antenna + Gimbals	2.34
X-Bending + Legs + Antenna + Gimbals	2.58
Y-Bending + Antenna + LMEDs	2.67
Torsion + Arms + Gimbals	3.31
Antenna	3.31
Antenna	3.31
X-Bending + Y-Bending + Torsion + Legs + Antenna	4.58
Torsion + Antenna	4.71
Antenna	4.71
Torsion	4.71
Antenna	5.34
Y-Bending + Legs + Antenna	5.84
Y-Bending + Z + Legs	6.92
Torsion	8.77
Gimbal Arm	8.82

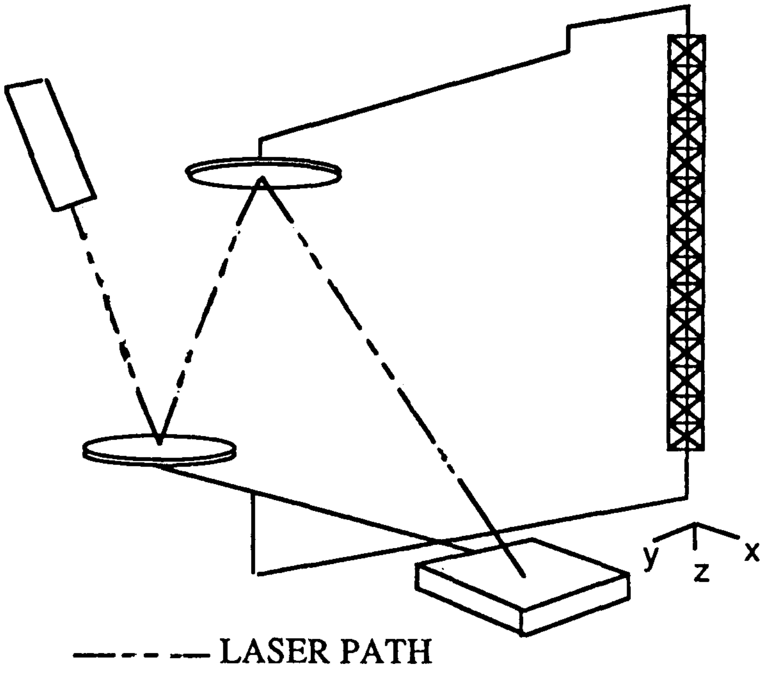


Figure 8. LOS geometry.

Modal gains and frequencies were provided for use in the control designs. Gains at the following specific locations were provided:

1) BET translations.

2) Translations at the base accelerometers.

3) Translations at the tip accelerometers.

4) Translations at the antenna base.

5) Translations at LMED1 and LMED2 pairs.

6) LMED 1 - mast and LMED 2 - mast relative translations.

7) AGS rotations.

8) Rotations at the base gyros.

9) Rotations at the tip gyros.

10) Rotations at the tip base.

11) Pointing gimbal rotations.

12) AGS relative rotations.

TABLE 6. EXAMPLE DATA

Mode Number	Translational Gains				
	BET		Base Accelerometers		
	X	Y	X	Y	Z
1	.2874E-01	-.9650E-03	.2874E-01	-.9650E-03	.1672E-09
2	-.2381E-01	.1694E-02	-.2381E-01	.1694E-02	-.1188E-09
3	-.1978E-02	-.3455E-01	-.1978E-02	-.3455E-01	-.1053E-10
4	-.3925E-02	-.3710E-04	-.3925E-02	-.3710E-04	-.3284E-10
5	-.1111E-03	.4255E-02	-.1111E-03	.4255E-02	.5111E-11
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
42	-.1865E-05	.2609E-07	-.1865E-05	.2609E-07	-.3482E-12
43	.7512E-03	.8661E-08	.7512E-03	.8661E-08	-.8268E-11

13) Pointing gimbal rotations.

14) LOS error for mirror 1, mirror 2, and the detector.

Table 6 shows an example table of data provided to the controls designers. The data were provided in the form of modal gains since two of the control techniques used the state-space form and could not directly utilize the transfer function data.

The control model has not been verified against experimental data, but Control Dynamics feels it is a good model based upon the preliminary model tuned with the modal test data and the transfer function data. For a more thorough explanation of the model, model results, and test results refer to the ACES Report on the Finite Element Model prepared by Control Dynamics.

CLOSING COMMENTS

Some valuable lessons have been learned from the ACES program and the configurations which have preceded it at the MSFC Ground Test Facility, and much has been learned about the development of a large flexible structure with the associated characteristics in a 1-g environment. The realization that appendages are necessary to reduce the structural frequencies led to the pointing/antenna ACES configuration. There have been difficulties in measuring the structure's behavior as the structure became more complex. The torsional behavior is especially difficult to measure since there needs to be a tremendous amount of energy to excite this motion. The structures have been modeled using fairly simple approaches and element types, and the models represent the structures well. Other more complex techniques are available, but when a simple approach works, as it does here, there is no need to spend extra time developing extremely detailed models. An important asset here was the in-house ability to perform transfer function testing on the structure. These tests provided valuable insights to the world of testing and about the structure itself. Some characteristics which may not have shown up in the modal testing were shown in the transfer function testing and vice versa.

It has been a great learning experience for Control Dynamics to have been involved with MSFC in the LSS arena. Dealing with the problems in modeling, testing, analysis, and hardware has left a sense of accomplishment as they have been overcome. This facility also directly applies the CSI goals: from the structural model development and tuning with test data, to the interaction with control engineers to provide them with the data they need, to the design and implementation of the latest control design techniques. Control Dynamics has been proud to have been involved in this effort and plans to continue working with MSFC and WPAFB in the LSS area.

APPROVAL

EMULATING A FLEXIBLE SPACE STRUCTURE: MODELING

By H. B. Waites, S. C. Rice, and V. L. Jones

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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