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NASA/MSFC GROUND EXPERIMENT FOR LARGE SPACE STRUCTURE CONTROL VERIFICATION

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16. ABSTRACT

NASA Marshall Space Flight Center has developed a facility in which closed loop control of Large Space Structures (LSS) can be demonstrated and verified. The main objective of the facility is to verify LSS control system techniques so that on-orbit performance can be ensured. The facility consists of an LSS test article which is connected to a payload mounting system that provides control torque commands. It is attached to a base excitation system which will simulate disturbances most likely to occur for Orbiter and DOD payloads. A control computer will contain the calibration software, the reference system, the alignment procedures, the telemetry software, and the control algorithms. The total system will be suspended in such a fashion that the LSS test article has the characteristics common to all LSS.

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TECHNICAL MEMORANDUM

NASA/MSFC GROUND EXPERIMENT FOR LARGE SPACE STRUCTURE CONTROL VERIFICATION

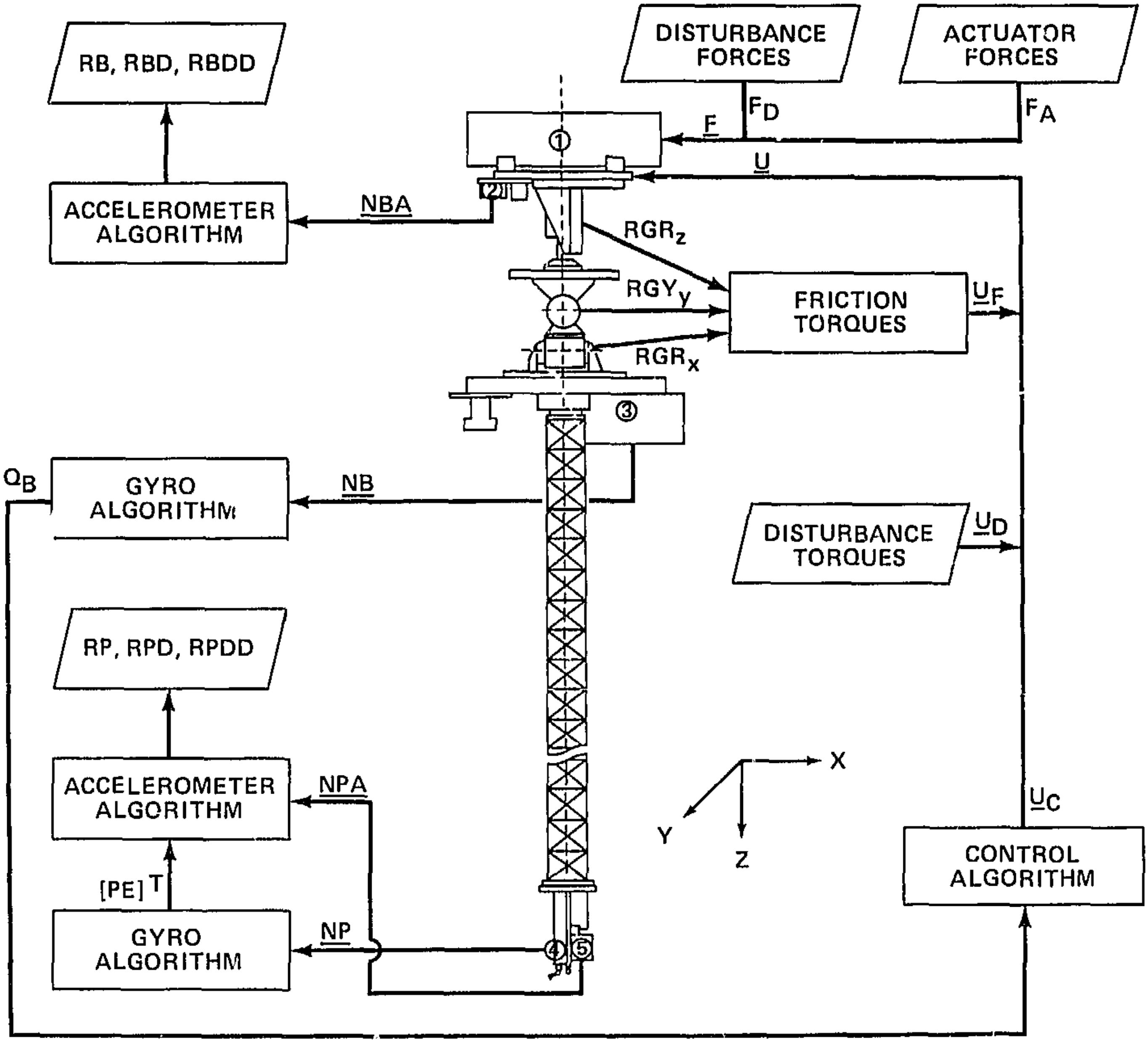
I. INTRODUCTION

Through the past decade considerable thought and effort have been expended to find solutions to the dynamics and control problems presented by Large Space Structures (LSS). In most of the previous NASA spacecraft dynamics and control system designs, the control engineer could specify structural constraints so that the control system would not interact with the structure. With the present LSS concepts, the control engineer no longer has the option of imposing constraints on the structure. The main LSS constraints that might affect the control system are a low fundamental vibrational mode, modal frequencies that are densely packed; large inertias and generalized masses for vibrational modes; low structural damping; and uncertainties in the dynamics model. Many analytical tools have been developed to analyze and control such structures. So far, none of these concepts has been proven on an LSS [1,2].

One of NASA/Marshall Space Flight Center's (MSFC) major objectives, relative to LSS proof-of-concept, is to design and build a ground test facility in which the dynamics and control system concepts being considered for LSS applications can be verified. The experiment must have the LSS pathologies previously mentioned and be sufficiently versatile so that the many analytical tools developed for LSS can be tested. A schematic for the MSFC ground test facility showing the various components and their interfaces is shown in Figure 1.

The viability and versatility of the MSFC LSS ground test facility was recognized by the U.S. Air Force Wright Aeronautical Laboratory (AFWAL) as a potential site for their Vibration Control of Space Structures (VCOSS) II testing. The VCOSS II controls testing central objective is to validate the theories developed in the VCOSS I program. The VCOSS I theories evince an approach which actively controls LSS vibrations through a mass-actuation concept. This mass-actuation hardware will be implemented into the NASA/MSFC Ground Test Verification facility (GTV) to provide a proof-of-concept for the VCOSS I study.

The VCOSS activities began under a joint effort directed by the Department of Defense Advanced Research Projects Agency (DARPA) and AFWAL. The thrust of VCOSS work was to survey all past, present, and future activities relative to spacecraft dynamics and control problems. After the survey was completed, a correlation was effected to determine common goals relative to the spacecraft dynamics and control performance objectives. For the particular spacecraft under scrutiny, its performance objectives determined whether past, present, or future technology issues would be necessary for mission success. The technology issues addressed such items as pointing stability and control, active and passive disturbance isolation, modular and evolutional control, maneuvering and pointing control, shape or figure control, reliability and reconfiguration, and system identification. The DARPA technology issues coincided with several objectives of the NASA/MSFC LSS/GTV facility. The apparent commonality led to discussion about common interests. The subsequent discussions were fruitful and the VCOSS II hardware testing will be performed in the



1. SHAKE TABLE
2. 3 AXIS BASE ACCELEROMETERS
3. 3 AXIS BASE RATE GYROS
4. 3 AXIS TIP RATE GYROS
5. 3 AXIS TIP ACCELEROMETERS

Figure 1. LSS simulation — GTV assembly input-output without cruciform.

MSFC facility. The coordination of LSS efforts, such as the VCOSS II program, provides a synergism between Government agencies which reduces duplication of effort in an expensive testing area.

Clearly, economics is one of the major drivers in the area of LSS ground testing. In the ensuing description of the test facility, the reader will see that much use has been made of available hardware already belonging to NASA and in particular MSFC.

The control system focus for the NASA/MSFC LSS/GTV work is to verify the dynamic models and control system methodologies. The LSS dynamics and control verification plan at MSFC is divided into four interacting areas which are: (1) dynamic modeling, (2) control law synthesis, (3) verification, and (4) the development of hardware flight systems. Each area interacts with the others from an initial experiment concept to the development of a hardware flight system. The control laws, which can be verified with the initial configuration, are the centralized control method and the distributed sensor control method, along with a disturbance isolation control technique. With the addition of AFWAL's VCOSS II hardware testing at the LSS/GTV facility, other control law concepts such as decentralized control and distributed control can be verified using the AFWAL control hardware in conjunction with that already in place. The AFWAL control hardware will be attached to the test structure and tested to determine whether the VCOSS II objectives are satisfied. Once the initial VCOSS II testing is complete, NASA/MSFC will use the hardware as previously stated.

NASA/MSFC is presently supporting both DARPA and the Space Defense Initiative office by LSS/GTV test result presentations and data dissemination. This synergistic effort is not only to support the NASA research and technology programs but to inform other Government agencies of the LSS/GTV facilities' capabilities.

It is the purpose of this paper to present a description of the NASA/MSFC GTV experiment for LSS dynamics and control system verification. The objectives have already been described in the introduction. In Section II a detailed description of the LSS/GTV is provided. This is followed by a discussion of the GTV system dynamics (Section III). A brief discussion of some of the control system work is provided in Section IV. Section V describes the next modification planned for the GTV, and Section VI briefly describes the test plan.

II. LSS/GTV FACILITY DESCRIPTION

The first version of the LSS/GTV facility is shown schematically on Figure 1. It consisted of an ASTROMAST beam mounted to the faceplate of the Angular Pointing System (APS). The APS, in turn, is mounted to the Base Excitation Table (BET). Six separately packaged inertial measurement assemblies comprise the control system sensors. The signals from these sensors are received and processed in the COSMEC-I data gathering and control system which computes and transmits control actuator signals to the APS actuators. The COSMEC-I interfaces with a Hewlett Packard HP9845C desktop computer which stores data as they are collected during test runs; it then provides post-experiment data reduction and off-line displays.

The original test configuration had all the desired LSS characteristics except the densely-packed vibrational modes. Several design configuration changes were considered so that this important missing structural constraint could be implemented.

The configuration change which could effect the densely-packed modes was the addition of a cruciform structure at the tip of the ASTROMAST. To a degree, the new configuration approximates an antenna or a radar system.

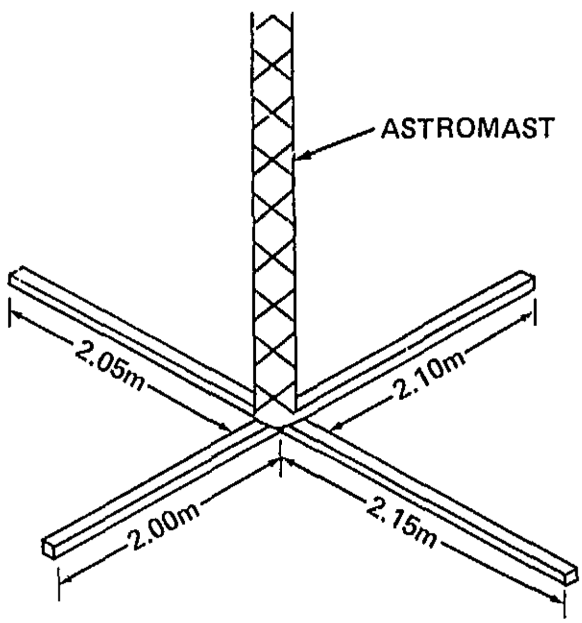
The next planned configuration change will be the addition of a three meter offset antenna to the ASTROMAST tip and an antenna feed located on the payload mounting plate. This addition will facilitate both decentralized and distributive control methodologies. Also, a bi-directional linear thruster system is planned for location at the ASTROMAST tip so that active vibration suppression can be tested using these thrusters. The integration of the previously mentioned LSS/GTV modifications will provide adequate sensors, effectors, and LSS dynamic pathologies so that the test facility can encompass many facets of dynamics and control verification.

A. Structure

The first test article is a spare Voyager ASTROMAST built by ASTRO Research, Inc. It was supplied to MSFC by the Jet Propulsion Laboratory (JPL). The ASTROMAST is extremely lightweight (about 5 lb) and approximately 45 ft in length. It is constructed almost entirely of S-GLASS. It is of the type flown on the Solar Array Flight Experiment-I (SAFE-I).

When fully developed, the ASTROMAST exhibits a longitudinal twist of about 280 deg. This twist contributes to the coupling between the torsional and bending modes.

As stated in the Introduction, the second test article consists of the ASTROMAST with a cruciform attached to the tip. The cruciform structure, which is made of aluminum, weighs 8 lb and is shown in Figure 2. The cruciform rods vary in length from 2.00 m to 2.15 m. They all have constant cross-section of 1/4 in. x 1/4 in.



FOR SIMULATION PURPOSES, THE 4 ALUMINUM BARS WERE PLACED AT THE TIP OF THE BEAM; IN ACTUALITY, THEY ARE TO BE LOCATED AT THE END OF THE TIP BRACKET. THE RODS VARY IN LENGTH FROM 2.00m TO 2.15m. THEY ALL HAVE A CONSTANT CROSS-SECTION OF 1/4" x 1/4".

Figure 2. The cruciform structure.

B. Angular Pointing System (APS)

The test structure is mounted to the payload mounting plate of an APS. The APS provides the control inputs for the initial configuration system and the cruciform-modified system. The APS actuators are the Advanced Gimbal System engineering model, produced by Sperry for the Spacelab program, and a third (roll) gimbal designed and built inhouse (as were the amplifiers used to drive the gimbal torquers). The roll gimbal, serving the vertical axis in Figure 1, is suspended by an air bearing which requires approximately 85 psi to operate. The roll gimbal provides a means of rotating the entire system to produce different test scenarios. The air bearing is connected to a Base Excitation Table (BET) which is free to translate in two directions. This actuator assembly setup, with its low friction torques, permits control in three angular directions. With the added roll gimbal, the test article can be rotated about its center line so that different test setups can be achieved.

In the initial research and technology task, the effectors for the LSS/GTV control system are three torque motors which are capable of providing control torques about three axes. The bottom two gimbals can generate up to 51 N-M of torque, and the roll or azimuth gimbal can generate up to 10 N-M of torque. The bandwidth limitation for all three gimbals is 100 Hz. The APS amplifiers receive torque commands from the COSMEC-I digital processor in the form of analog inputs over the range of -10 to +10 V. This saturation represents the current limit of 27 A which is built into the APS servo amplifiers. Because the APS servo amplifier outputs a current which is proportional to torque, the control law algorithm was designed to produce torque command signals. The gimbal torquers are shown in Figure 3.

C. Base Excitation Table (BET)

All of the GTV configurations need a device to excite the system in a consistent manner so that the effectiveness of the different control methodologies can be determined. Initially, these disturbances will represent either an astronaut pushoff, or a Reaction Control System thruster firing, or a free flyer disturbance. The BET which is attached to the building support structure, is shown in Figure 3. It provides a means of producing such disturbance inputs. The BET is comprised of signal generators (deterministic or random noise), DC conditioning amplifiers, hydraulic servo controllers, and an oscillograph. The DC conditioning amplifiers are used to scale the signal generator while the signal conditioners are used to condition the electronic deflection indicator motion monitors for display. The oscillograph is used for recording the actual motion of the BET.

The precise motion of the BET is obtained by supplying a commanded voltage input to the BET servo control system. The BET movements are monitored by the directional feedback electronic deflection indicators which are fed back to the servo controllers. The servo controllers compare the commanded input voltage to the electronic deflection indicators and automatically adjust the position of the BET. The closed loop controller allows any type of BET movement within the frequency limitations of the hydraulic system. Figure 4 illustrates the frequency versus displacement response of the BET using a sinusoidal commanded input.

D. Suspension System

Originally, the test article was to be suspended by a constant tension cable connected to a tripod which was free to translate on air bearings. This original

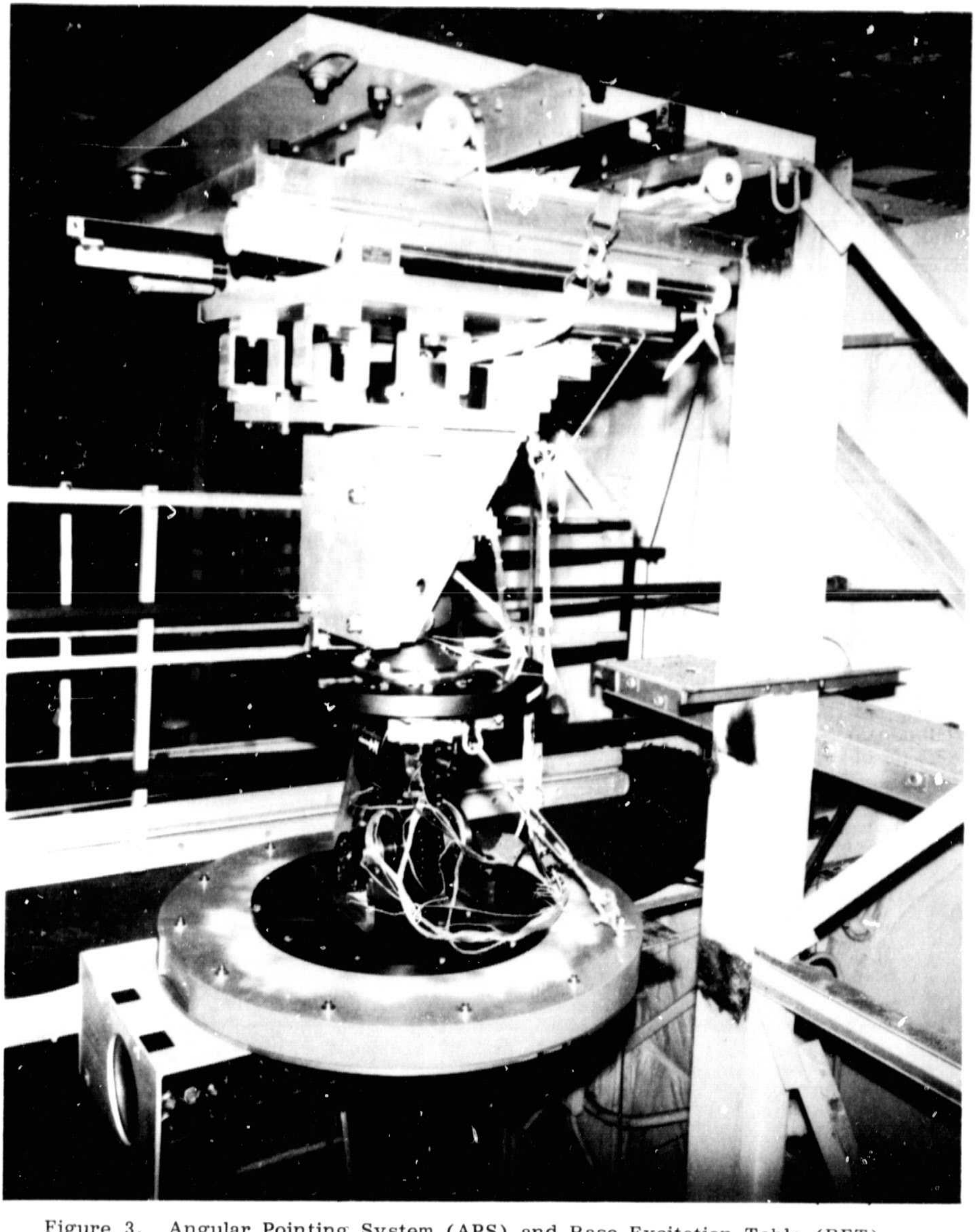


Figure 3. Angular Pointing System (APS) and Base Excitation Table (BET).

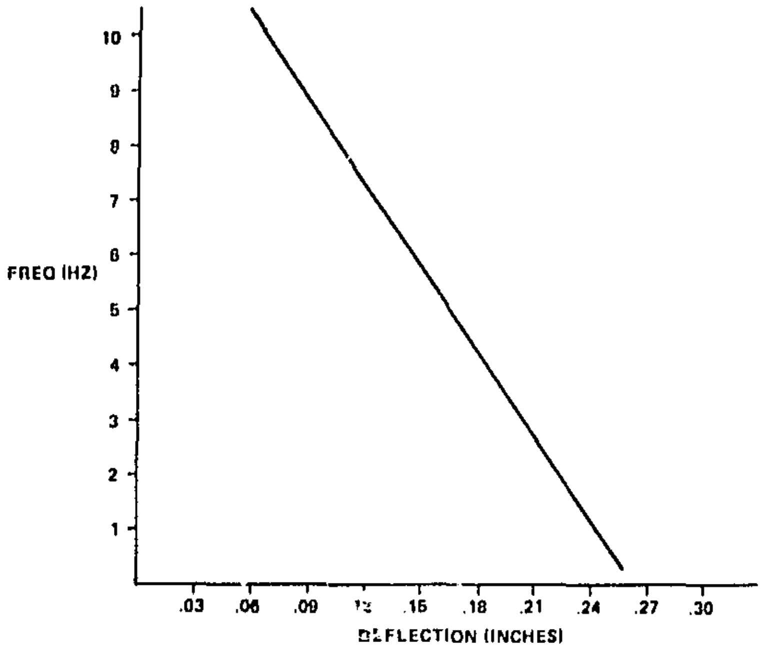


Figure 4. BET frequency versus displacement response.

concept was rejected for several reasons. Analysis of the tripod suspension assembly showed that the constant tension cable system and the tripod translational dynamics system would require use of active control to meet performance requirements. Simulation of these two controllers with the LSS/GTV closed loop configuration showed that it was extremely difficult to ascertain which controller was actually affecting the LSS modes. Also, the complication of having two control systems just for the suspension assembly was out of the question. In addition to these complications, the cost and check-out of the suspension control systems would have been prohibitive for a research effort. With the LSS/GTV as it is presently configured, the cost and check-out time will be less, and the control system evaluation will be more straightforward.

E. Sensors

Six separately packaged inertial measurement assemblies comprise the control system sensors. Two of the packages, containing three-axis translational accelerometers, are identical. One is mounted on the mast tip and the other on the lower surface of the BET. Three other packages contain Skylab ATM (Apollo Telescope Mount) rate gyroscopes and are mounted on the APS faceplate. The sixth package, the Kearfott Attitude Reference System (KARS), is located on the mast tip along with the remaining accelerometer package.

The Kearfott Attitude Reference System (KARS) includes three rate gyros and three accelerometers. The KARS unit is mounted to the test article tip as shown in Figure 5, so that the sensors provide information about the tip motion. The rate

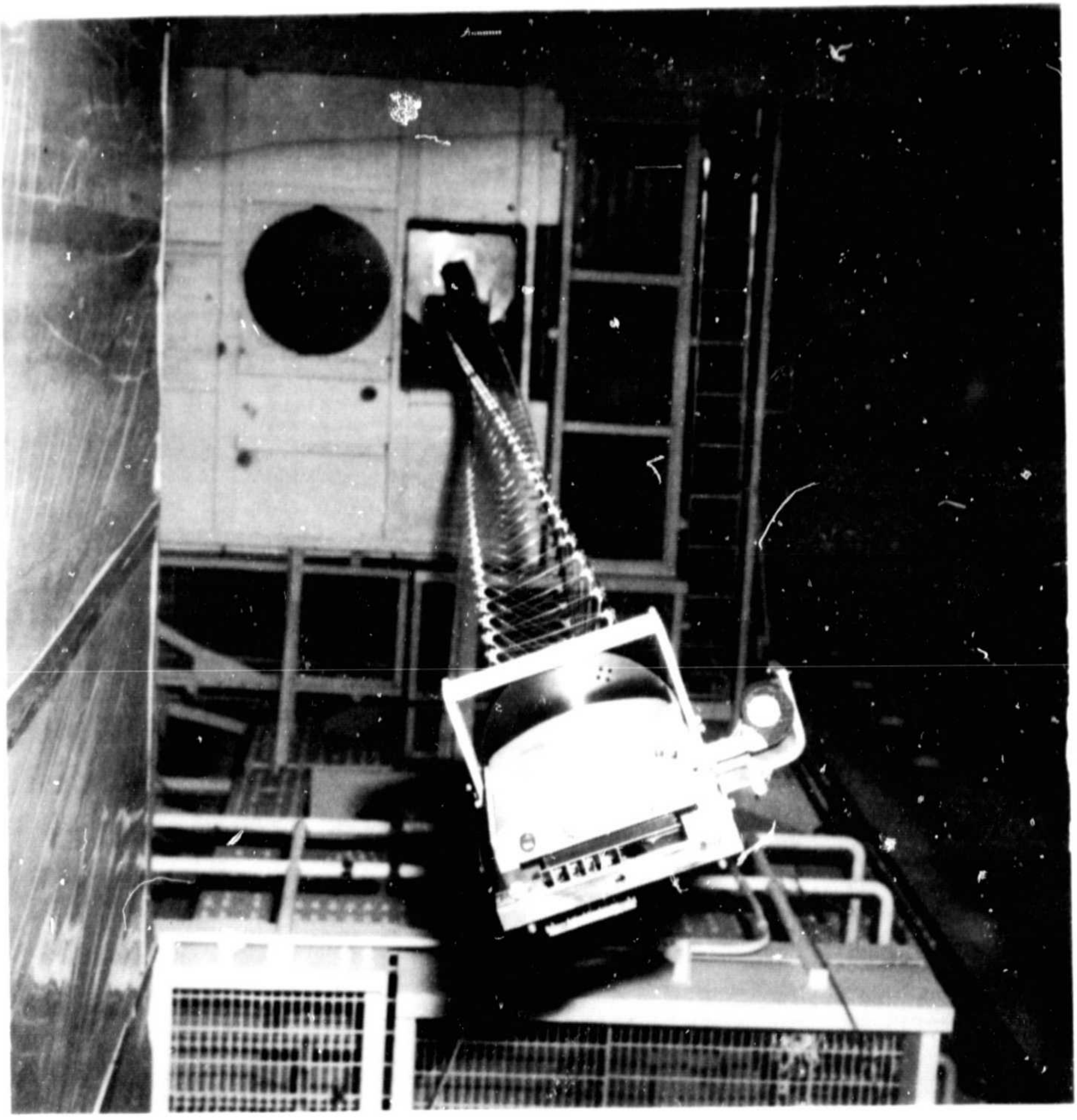


Figure 5. ASTROMAST and tip sensors.

gyros have a resolution of approximately 50 arc-sec/sec about two axes and 90 arc-sec/sec about the third axis. The KARS rate gyro bandwidth is about 70 Hz.

The ATM rate gyros are mounted to the APS payload mounting plate. The minimum resolution for the ATM gyros is approximately 2 arc-sec/sec. The gyros operate in a fine mode, which has a bandwidth of 12 Hz, and a course mode which has a bandwidth of 40 Hz.

The two three-axis accelerometer packages incorporate six Kearfott 2401 accelerometers. The minimum resolution for each of these units is 11 microg's, and their bandwidth is 25 Hz.

The signals from these instruments are read by the COSMEC-I data gathering and control system and processed according to the particular control strategy under scrutiny. The control actuator signals are then transmitted to the APS as inputs to the dynamical system.

F. Computers

The signals from the sensors are utilized by the control computer and processed according to the control law under consideration. The COSMEC-I is the control computer which is used for data acquisition, reference identification, and feedback control for the first experiment configuration. The COSMEC-I is a highly modified AIM-65 microcomputer system. It was developed originally by MSFC for the solar heating and cooling program. As a result the development cost was not underwritten by the LSS/GTV facility.

The main purposes of the control computer are to process the sensor inputs, keep up with the laboratory coordinate system, provide torque commands for the APS, and off-load control and sensor data to the Hewlett Packard HP9845C desktop computer. The COSMEC-I performs these tasks with twelve sensor inputs and three torque outputs, while maintaining a 50 Hz sampling rate.

The COSMEC-I has the capability to manage 32 differential analog inputs and 32 8-bit digital words. The input rate per channel is 20 μS for either 8 or 16 bits parallel digital information and 80 μs for a 12-bit analog data resolution. The COSMEC-I output capability is 16 analog channels at either ±15 V or 0 to 10 V and 32 8-bit digital channels. The output rate per channel is 20 μs for either 8-bit or 16-bit parallel digital information and 40 μs for a 12-bit analog data stream. The RAM size for the COSMEC-I processor is 32 kbytes and the clock rate is 2 MHz. The COSMEC-I also has an alphanumeric keyboard, a single line display, a cassette tape machine for mass storage, and a small printer. The entire system, which is shown in Figure 6, is based in a very portable package, much like a suitcase.

The COSMEC-I "reads" a variety of types of sensor output signals via interface cards which are an integral part of the COSMEC-I system. These cards allow the COSMEC-I processor to interface in a similar manner (with regard to computation) with the ATM rate gyros, the KARS, the accelerometer packages, and the APS, each of which has a different type output or input signal. The COSMEC-I also features a real time clock which will prove useful in the recording of experimental data.

In order to carry out the large number of calculations required for implementation of the inertial strapdown algorithm and the control algorithm, the COSMEC-I employs four hardware arithmetic processors connected on the system bus. Each of these processors can execute a 32-bit floating point multiply in 42 microseconds. They are operated so that they process in parallel, thus minimizing computation time. The dynamic range of the processors is $\pm 9.2 \times 10^{18}$, so there is little possibility of exceeding the computational range of the machine. Also, this eliminates the need for scaling of measurements in order to avoid machine overflow. Using the arithmetic processor units and assembly language programming, the inertial strapdown algorithm can be executed in approximately 10 milliseconds and the first proposed control

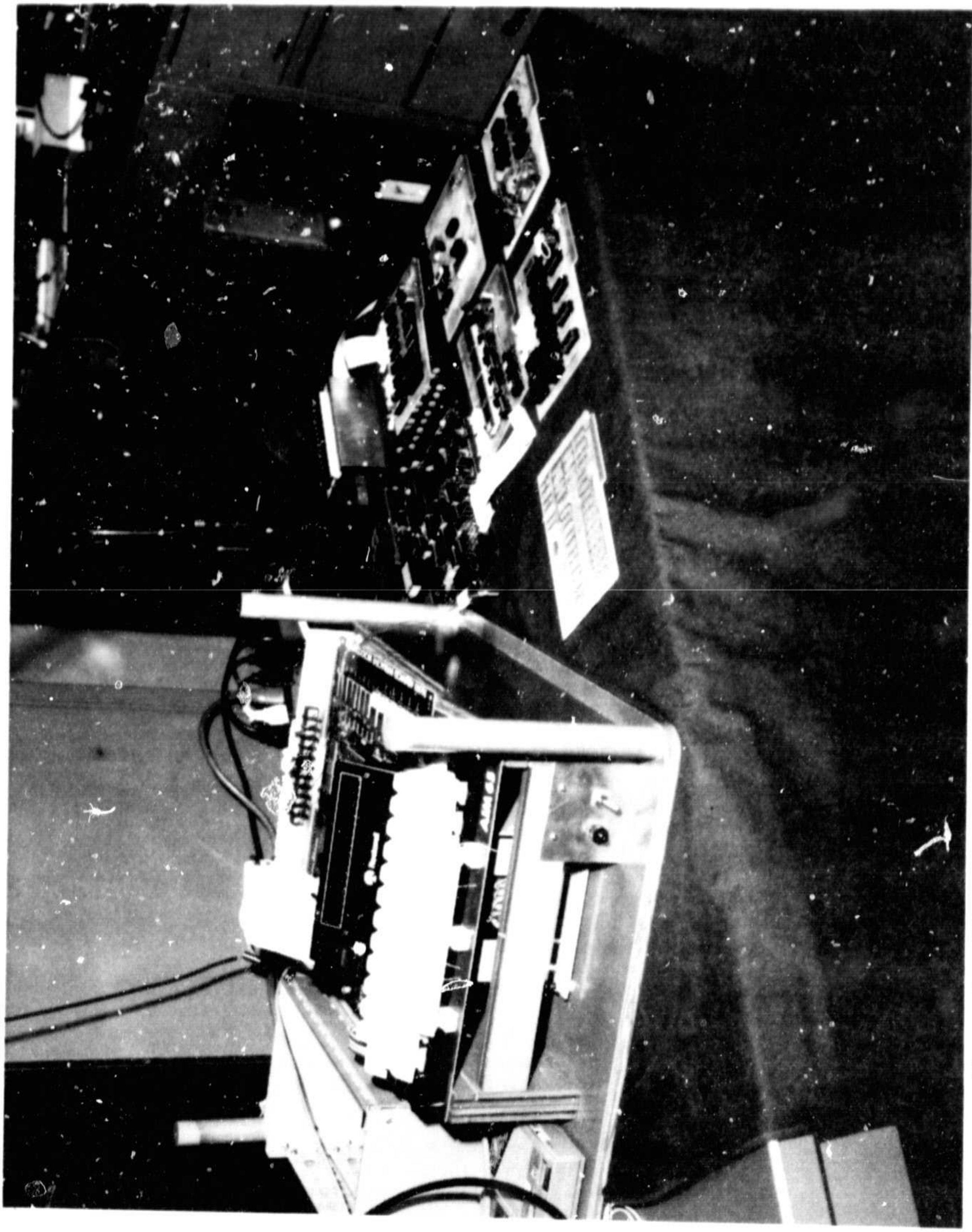


Figure 6. COSMEC-I laboratory system featuring the AIM 65 micro-computer.

control algorithm is about 6 milliseconds. This puts the total computation time at well under the allowed 20 milliseconds required to meet the 50 Hz sample rate.

Presently the COSMEC-I can off-load data to an HP9845C desktop computer. The HP9845C has 32 input channels and one output channel. The word size is 16-bits, and the RAM size is 128K. With its 32-bit accumulator, the HP9845C has a double precision capability.

On order for the LSS/GTV is an HP9020AS with options 500 and 247 plotter interface card, a 16-bit parallel interface, a 6-pen graphics plotter, and 512 Kbytes of extra memory. The HP9020AS is a 32-bit machine with an 18 MHz clock rate. Benchmark test times for processing the distributed sensor control, the disturbance isolation, and the strapdown algorithms are 6 to 10 μs. This computer, when combined with the COSMEC-I, will provide sufficient computing power to satisfy the LSS/GTV needs for the next few years.

The software used in the COSMEC-I system may be separated into four basic groups: (1) utility software for handling the various hardware cards which interface to instruments, (2) software to implement the control algorithm, (3) software to implement the inertial strapdown algorithm, and (4) initialization and startup software to ready the instruments and equipment for a test.

The hardware cards which interface the COSMEC-I's processor to the measurement instruments and actuators are individual by their very nature, and some special software is required to handle each card. However, each card makes information available to the processor as digital words, which is the unifying feature of the system.

The digital controller software for the first ground test experiment implements a linear discrete multivariable controller having multiple inputs and outputs. The controller is in state variable form. It is programmed so that the system matrices are initial input data to the program and can be stored on tape and easily changed. The first controller software is designed to implement a controller of up to ninth order having nine inputs and three outputs.

Because the inertial measurement instruments measure with respect to inertial reference space, there is a natural bias in the measurements due to the acceleration of gravity and earth's rotation. That is, in the earth-based experiment the accelerometers measure about 1 g acceleration in a downward direction. The rate gyros measure about 15 deg/hr rotation while at rest with respect to the laboratory reference frame. The inertial strapdown algorithm provides a means of removing this bias from the measurement instruments.

In order to give the measurement instruments initial conditions and begin measurements for a test, initialization software is provided for the inertial strapdown algorithm. To begin a test, the structure is stabilized with respect to the laboratory reference frame, and the initialization routine is executed. The strapdown algorithm is then started, and the apparatus is ready to carry out a test.

The HP9845C computer stores the data collected from the test runs. Analog data collection is also available through a strip chart recorder and an analog tape unit. The digital test data, obtained by the HP9845C, are either transferred to disk or tape for off-line data reduction. If desired the analog tape data can be processed off-line to gain higher frequency information than possible with the digital test data.

G. Building Support Beams

Since the BET and other LSS/GTV equipment are attached to the building structure, it is important to examine the structural characteristics of the building support beams. With the LSS/GTV equipment mounted to the support beams, the seismic data were taken to determine whether the support structure would interact with the LSS/GTV. Seismic vibration data were measured on the LSS/GTV and the support beams. The first significant vibrational mode of the support beams was determined from driving point impact transfer functions measured at the midpoint of the beams. It has a frequency of approximately 22 Hz. Presently, the 22 Hz presents no interaction problem relative to the LSS/GTV dynamics and control testing.

III. SYSTEM DYNAMICS

One of the important aspects of the LSS/GTV is to verify the analytical model of the test article. The procedure is to describe the stucture mathematically as well as possible, then perform structural tests on the test article, and finally to factor these results into the mathematical model.

The first analytical model was developed for the ASTROMAST alone. The ASTROMAST is a symmetric beam with a triangular cross section. Three longerons form the corners of the beam and extend along its full length unbroken. The cross members which give the beam its shape divide the beam into 91 sections having equal length and mass and similar elastic properties.

An analytical model of the ASTROMAST in a cantilevered configuration was developed prior to testing of the ASTROMAST. Once the test results for the beam in such a configuration were available, the analytical model was "tuned," by varying the torsional and bending stiffness which were considered to be poorly known pre-test.

Next, the modeling effort was expanded to include the APS, BET, and instrument packages. This model was used as an aid in conducting the modal test on the structure in this configuration. Again, the test data were used to refine the corresponding structural model. Table 1 provides the corresponding synopsis of the modal frequencies as predicted pre-test, measured, and "tuned." Tuning was accomplished by varying the inertial properties which were poorly known and the bending and torsional stiffness which change with the different gravity loading in this configuration. Examination of the percentage errors in Table 1 shows the refinement of the model.

A typical mode shape for the structure is presented in Figures 7 and 8. Figure 7 represents the third bending mode (3.91 Hz) resulting from the pre-test analytical model. Figure 8 presents the mode shape for the corresponding mode in the measured model (3.94 Hz).

Finally, the modeling was expanded to include the cruciform structure at the ASTROMAST tip which was added to obtain more LSS-like pathologies, i.e., closely spaced modal frequencies. The "model-test-tune" procedure described in the previous paragraph was carried out for this configuration in order to produce a high fidelity model of the LSS/GTV experiment structure. The modal frequencies and damping for the two previous measured models are shown in Table 2. The results described as "local modes," in Table 2 primarily involve deformation of the cruciform arms.

TABLE 1. STRUCTURAL NATURAL FREQUENCIES WITHOUT CRUCIFORM

Mode No.	Description	Original Analytical	Measured	Δ (%)	Tuned Analytical	Δ (%)
1	RB (xy-plane)	0.00				
2	RB (yz-plane)	0.00				
3	RB (torsion)	0.00				
4	1st Bend (yz-plane)	0.14	0.14	0.0	0.14	0
5	1st Bend (xz-plane)	0.15	0.15	0.0	0.15	0
6	2st Torsion	0.18	0.99	19.0	1.02	3
7	2d Bend (xz-plane)	1.27	1.33	4.5	1.29	3
8	2d Bend (yz-plane)	1.40	1.80	22.0	1.64	9
9	3d Bend (xz-plane)	3.02	3.30	8.5	3.34	1
10	3d Bend (yz-plane)	3.91	3.94	0.0	4.32	11
11	4th Bend (xz-plane)	6.69	8.06	17.0	8.10	0
12	4th Bend (yz-plane)	7.03	8.13	14.0	8.21	1
13	2d Torsion	8.42	9.60	12.0	9.61	0

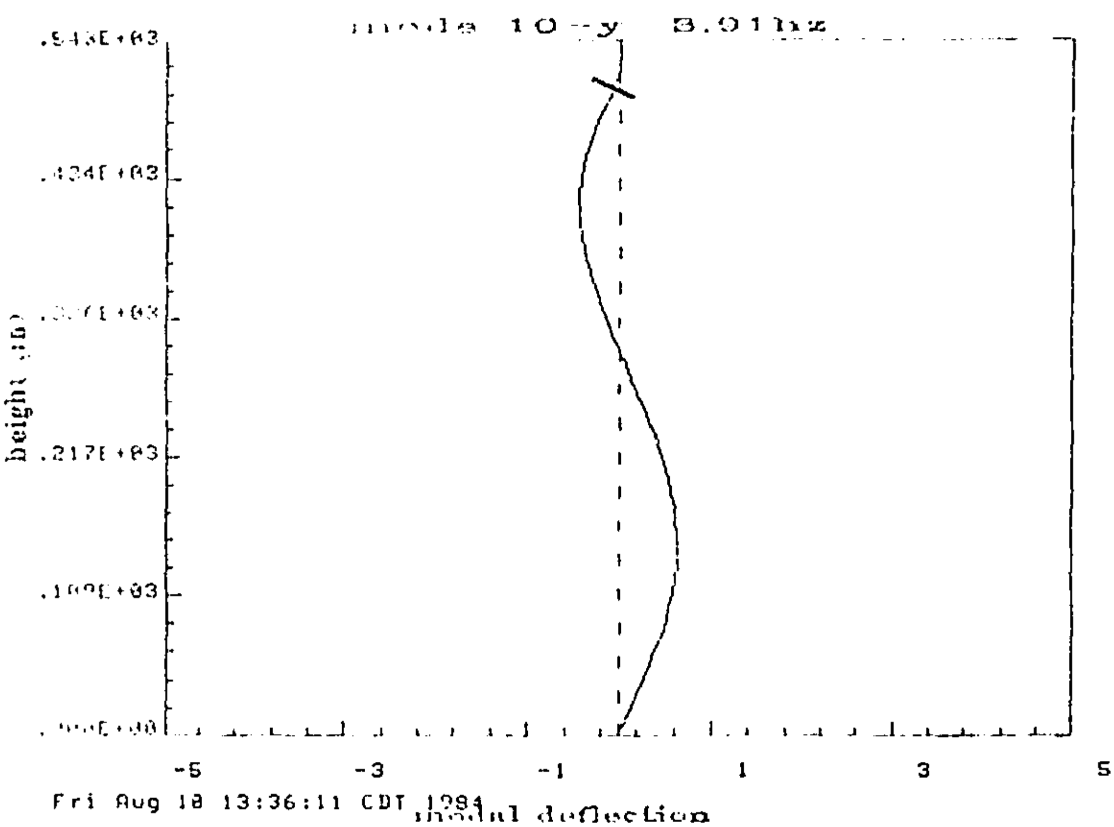


Figure 7. Analytical third bending mode.

The last modal test that was performed was to determine the effects of connecting cables to the various components on the test structure. All the cabling was stripped off the stiff external wrapping and sufficient length and coiling was provided to reduce any cabling effect on the structural dynamics. The acquired test data conclusion is that no significant modal shifts occurred when the cables were connected.

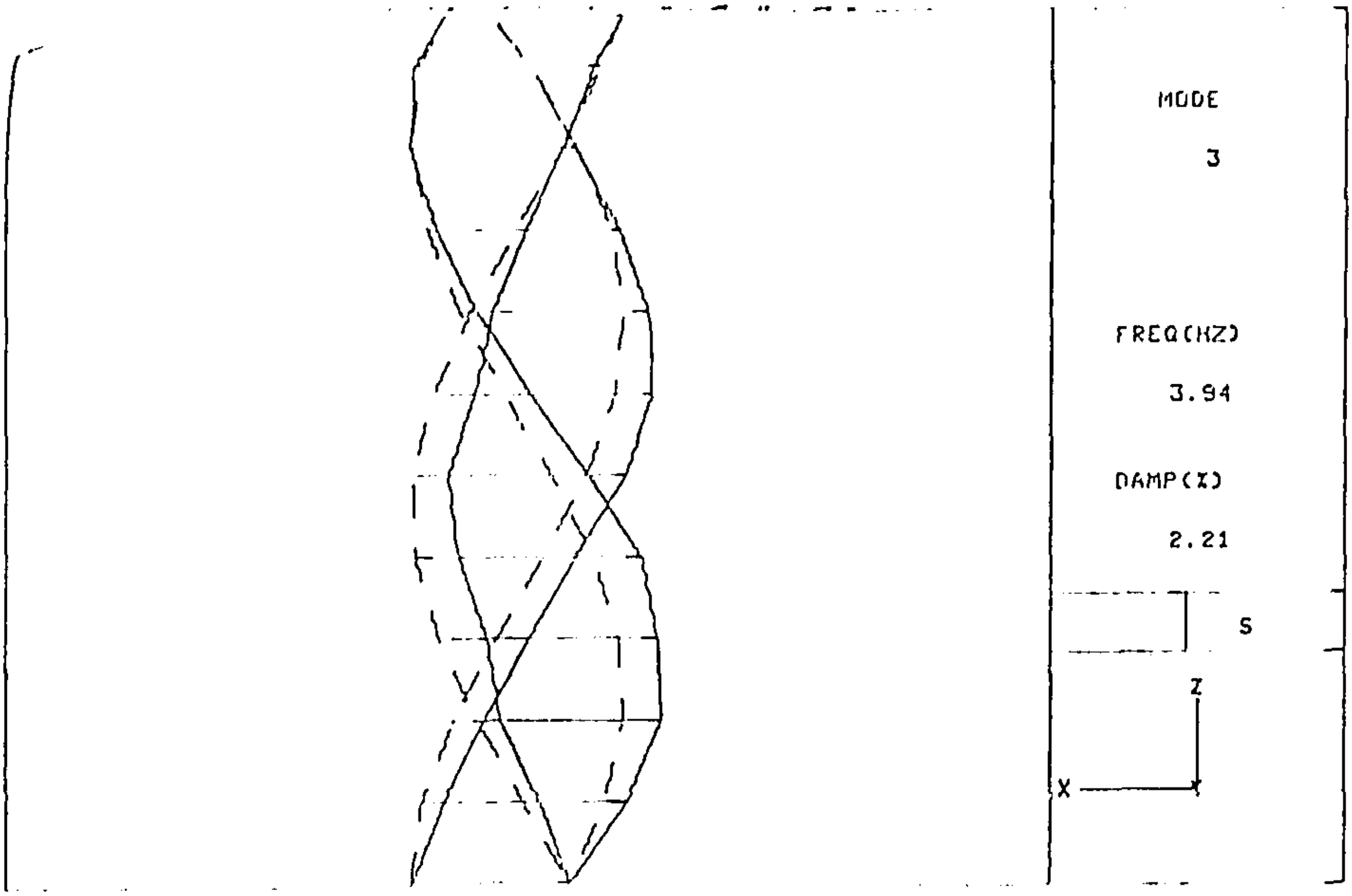


Figure 8. Measured third bending mode.

TABLE 2. SUMMARY OF LSS/GTV MODAL TEST RESULTS

Description	W/o Cruciform			W/Cruciform		
System Mode	Freq Hz	% Damp	TSS	Freq Hz	% Damp	TSS
1st Bending (x)	0.144	0.35	002	No Data	No Data	N/A
(y)	No Data	No Data	N/A	No Data	No Data	N/A
2nd Bending (x)	1.33	1.33	002B	1.36	1.9	005
(y)	1.83	1.88	002A	1.83	1.9	004
3rd Bending (x)	3.38	1.76	002B	3.24	1.7	005
(y)	3.9	2.2	002A	3.74	2.0	004
4th Bending (x)	8.06	2.9	003	6.36	1.1	005
(y)	8.13	4.5	003	6.67	1.85	004
1st Torsion	0.991	0.44	001	0.377	0.56	006
2nd Torsion	9.6	1.1	001	3.02	0.34	007
Local Modes						
Y Bending	N/A	N/A	N/A	0.38	0.53	008
Y Bending	N/A	N/A	N/A	1.149	0.53	008
Y Bending	N/A	N/A	N/A	6.418	0.70	008
Y Bending	N/A	N/A	N/A	6.876	0.44	008
Y Bending	N/A	N/A	N/A	7.326	0.415	008
Y Bending	N/A	N/A	N/A	7.706	0.156	008
Z Bending	N/A	N/A	N/A	1.143	0.79	008
Z Bending	N/A	N/A	N/A	6.756	1.09	008
Z Bending	N/A	N/A	N/A	7.062	1.23	008

IV. CONTROL

Design of control strategies for the GTV fixture model under DARPA's ASCOT (Advanced Structural Control Technology) effort has a two-fold objective. The primary objective, in the spirit of ACOSS (Active Control of Space Structures) and VCOSS (Vibration Control of Space Structures), is that of vibration control. More specifically, the goal is to add damping to the vibrational (flexible body) modes of the structure. As a secondary objective, active pointing control is considered. This of course encounters implementation problems because of the steady state torque exerted upon the structure by gravity when pointed in any direction other than that of the g vector.

The design technique used to arrive at the control algorithms is that of 1CAT (one-Controller-At-a-Time) [8]. 1CAT finds its basis in the fundamental principles of classical analysis and design control theory. It springs from the fact that the marriage of a MIMO system (plant) and a controller can be reviewed as a coupled multiloop system. The controllers for the loops cannot be designed independently, but they can be designed one at a time. Under this philosophy, each time a controller is designed for a particular feedback loop, it is then closed to become part of the "plant" for the design of the succeeding controller. In this way all the feedback paths can be closed having taken into account the effects upon the system of all previous loop closures.

The first and simplest of the control strategies for the MSFC GTV fixture designed under ASCOT is a centralized controller which makes use of the rotational rate measurements at the faceplate provided by the ATM rate gyros. These rate measurements in three axes transformed to the laboratory reference frame by the inertial strapdown algorithm along with the three-axis torquers provided by the APS (Angular Pointing System) form the measurement/effector complement for the design. By closing a rate feedback loop in each axis between the collocated complementary sensor/actuator pairs, significant damping can be added to the flexible modes of the structure. In this analysis, however, an interesting feature of the GTV experiment structure appeared. Because of gravity, the typically zero frequency rigid body modes of the pointing system appear instead as "pendulum" modes. That is to say, the mode shape is that of rigid body behavior, but the frequency is that of a pendulum having an effective length equal to the distance from the gimbal point to the center of mass of the structure below the gimbal point. This poses no serious problem for the 1CAT design technique, but the fact that the "pendulum" modes are sensed and acted upon with much less control than the bending modes makes addition of damping to these modes difficult. Since this is viewed as a pointing requirement, it is of secondary interest to damping of the flexible body modes. Also included in the control scheme is position feedback generated by integration of the rate signals in the strapdown algorithm. This facilitates active pointing control.

A second and more complicated control strategy is under development within the ASCOT effort. This distributed sensor control law will use not only the measurements made at the faceplate, but also accelerometer measurements from the tip of the ASTROMAST. These measurements will be used through a low bandwidth feedback path to add more damping to the "pendulum" modes than could be achieved with the centralized controller. Additional disturbance rejection may also be achieved by using the accelerometer measurements from the BET.

V. FUTURE CONFIGURATION

One of the first configuration changes for the LSS/GTV facility will be the addition of a 3-m antenna. The antenna will replace the cruciform structure which is at the ASTROMAST tip. With the antenna at the tip, an antenna feed will be mounted to the payload mounting plate from an extended boom. The feed will consist of a two-axis gimbal system which will have an optical reflector on the inner gimbal. Torque motors will be located on each gimbal axis so that the gimbal system can be used in a closed loop. The optical-mechanical closed loop system will derive an error signal from an optical detector located near the antenna. The error signal generated by the detector will be fed back through the digital processor which will in turn energize the gimbal torque motors and activate the gimbals. This configuration, which is shown in Figure 9, will use a light source and an optical system to transmit the radiation from the antenna to the gimbals and then to the optical detector. This test configuration will provide a means to verify both decentralized control and distributive control methods; thus it will provide a form of active image motion compensation.

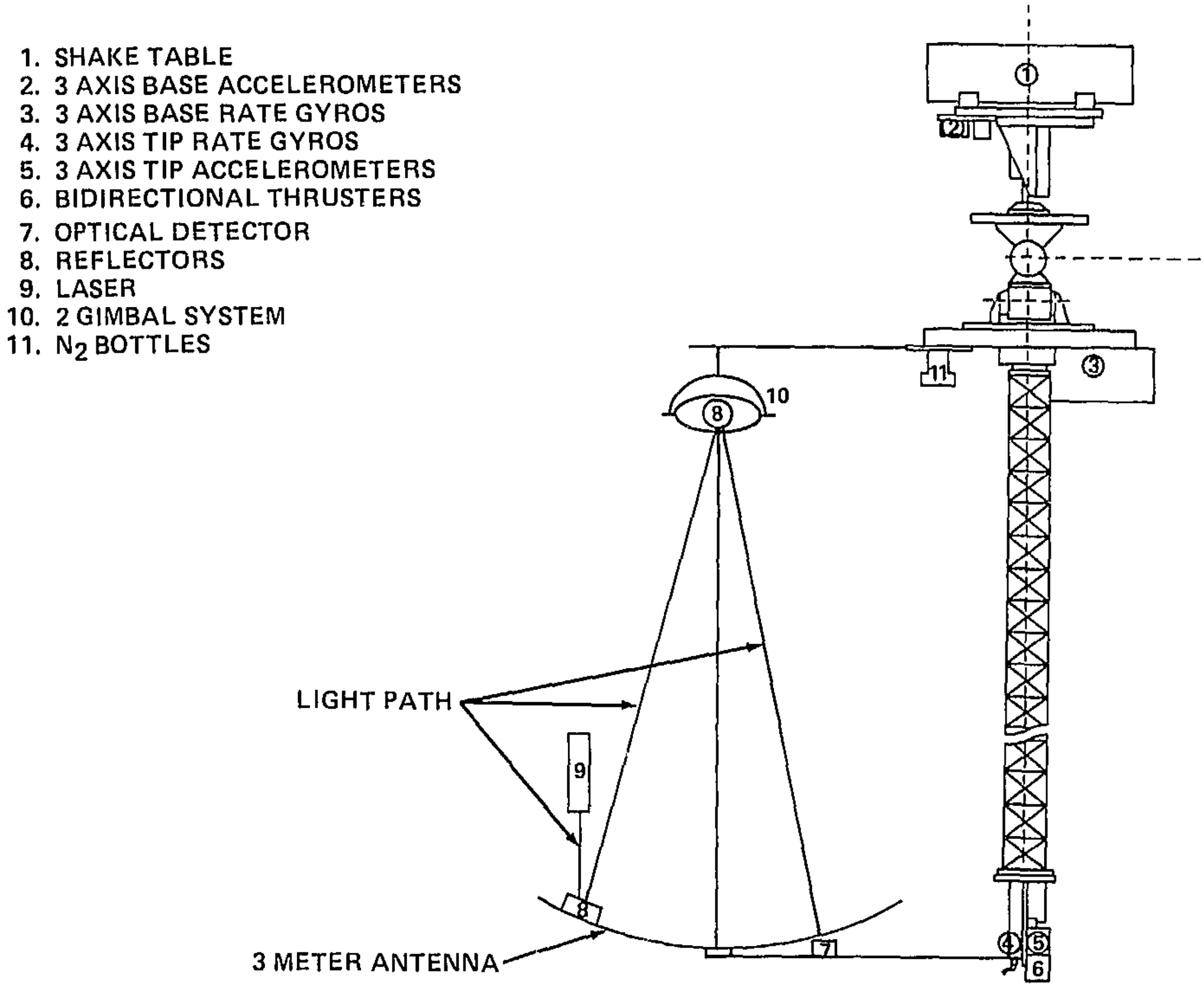


Figure 9. Future LSS/GTV setup.

VI. TEST PLAN

With the conclusion of the modal testing, the subsystem and system test plan can be effected. All of the subsystem components were checked out individually (and some in groups) before they were transported to the LSS/GTV facility for checkout and integration. The evaluation of the subsystem will include functional and performance checks for the BET, the sensors, the COSMEC-I, the APS with electronics, the data acquisition computer (either the HP9845C or HP9020AS or both), and the ancilliary data acquisition equipment such as the strip chart recorder and the FM tape. This detailed testing is necessary evil for both analysis and for debugging purposes. The completion date for the subsystem testing is the middle of November 1984.

For a system with this many subsystems, system interface checks are mandatory. Subsystem interface checks are being performed on the following subsystem combinations:

1) Sensors — COSMEC-I.

2) COSMEC-I — APS.

3) COSMEC-I — data acquisition system.

4) A complete system interface which includes all of the previous elements.

The completion date for the system interface checks is the last week in November, 1984.

After the system interface checks are concluded, testing of the total system can commence. The first order of business is to conduct open loop tests by using the BET. Sinusoidal inputs with varying frequencies and amplitudes will be generated by the BET so a frequency response can be determined for the total system. Results of these tests will be compared to the previous modal tests to determine whether there are any system anomalies. If there are no anomalies, then the closed loop tests can start. The completion date for the system tests is the first week in December, 1984.

The closed loop tests are next in the sequence of testing. The initial closed loop testing is for a low gain controller set up just to check the stability of the total system and to compare data with the analytic simulation. Once this data collection is complete, a high performance centralized control test will be conducted with various checks such as robustness and analytic simulation validation. The closed loop testing will proceed with the following control situations:

1) Centralized control with acceleration feedback.

2) Centralized control with disturbance isolation.

3) Distributed sensor control.

4) Distributed sensor control with acceleration feedback.

5) Distributed sensor control with disturbance isolation.

6) When the VCOSS-II hardware is added to the structure, decentralized and distributive control with and without acceleration feedback or disturbance isolation can be effected.

With the fine LSS/GTV team that has been assembled at NASA/MSFC, the following control law concepts can be implemented and evaluated:

1) High authority/low authority control [3].

2) Positivity control concepts [4].

3) Model reference adaptive techniques [5].

4) Eigenvalue placement schemes [6,7].

5) Various combinations of the previously mentioned schemes.

The near term growth potential for the NASA/MSFC LSS/GTV can be seen in Figure 9. The figure depicts such potential activities as:

1) Active image motion compensation.

2) Vibrational control via linear thrusters.

3) Evolutionary control.

4) Remote sensing control.

5) Closed loop parameter estimation/control.

6) Evolutionary dynamics verification.

VII. SUMMARY

A description of NASA/MSFC's evolutionary LSS/GTV has been presented. Interim analytical and test results have been shown. Future planned activities have been indicated.

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APPROVAL

NASA/MSFC GROUND EXPERIMENT FOR LARGE SPACE STRUCTURE CONTROL VERIFICATION

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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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