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GROUND TEST EXPERIMENT FOR LARGE SP.ıCE STRUCTURES

By Danny K. Tollison and Henry B. Waites

Systems Dynamics Laboratory

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Danny K. Tollison* and Henry B. Waites

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16. ABSTRACT

In recent years a new body of control theory has been developed for the design of control systems for Large Space Structures (LSS). The problems of testing this theory on LSS hardware are aggravated by the expense and risk of actual "in orbit" tests. Ground tests on large space structures can provide a proving ground for candidate control systems, but such tests require a unique facility for their execution. The current development of such a facility at the NASA Marshall Space Flight Center (MSFC) is the subject of this report.

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INTRODUCTION

As the U.S. moves into the Shuttle era of space technology, there are numerous proposals from the scientific, civilian and Defense Communities which envision the use of Large Space Structures (LSS). By definition, a LSS is very flexible, lightly damped, and exhibits multiple vibrational modes of very low frequency. Many of the missions alluded to above require high performance from the LSS in areas such as precision pointing and preservation of vibration free image planes. To test the new and various schemes proposed for LSS control, Marshall Space Flight Center (MSFC) is establishing a LSS laboratory in which experimentation with LSS-like structures may be performed. The first experiment to be installed in the laboratory is being developed concurrently.

SYSTEM OVERVIEW

The Ground Test Verification (GTV) experiment is described by the drawing of Figure 1. The first test article will be the ASTROMAST beam as shown. The ASTROMAST is extremely lightweight (about 5 lb) and approximately 45 ft in length and is constructed almost entirely of S-GLASS.

The test article will be mounted on the faceplate of the Advanced Gimbal System (AGS) engineering model which, along with an additional torque actuator in the azimuth, provides the control inputs for the system. The azimuth gimbal also provides a means of rotating the entire experiment manually to produce different test scenarios. The ASTROMAST will be gravity unloaded by a cord extending downward from the base excitation system of the ASTROMAST to the tip. The tension in this cord will be adjustable to provide a means of "tuning" the structure.

The AGS will be supported by the base excitation system of the beam containment structure which will be free to translate in the horizontal plane and will include hydraulic actuators to provide translational disturbance inputs to the test fixture. These disturbances will represent Astronaut push-off or RCS (Reaction Control System) thruster firing.

Six separately packaged inertial measurement assemblies comprise the control system sensors. Two of the packages, containing three axis translational accelerometers, are identical. One will be mounted on the mast tip, and the other on the AGS side of the base excitation system. Three other packages contain ATM (Apollo Telescope Mount) rate gyros and will be installed on the AGS faceplate. The sixth package, the Kearfott Attitude Reference System (KARS), will be placed at the mast tip along with the accelerometer package.

The signals from these instruments will be read by the COSMEC I data gathering and control system, and processed according to the control strategy under scrutiny. The control actuator signals will then be transmitted to the AGS as inputs to the dynamical system.

The COSMEC I will be interfaced to a Hewlett Packard HP9845C desktop computer which will store data as it is collected during a test run, and then provide post experiment data reduction and display off-line. The controller inputs and outputs (measurements and commands) can be recorded at each sample period or at some multiple of sample periods.

SUBSYSTEMS

The subsystems which comprise the LSS/GTV experiment fixture as described are currently in various stages of development at NASA MSFC. Thorough verification of each of the subsystems in controlled test environments comprises a significant part of the preliminary system testing. The subsystems will not only be tested individually, but will be tested in an integrated laboratory environment where each of the subsystems will interact with the others in a manner much as if an actual test article were being used. Such testing is designed to ensure proper operation of the complete test fixture upon assembly.

Advanced Gimbal System

The Advanced Gimbal System (AGS) is a precision, two axis gimbal system designed for high accuracy pointing applications. The AGS gimbals serve the elevation plane and a third gimbal has been added to the system in the azimuth. The AGS receives torque commands from the COSMEC I data and control system in the form of analog inputs over the range of -10 to +10 volts. Because the AGS servo amplifier outputs a current which causes an applied torque proportional to the current, the control algorithms used in the COSMEC I must be designed to produce torque command signals. The AGS gimbal torquers can generate 37.5 ft-lb of torque and the azimuth torquer can generate 13.8 ft-lb.

Computational Electronics

The COSMEC I is an AIM 65 based (MC6502 processor) micro system which is used to handle data from the control system sensors, output commands to the control system actuators, transmit data for storage to the HP 9845C desk-top computer, and implement the control and inertial strapdown algorithms. The COSMEC I uses special hardware and software to allow the handling of a variety of devices (sensors, actuators, etc.) in real time. It also makes use of four hardware arithmetic processors to reduce computation time.

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 with each of its peripherals in a similar manner.

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 digital controller software for the first ground test experiment will implement a linear discrete multivariable controller having multiple inputs and outputs.

The controller will be in state variable form and will be programmed so that the system matrices are initial input data to the program and can be stored on tape and easily changed.

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 one g acceleration downward and 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.

Inertial Measurement Assemblies

Three different types of inertial measurement assemblies are planned for use on the Ground Test Verification structure in the first experiment: the Kearfott Attitude Reference System (KARS), the Apollo Telescope Mount (ATM) rate gyros, and two accelerometer packages developed by NASA. Each of the instrument packages generates signals in a particular form different from the other instruments as was mentioned in the section dealing with the COSMEC I interface cards. These different signal types are discussed in the following as each of the instruments is discussed individually.

The Kearfott Attitude Reference System (KARS) is an attitude measurement system designed for use in the U.S. Army remotely piloted vehicle. It provides measurement resolution of 13.9×10^{-3} deg/sec in the pitch and yaw axes (axes transverse to the ASTROMAST) and 25.0×10^{-3} deg/sec in the roll axis (axis along the length of the ASTROMAST). The dynamic range of the rate gyro outputs of the KARS is 40 deg/sec in pitch and yaw and 70 deg/sec in roll. Because of its light weight (8.9 lb), the KARS will be used as the mast tip rotation sensor in the first ground test experiment.

The output signals of the KARS are in the form of asynchronous digital pulses. One signal, the change in angular position in yaw for instance, requires two channels one for pulses representing positive rotation and the other for pulses representing negative rotation. The COSMEC I system accumulates the pulses over a 20 millisecond period to produce measurements of the angular rate and position of the ASTROMAST tip.

The Apollo Telescope Mount (ATM) rate gyro packages are designed to measure small angular rates very precisely. Each package measures angular rates in one axis with resolution finer than 0.5×10^{-3} deg/sec and offers a dynamic range of ± 1.0 deg/sec. The ATM rate gyro packages will be mounted on the faceplate of the engineering AGS so that they will measure the rotation of the base of the test article.

The output signals of the ATM rate gyro packages are ± 45 volt analogs and are handled by the analog to digital converter card of the COSMEC I system where they are converted to 12 bit binary words.

Two identical accelerometer packages will be used on the ground test experiment fixture in the first test. One package will be placed on the mast tip along with the KARS and the other on the test fixture base excitation system as shown in

Figure 1. The accelerometers provide resolution finer than 0.0001 g and a dynamic range of ±3 g with a bandwidth of 25 to 30 Hz.

The signals from the accelerometers are different from either those of the KARS or the ATM rate gyros. As in the case of the KARS, two channels are required for each of the degrees of freedom of the accelerometer package, i.e., six channels per accelerometer package. One channel of each pair carries a 2.4 kHz square wave synchronization signal and the other channel carries the acceleration information. Zero acceleration is represented by a signal identical to that of the synchronization channel, positive acceleration by an increase in frequency, and negative acceleration by a decrease in frequency as compared to the synchronization channel. As in the cases of the other instruments, these signals are monitored by a hardware card in the COSMEC I system.

Beam Containment Structure

The beam containment structure includes the base excitation system, the disturbance actuators and signal source(s), and power supply for the entire test fixture. This is essentially that equipment required of a laboratory to carry out dynamic testing of structures such as the ground test experiment. As depicted in Figure 1, the beam containment area can accommodate structures approaching 120 ft in height. Access is provided at various levels along the structure via catwalks. Also the control room for experimental operations is at a position about 50 ft above the floor of the test facility, thus making the experiment easily accessible.

The base excitation system for the GTV experiment incorporates a linear bearing arrangement which is designed to restrain the experiment as little as possible in the two translational degrees of freedom while allowing no rotation. Translation of the base of the AGS via the base excitation system provides the means of applying disturbances to the system. The base excitation system uses a high pressure hydraulic system to effect force inputs to the structure.

SYSTEM MODELING AND PERFORMANCE

For purposes of system studies and controller design, an analytical model of the Ground Test Experiment is necessary. Modeling of the Ground Test Verification (GTV) experiment was carried out in two distinct stages. The first stage involved modeling the ASTROMAST itself as it would be tested in the first open loop modal test, i.e., the beam alone in a cantilevered position. (See Table 1 for a listing of the resulting modal frequencies.) This produced modal frequencies, mode shapes, and mass integrals which were used in the second stage of the modeling process to develop, through modal synthesis, a model of the entire GTV experiment including the AGS and the beam containment structure. The modal frequencies resulting from the analytical model of the complete experiment appear in Table 2.

To date, modal tests have been conducted on the ASTROMAST beam alone in a cantilevered configuration at Marshall Space Flight Center. So that gravity would have as little effect as possible on the test results, the ASTROMAST was cantilevered in a hanging position. When fully deployed, the ASTROMAST exhibits a longitudinal twist of about 280 deg which contributes to coupling between the torsional and bending modes.

Measured modal frequencies resulting from the tests are shown in Table 3 along with the predicted modal frequencies and percentage errors. The errors are reasonable given the limited amount of knowledge about the percent composition of the S-GLASS composite and the unexpected twist which was not included in the mathematical model.

SUMMARY AND FUTURE DEVELOPMENT

Marshall Space Flight Center is developing a Large Space Structure Ground Test Verification experiment facility having adequate fidelity and flexibility to accommodate the demands of LSS control theory testing. The first experiment is in the subsystem verification and integration phase with the first "all up" test targeted for spring 1984. This test employs the ASTROMAST, a lightweight S-GLASS composite deployable beam structure, as the test article and is cited to prove out centralized and distributed sensor control strategies.

Future plans for the facility include the test of more complicated structures and sensor/actuator arrangements. The first of these will be the addition of structural hardware to the existing ASTROMAST in order to produce a structure having more LSS-like characteristics.

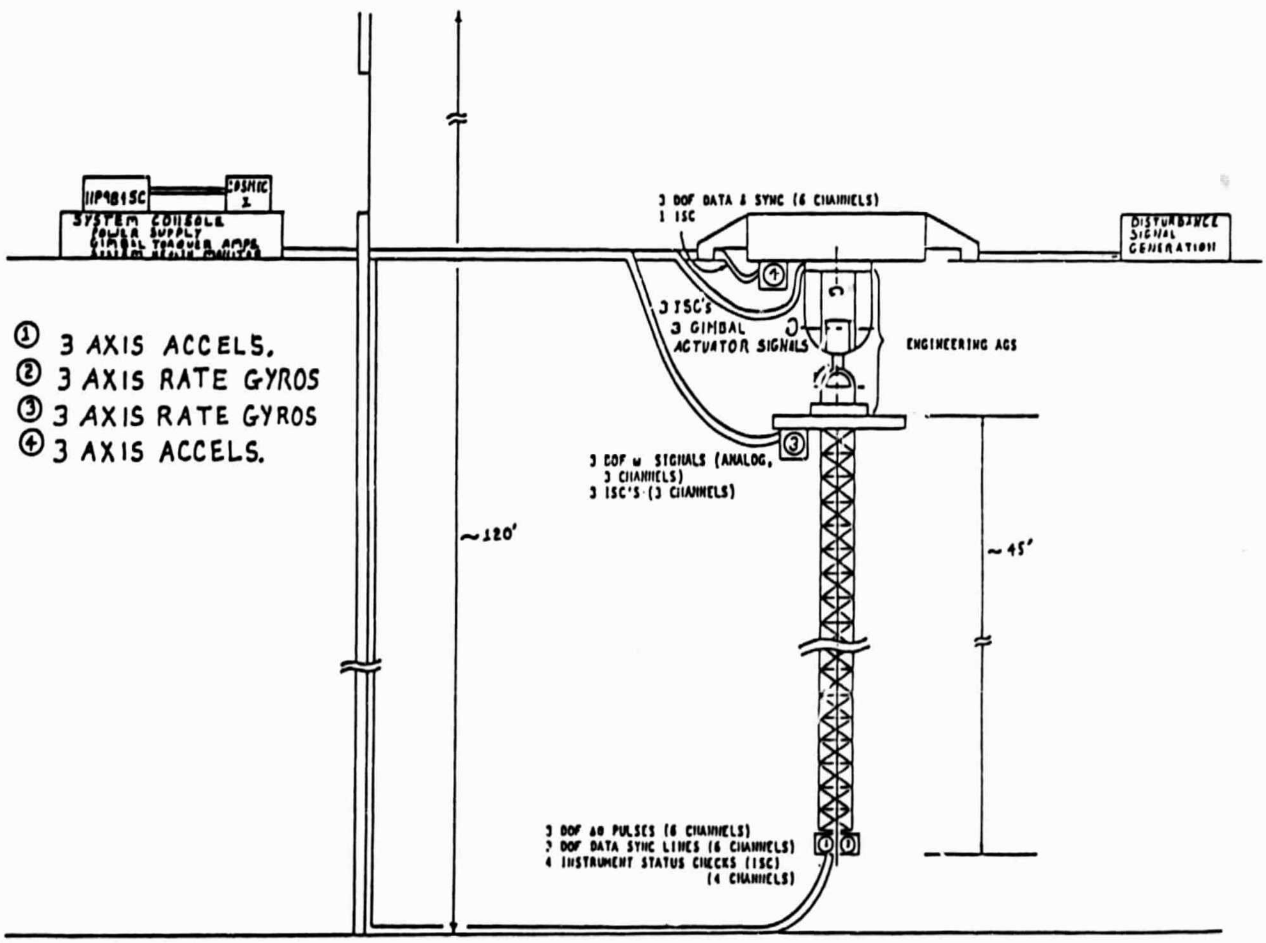

Figure 1. NASA Marshall Space Flight Center LSS/GTV experiment.

TABLE 1. MODAL FREQUENCIES OF CANTILEVERED ASTROMAST BEAM MODEL IN BENDING AND TORSION

Mode	Frequency (Hz)
First Bending Mode	0.618
Second Bending Mode	3.917
Third Bending Mode	11.179
First Torsional Mode	6.877
Second Torsional Mode	20.628
Third Torsional Mode	34.373

TABLE 2. LSS/GTV EXPERIMENT STRUCTURE MATHEMATICAL MODEL FLEXIBLE BODY MODES

Mode Number	Mode Frequency (Hz)
1	0.94
2	1.16
3	1.80
4	3.25
5	3.71
6	9.21
7	9.23

TABLE 3. SUMMARY OF ANALYTICAL AND EXPERIMENTAL MODAL FREQUENCIES AND MODE TYPES (b = bending, t = torsion)

Mode Frequencies (Hz)		Mode Type		Percent Error
Experimental	Analytical	Experimental	Analytical	
0.555	0.618	b	b	11
3.43	3.92	b	b	14
4.02	6.88	t	t	71
8.83	11.2	b	b	27
12.23	20.6	t	t	68
15.71	34.4	b	t	119