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GROUND FACILITY FOR LARGE SPACE STRUCTURES DYNAMICS AND CONTROL VERIFICATION

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INTRODUCTION

With the increase in complexity of the spacecraft (Fig. 1), the experiments have become more ambitious and multifaceted. On one such LSS, the stationkeeping of the spacecraft would be disturbances to any fine pointing system(s) or some low gravity material's processing or both. The vibrational modes of the structure are excited by the disturbances which in turn interact with the experiments in a deleterious way. Either active vibrational control or disturbance isolation control or both are required to isolate or reduce the structural interactions with the experiments so as to improve payload system performance.

Due to a more active use of space for Earth sciences, solar physics, astrophysics, material sciences, and defense, spacecraft structures and requirements have become more complex and stringent. To meet the desired objectives of these more complex space projects, the MSFC started a program to deal with such issues as the dynamic modeling, control development and synthesis, dynamics verification, and the hardware flight systems for these space structures, most of which were very large. Since these large spacecraft issues cover a wide range of technical disciplines, a team development was necessary in the areas of control, structures, optics, sensors

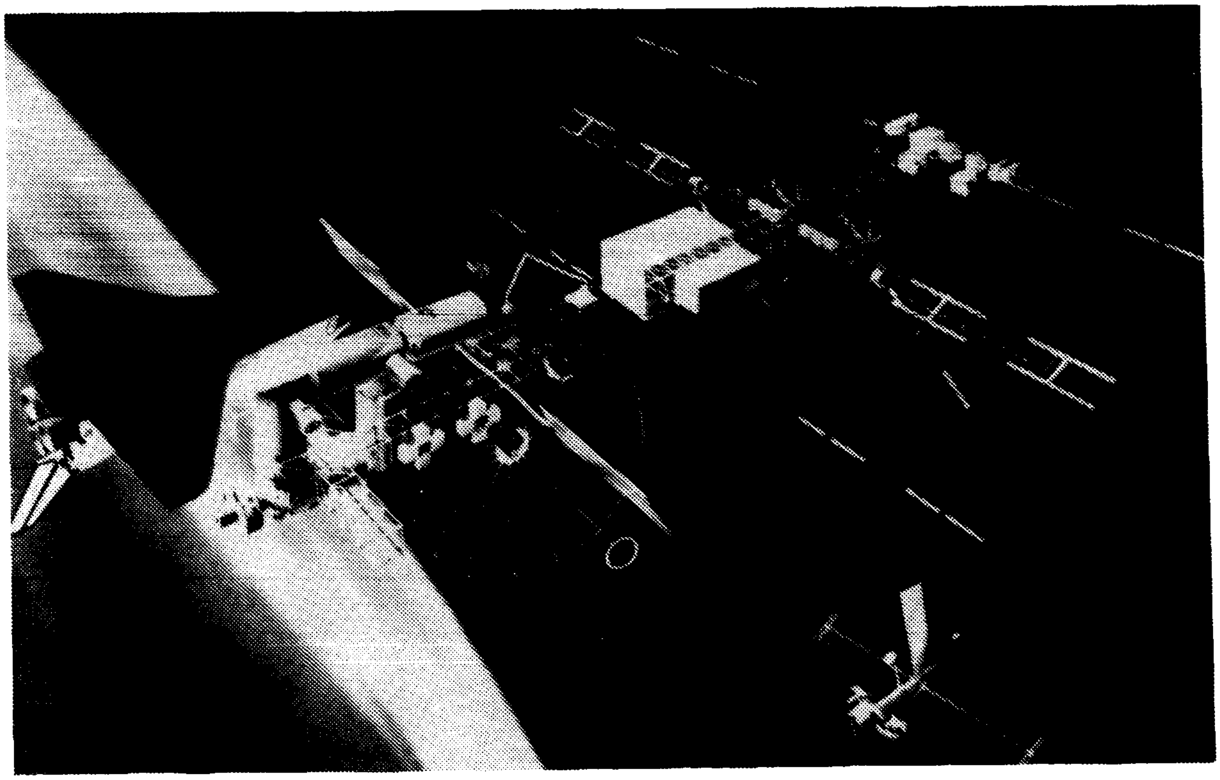


Figure 1. Multimission spacecraft.

and effectors, thermal propulsion, and materials. The multidiscipline methodology is now an integral part of the MSFC Large Space Structure (LSS) control verification. A block diagram of this methodology is shown in Figure 2.

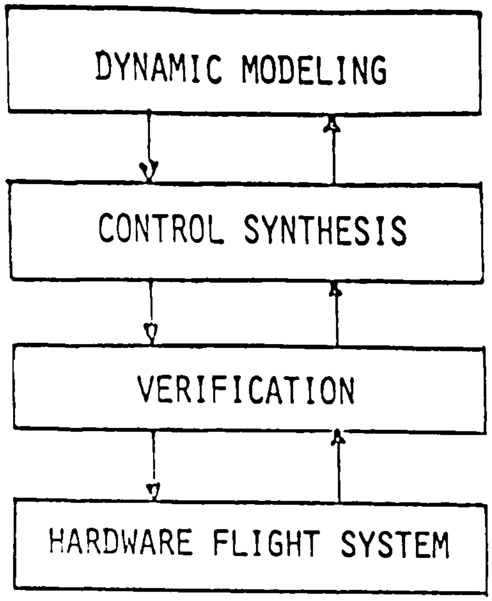


Figure 2. Methodology for LSS control verification.

INITIAL LSS CONTROL GOALS

The goals for the LSS control verification team were to automate as many of these technical disciplines as possible and to integrate where possible, these discipline tools into a user friendly analysis methodology. To that end, the initial 1982 objectives of the LSS Control Verification Team were as follows:

1. Develop control system design technique based upon closed-loop pole placement to assure desired performance.

2. Investigate control system design techniques to isolate disturbance forces utilizing computer software.

3. Develop centralized controller for Large Space Structure Orbital Experiment (LASSOE) test article.

4. Conduct trade study of centralized, decentralized, and software disturbance isolation.

5. Integrate control concepts to determine actual sensor and effector need for the LASSOE test article.

6. Establishment of a Proof of Concept (POC) ground demonstration test.

7. Development of real time test procedure for control optimization.

8. Data reduction to feret out pertinent model parameters.

9. Verification of modeling techniques.

10. Application of the design and control methodology to larger structures with various performance constraints.

11. Shape control Scope of Work development.

The expected outputs of the LSS Control Verification Team were as follows:

1. An automated control design technique for space vehicles.

2. Demonstration of utility of decentralized controllers.

3. Development of a disturbance isolation control system.

4. Establishment of POC ground demonstration test approach for Large Space Structures.

5. Real time testing procedures for space systems.

6. Development and utilization of parameter estimation methods.

7. Improvement of modeling techniques.

8. Shape control RFP.

As can be seen from these objectives and outputs, they are parochial relative to controls, sensors and effectors, and structures, but with the program evolution came an awareness that a multi-discipline methodology was necessary for LSS control verification.

DYNAMIC MODELING

One of the more time consuming areas of LSS control verification is the development of the structural model. In most space projects the data trickles in a substructure at a time until the whole spacecraft is defined and that is usually for a fixed substructure orientation. Most of the LSS have several flexible substructures that are changing their orientation which implies that a multitude of structural models are required to effect an LSS control verification. This scenario is not only time consuming, but it also contains many possible sources of error.

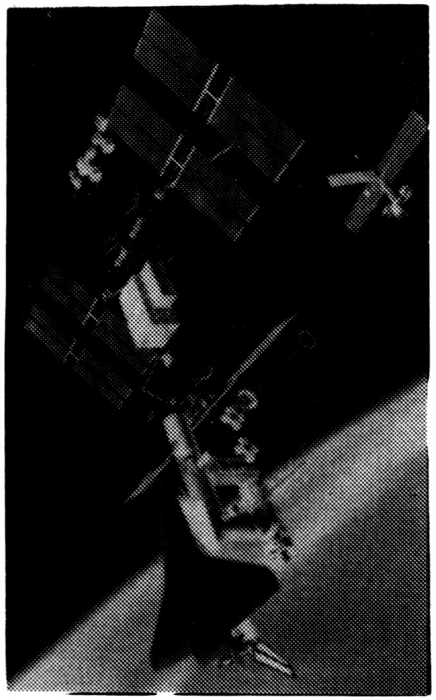
To eliminate the aforementioned problem (time and errors) and to work within the constraints of the system (substructure determinations and different orientations) a user friendly computer analysis tool was developed to automatically effect nonlinear modeling and simulation of complex flexible structure (Fig. 3). The significant features of the computer analysis tool are as follows:

1. Modular concept allows for rapid reconfiguration.

2. Models large angle rotations and angular rates for any module.

3. Allows for chain, tree, and ring topologies of flexible bodies.

NON-LINEAR SIMULATION AND MODELING



SIGNIFICANT FEATURES

- MODULAR CONCEPT ALLOWS RAPID RECONFIGURATION
- MODELS LARGE ANGLE ROTATIONS OF APPENDAGES
- CHAIN, TREE AND RING TOPOLOGIES HANDELED
- VARIETY OF CONTROL MODULES AVAILABLE

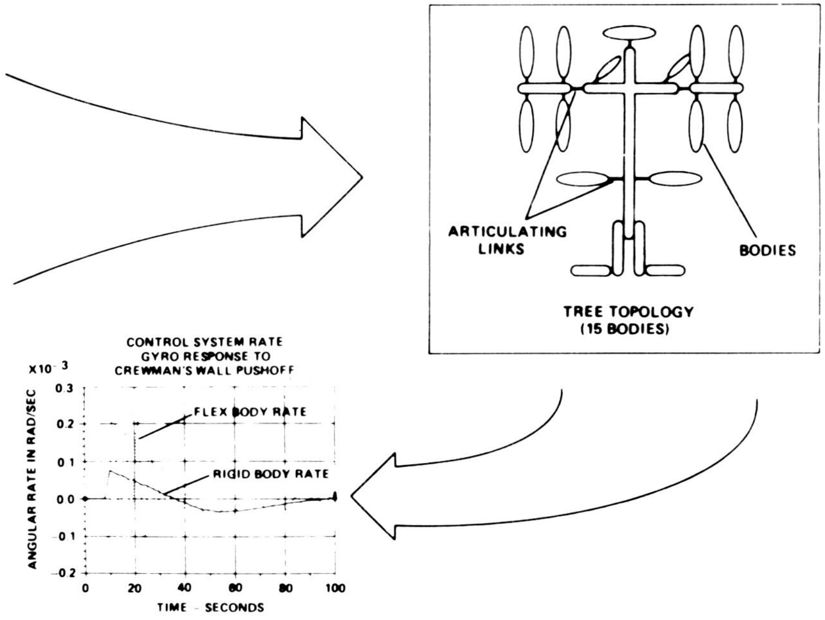


Figure 3. Dynamic modeling.

4. A variety of control modules are available.

5. Allows equality and inequality constraints between any two or more elements of the substructures.

The ring topology of flexible bodies is the latest feature that has been added to this computer analysis tool. The ring joints for each substructure has either equality constraint or inequality constraints (Fig. 4). The equality constraints consist of kinematic conditions and the inequality constraints are set conditions such as:

1. Hard stops.

2. Coulomb damper.

3. Velocity squared damper.

4. Solid damper.

5. Displacement squared springs.

- CONTOPS
  - EQUALITY CONSTRAINTS (KINEMATICS).
  - INEQUALITY CONSTRAINTS.
    - HARD STOPS.
    - COULOMB DAMPER (SIGN ($\dot{Q}$)).
    - VELOCITY SQUARED DAMPER ($\dot{Q}/\dot{Q}/$).
    - SOLID DAMPER (Q SIGN $\dot{Q}$).
    - DISPLACEMENT SQUARED SPRINGS ($Q/Q/$).
- CONTOPS ENHANCEMENTS
  - GG MODEL.
  - ATMOSPHERIC MODEL.
  - MAGNETIC MODEL.
  - MODAL SELECTION METHOD.
  - CMG MODELS.

Figure 4. Closed tree topology options.

The ring topology with the joint constraints can effect the dynamic model and simulation of many LSS, but future enhancements are needed to upgrade the disturbance models, selection of critical structural modes, and the modeling of effectors with momentum. The enhancements for the nonlinear modeling and simulation program will be a gravity gradient model, an atmospheric model, a magnetic model, modal selection methods and momentum effector models. With these additions, very complex structures can be modeled and simulation, using various control options, with relative ease and in a small time period. The system model objectives, which were relative ease and reasonable times to model LSS, were achieved with the development and use of the computer analysis tool.

LSS CONTROL SYNTHESIS

Another facet of the total plan is the control synthesis which uses the model generated by the user friendly computer tool, CONTOPS. Essentially, there are two control synthesis techniques and they are pole placement methods and quadratic minimum techniques. Initially, the synthesis tack was in the direction of pole placement techniques because of the parallels to the well understood frequency techniques. The pole placement control synthesis technique was divided into several control categories and they were centralized control, centralized control with disturbance isolation, distributed sensor control, distribution sensor control with disturbance isolation, distributed control, distributed control with disturbance isolation, decentralized control, and decentralized control with disturbance isolation. All of these categories will eventually be analyzed in the Ground Facility for Large Space Structure Control Verification (GF/LSSCV).

With the constraints of time and hardware, two preliminary control techniques were demonstrated in the GF/LSSCV. The first test configuration for the centralized control technique was comprised of the Base Excitation Table (BET), the Advanced Gimbal System (AGS), the Voyager Magnetometer Boom (VMB), the tip inertial reference unit, and the cruciform. This configuration had 15 modes below 2.5 Hz of which the fundamental mode was 0.5 Hz and these modes had damping of 1.5 percent or less. With this test article, a preliminary centralized control design was effected. The open loop rate gyro responses to an Orbiter thruster-like disturbance at the BET are shown in the first column time plots. The closed loop rate gyro responses to the same stimuli are shown in the second column time plots. The comparison of the two columns of time responses show the effectiveness of the centralized control on this generic Large Space Structure (Fig. 5).

The Structures/Controls Test Facility Configuration 2 is comprised of the following elements:

1. Shake table.
2. Three axis base accelerometers.
3. Three axis base rate gyros.
4. Three axis tip rate gyros.
5. Three axis tip accelerometers.
6. Bidirectional thrusters.

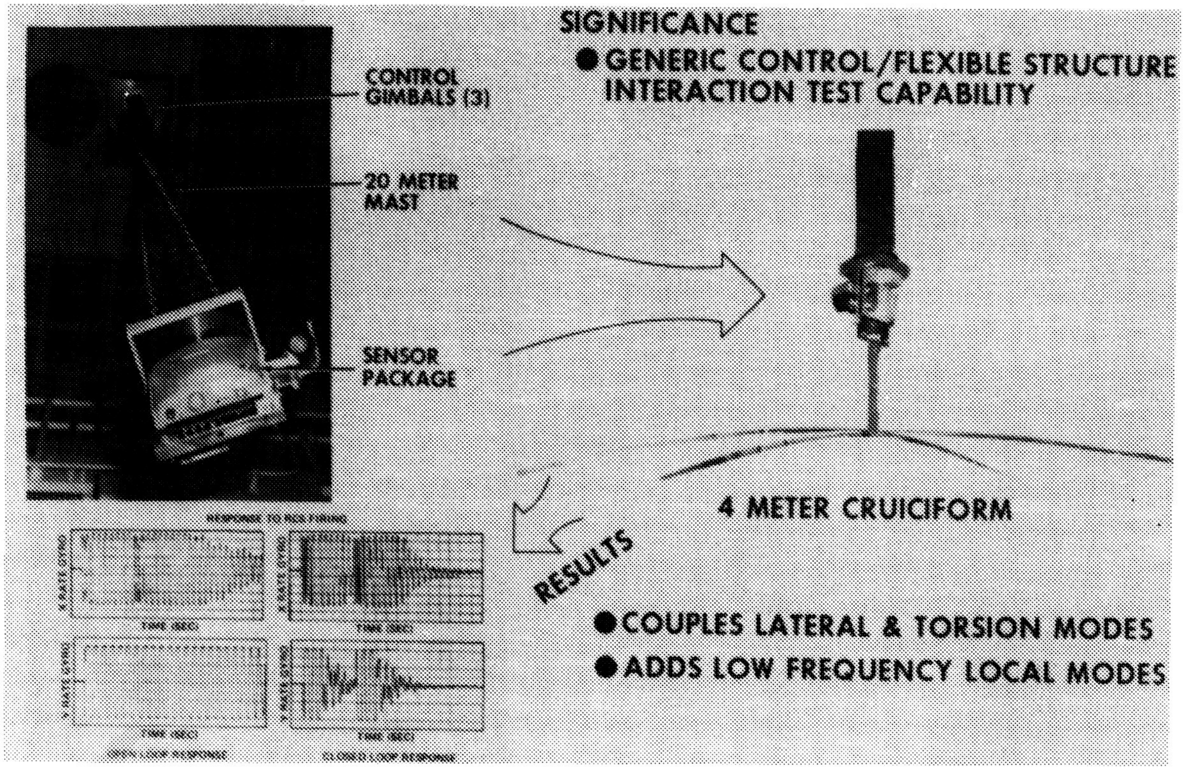


Figure 5. LSS control for configuration 1.

7. Optical detectors.

8. Reflectors.

9. Laser.

10. Two axis gimbal system.

11. N_2 gas bottles.

12. Two planar sets of Linear Momentum Exchange Devices with accelerometers.

Items 1 through 5, 7 through 10, and 12 are presently in-hand for configuration 2 while items 6 and 11 are on order. With items 1 through 12, several control/structures techniques will be demonstrated, which fall into the control categories of either decentralized or distributed control on configuration 2. The control/structures techniques to be demonstrated are active image motion compensation for a long flexible focal length, vibrational suppression using linear cold gas thrusters, evolutionary control by using the Voyager Magnetometer Boom in various stages of deployment, and simultaneous closed loop parameter estimation/control. These demonstrations will provide much insight into the structural/control interaction of LSS but much work still remains (Fig. 6).

One area of interest relative to control hardware is an unobtrusive sensors and effectors. Currently most control hardware concepts are distribution lump mass elements and these hardware configurations are such that they alone change the

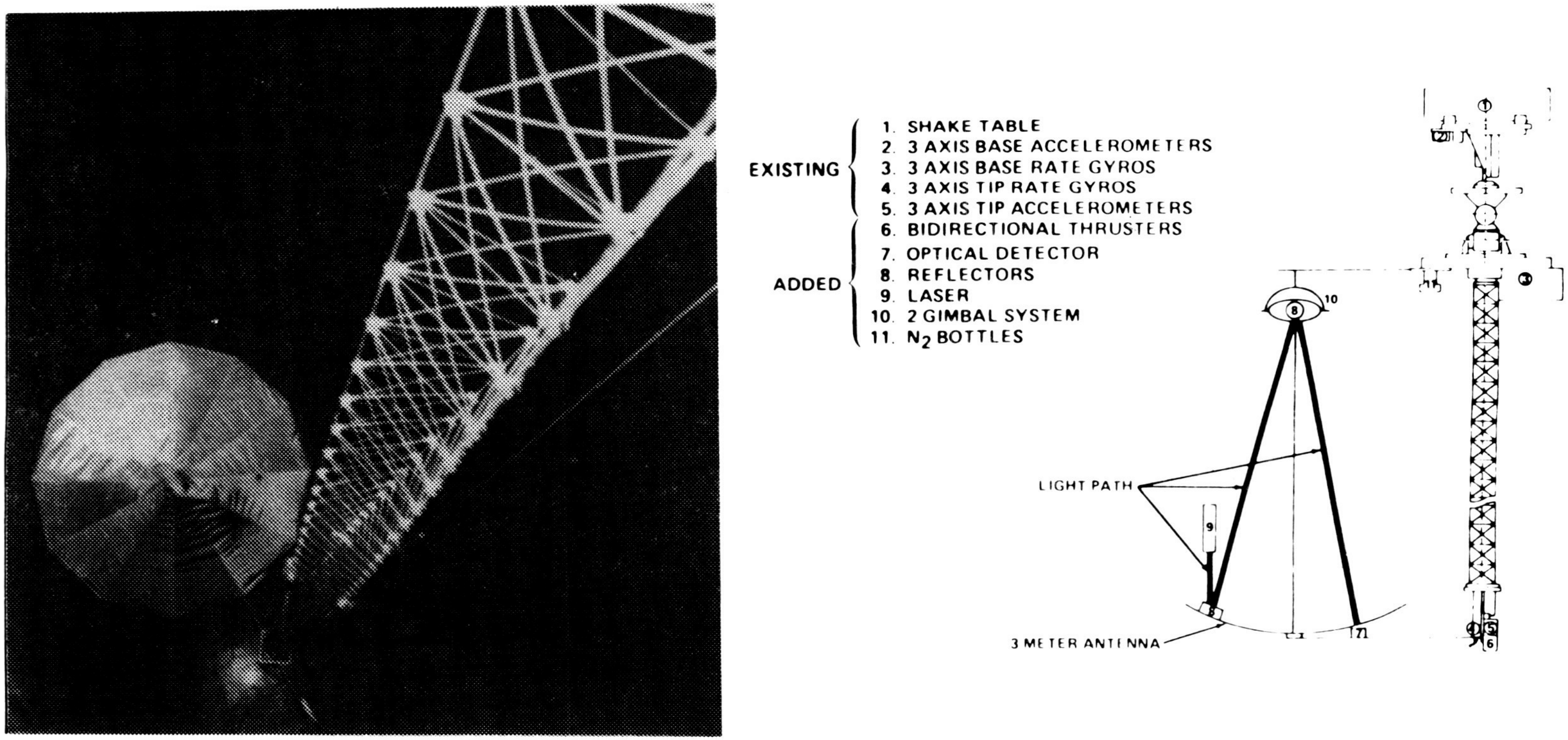


Figure 6. LSS control for configuration 2.

structural character of the payload. The unobtrusive sensors and effectors would assuage this type of problem for LSS control. One material that could be used for LSS vibrational suppression is piezo-electric polymer. The piezo material could be used as either a sensor or an effector or both. The use of fiber optics as an unobtrusive sensor is another viable alternative as is using remote sensing techniques such as optical reflectors. The implementation of unobtrusive sensor and efforts is a multi-discipline technology in which more work remains. This is one of the future objectives for the MSFC Ground Facility for LSS control verification.

FUTURE LSS ACTIVITIES

The structural interaction with spacecraft experiments is a most complex issue for evaluating the performance of a spacecraft. In particular, one control challenge is the Multiple Payload Pointing Mount (MPPM) situation on a flexible support structure. Little work has been effected to analyze the problems which are endemic to the MPPM experiment. The Advanced Solar Observatory (ASO) is an example of such a situation in which at least two pointing mounts will be operating independently of one another while secured to a flexible structure. This is depicted in Figure 7.

To address the MPPM problem, MSFC plans to erect, in its LSS ground facility, an experiment situation similar to the ASO. The first phase of this plan will be the construction of the air bearing table, which will allow translation in a plane and rotation perpendicular to that plane, and the experiment mount with the Pinhole/Occulter Facility (POF). The POF will consist of a 3-axis gimbal system with its payload mounting plate on which will be located an inertial reference unit and the SAFE-I boom.

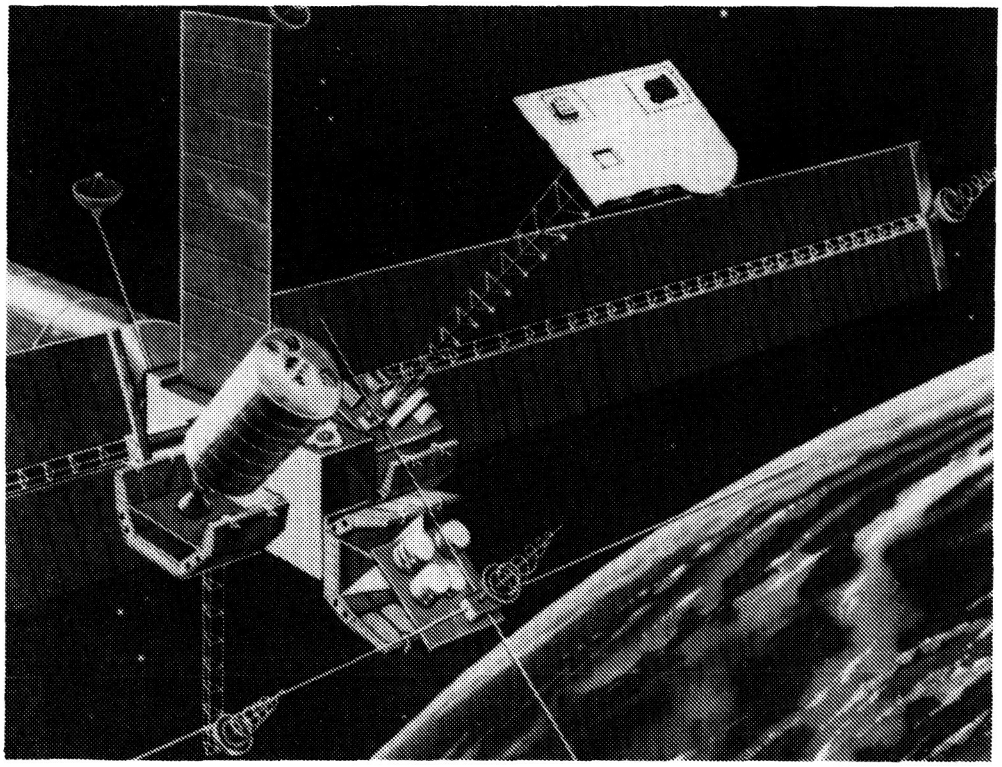


Figure 7. Advanced Solar Observatory.

The SAFE-I boom will have an end plate similar in mass characteristics to the tungsten end plate of the POF. The total structure configuration will be "tuned" so that it possesses similar structural characteristics of the POF. After "tuning" this structure, a dynamics and control verification will be effected so that any possible "surprises" can be studied and eliminated before the POF flight.

A natural extension to this facility would be the addition of a horizontal structural member with two more pointing mounts and their associated payloads. The two additional payloads which will be models of an optical telescope and an infrared device, along with the POF will simulate the ASO or the MPPM problem (Fig. 8). This facility should provide a sufficient challenge to the present control verification technology until a system akin to this configuration is flown.

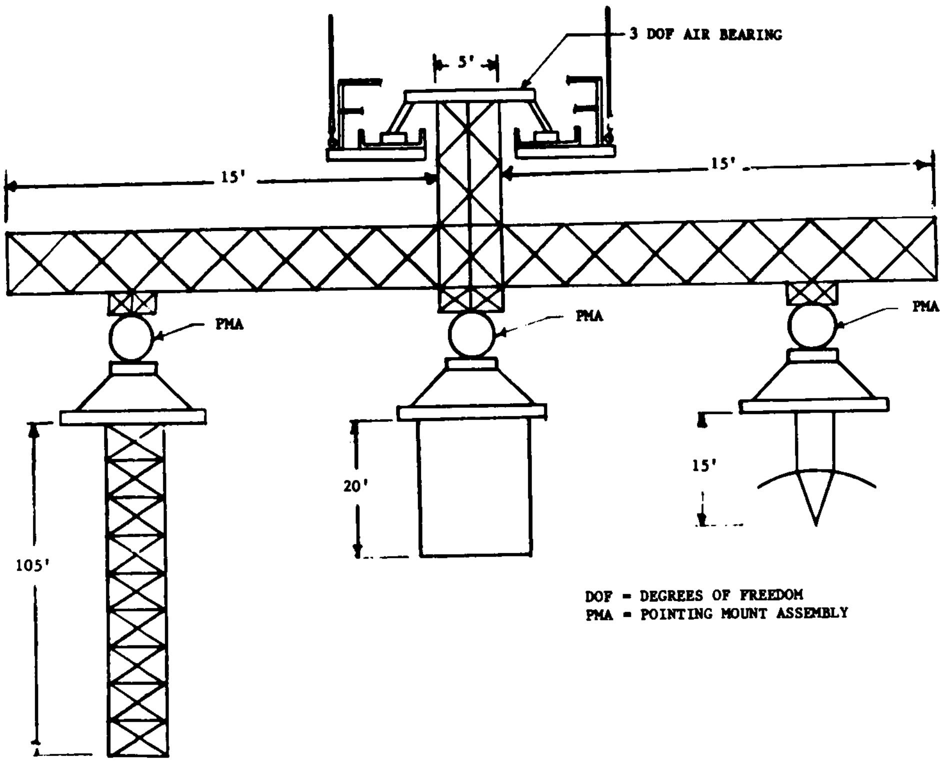


Figure 8. ASO ground verification.

APPROVAL

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By Henry Waites

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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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 or payload which is connected to a 3-axis angular pointing mount assembly that provides control torque commands. The angular pointing mount assembly is attached to a base excitation system which will simulate disturbances most likely to occur for Orbiter and DOD payloads. The control computer contains the calibration software, the reference systems, the alignment procedures, the telemetry software, and the control algorithms. The total system is suspended in such a fashion that the LSS test article has the characteristics common to all LSS.

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