ACTIVE CONTROL OF SPACE STRUCTURES: PROOF OF CONCEPT EXPERIMENT

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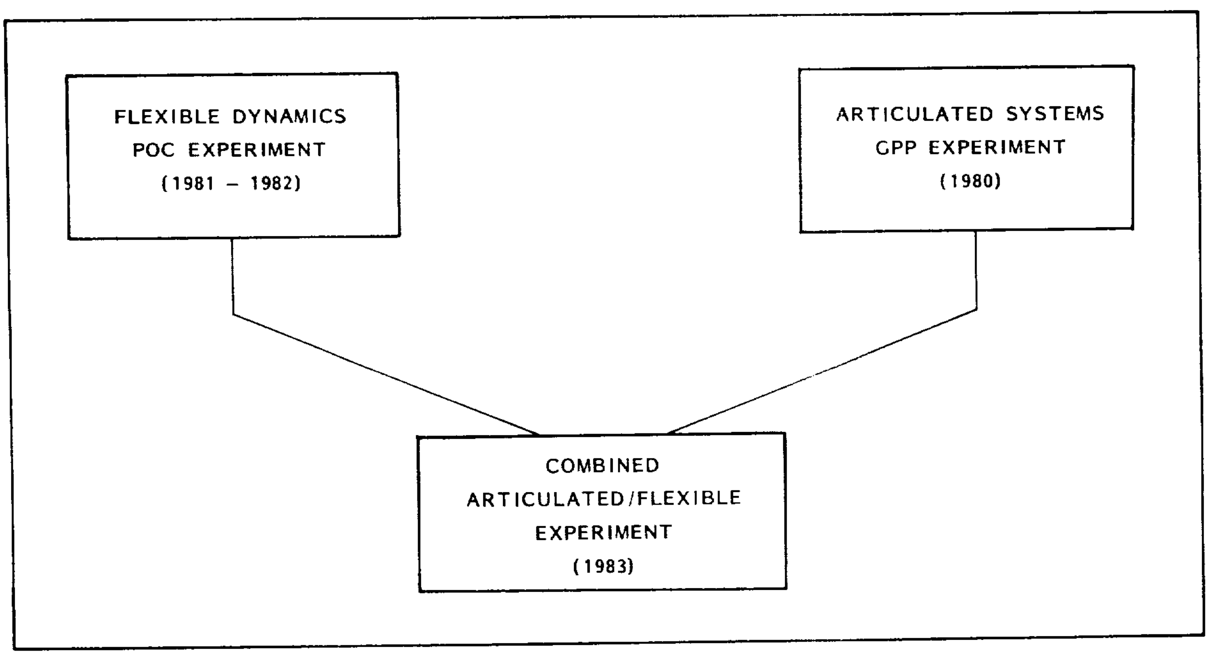
MULTIPLE INPUT/MULTIPLE OUTPUT CONTROLS

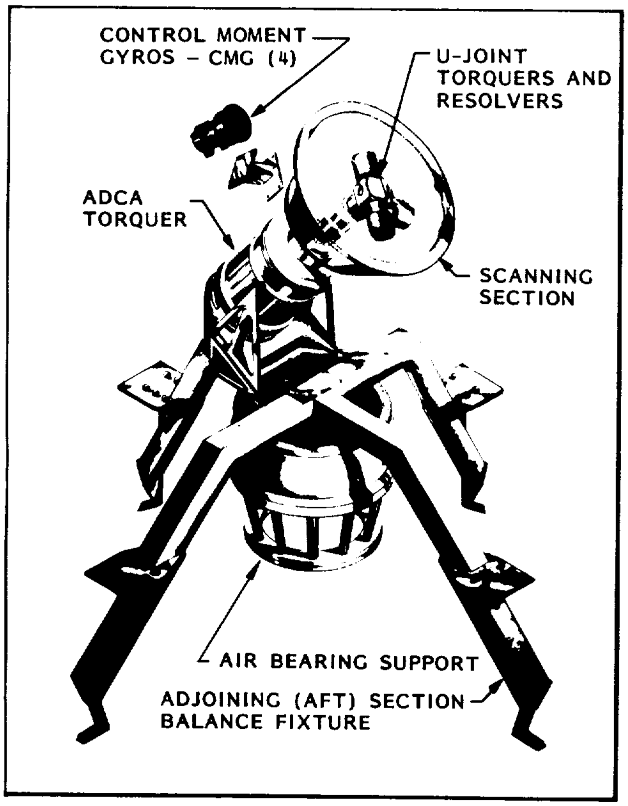
One of the main advantages of modern control theory is its ability to deal easily with multiple input/multiple output systems. Two types of systems which fall into this category are flexible systems, where many measurements and several actuators may be necessary to provide control over bending behavior, and articulated systems which consist of several rigid bodies connected together by pivoting connections. In this latter case, multiple controls could be implemented, for instance, as torquers at the joints.

LMSC has conducted hardware tests of both types of systems and plans to do tests of a combined flexible/articulated system in the near future.



TYPICAL PERFORMANCE DEMONSTRATION

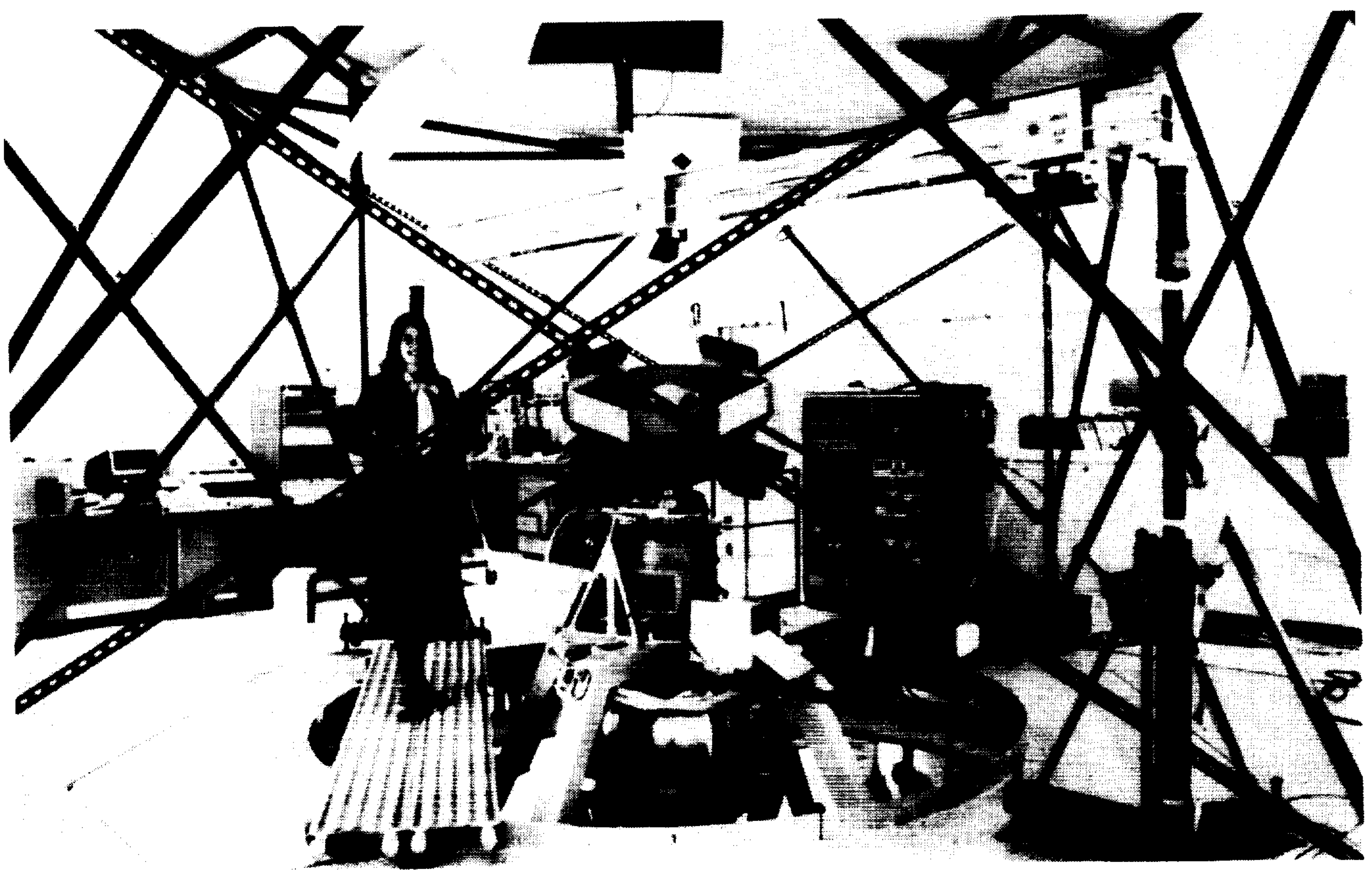
The test article consists of a payload (P/L) section and an equipment section (E/S) connected via three gimbals. The P/L, which performs large angle high rate maneuvers, is driven by four control moment gyros (CMGs) oriented so as to provide full three-dimensional torque capability. To minimize disturbances transmitted to the E/S, the axes of the three gimbals all intersect at the P/L center-of-mass. The E/S, which is to remain fixed in a laboratory reference frame, is controlled by torquers on the three gimbals. Attitude reference is provided by a rate gyro package and simulated star sensors mounted on the E/S plus optical encoders and resolvers on the gimbal axes. The total system weighs approximately 5,000 lbs and has maximum dimensions of approximately 10 feet in each direction.



- **DEMONSTRATED MULTIBODY GIMBALLED SPACECRAFT MANEUVERING**
- **PERFORMED POINT-TO-POINT STEERING AND SYSTEMATIC SCANNING WHILE ADJOINED SECTION REMAINS FIXED IN ORBITAL COORDINATES**
- **DESIGNED, CONSTRUCTED AND FUNCTIONALLY TESTED AN AIR BEARING WORKING MODEL INCORPORATING MOMENT CONTROL TORQUERS**

MULTI-BODY MANEUVERING SYSTEM TEST

The test article is floated on a spherical air bearing (A/B) to allow for three rotational degrees of freedom with minimum environmental disturbance torques. The command/control computer and power supplies for sensors and actuators are located on the laboratory floor adjacent to the A/B. Power and data lines are connected to the floated test article via specially designed low friction mercury pool connectors. A laser beam is reflected off a mirror on the P/L to simulate the line-of-sight, and fixed laser detectors provide a measurement of pointing accuracy.



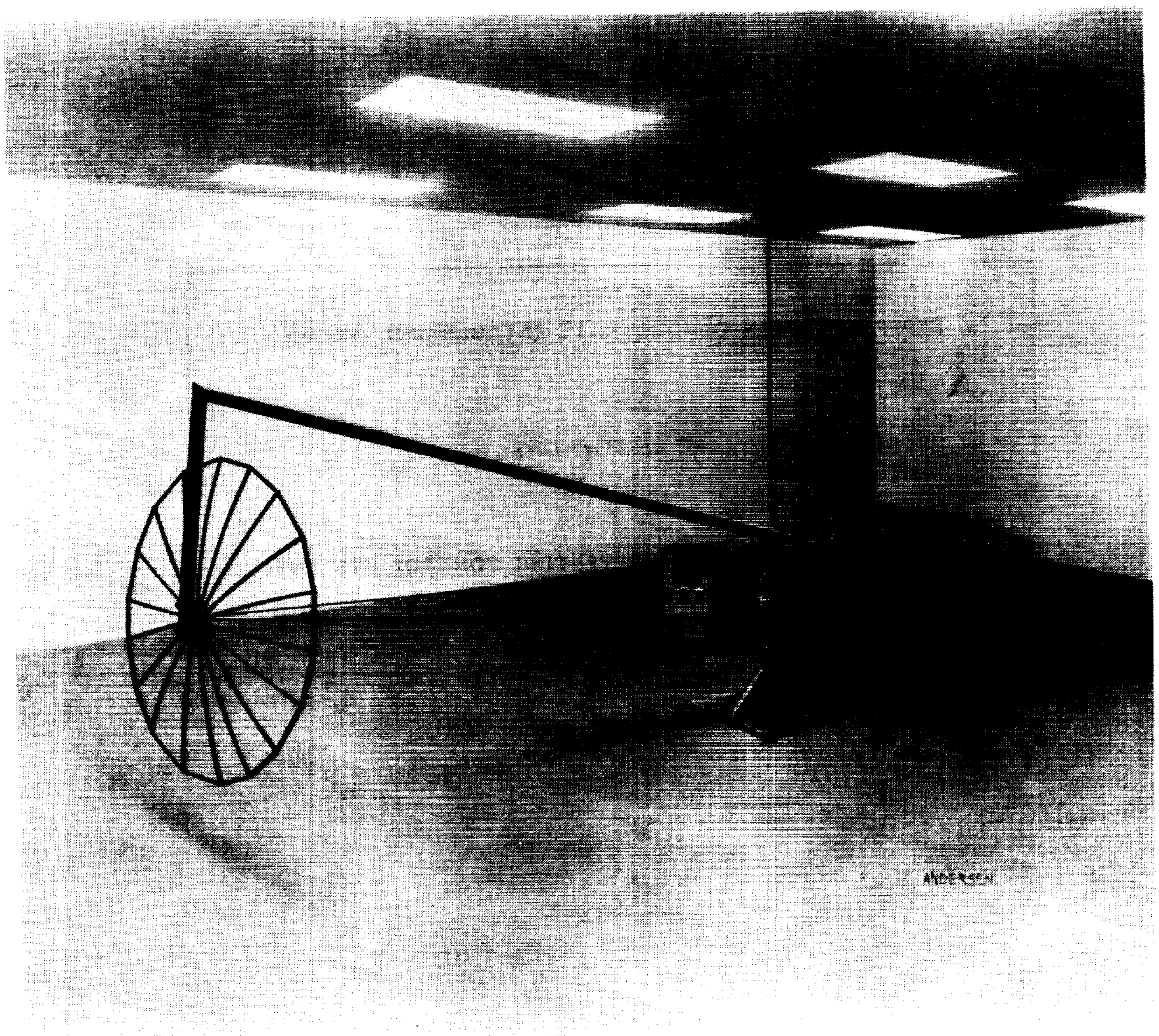
OBJECTIVES OF THE PROOF OF CONCEPT EXPERIMENT

The purpose of the ACOSS POC experiment is to demonstrate existing theories of LSS control on a realistic facsimile of a spacecraft, using sensors and actuators such as will actually be used in space. Beyond this goal, we will start work on establishing a testing procedure for these new control systems.

- EXPERIMENTALLY DEMONSTRATE ESTABLISHED THEORY
- ESTABLISH HARDWARE LIMITATIONS
- DEVELOP TECHNIQUES FOR TESTING CONTROL SYSTEMS

ARTIST'S CONCEPTION OF EXPERIMENT

The POC experimental specimen is a scaled down model of an offset fed RF antenna. An early goal is to control flexing of the specimen, using the CMG package, sufficiently to allow steady pointing of the line of sight (simulated by the laser path) at an inertial target. Later goals will be to control the dynamics of the entire antenna dish.



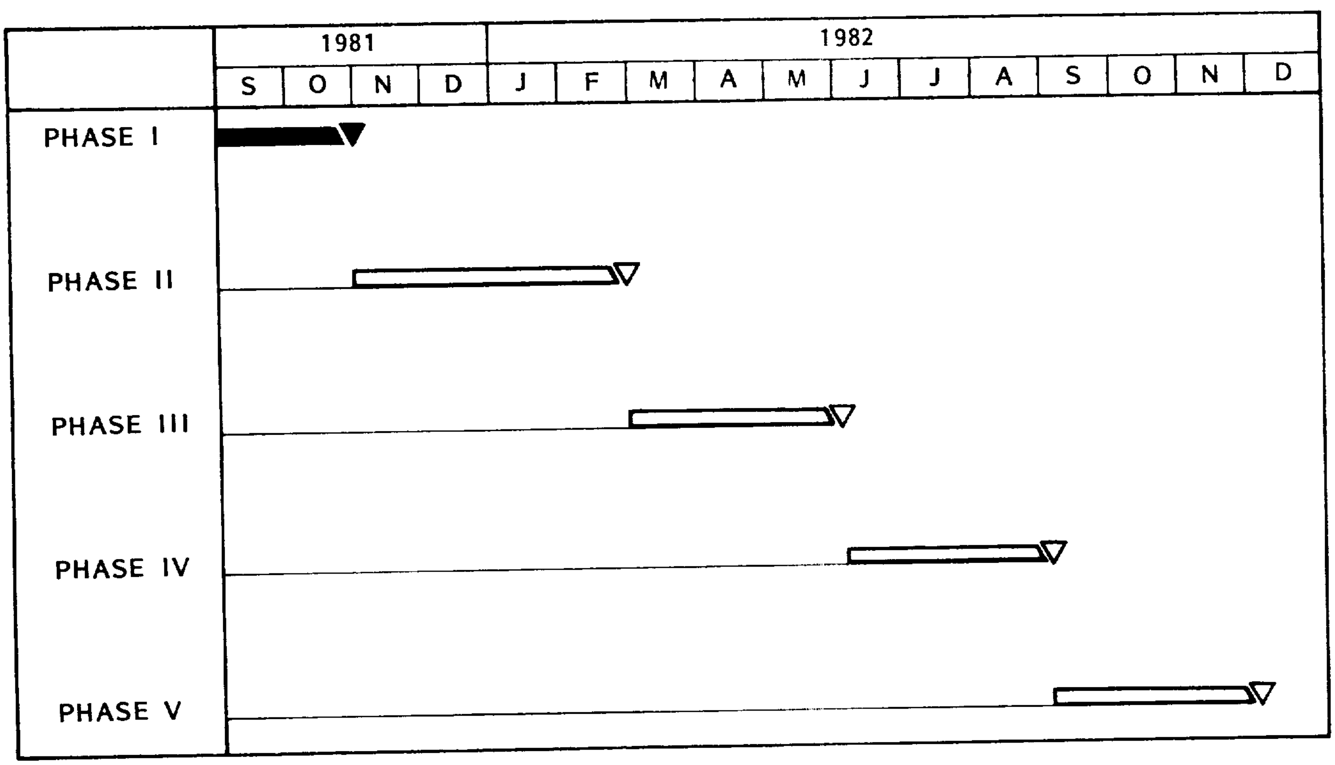
EXPERIMENT PHASES

Plans for 1982 are to complete the experiments which demonstrate line-of-sight (LOS) control capability with central actuators (CMGs) alone. Next, distributed actuation in the form of proof-mass actuators will be added to improve pointing performance. Eventually we will also demonstrate optimal slewing.

PHASE
PHASE I OPEN LOOP MODAL CHARACTERIZATION
PHASE II DEMONSTRATION OF LINE OF SIGHT CONTROL WITH A SINGLE CENTRAL ACTUATOR; CONTROLS DESIGNED FOR TRANSIENT DISTURBANCE REJECTION
PHASE III DEMONSTRATION OF LINE OF SIGHT CONTROL WITH DISTRIBUTED ACTUATORS; CONTROLS DESIGNED FOR TRANSIENT DISTRUBANCE REJECTION
PHASE IV SAME AS PHASE III EXCEPT THAT CONTROLS DESIGNED FOR ON BOARD STEADY STATE DISTURBANCE REJECTION
PHASE V OPTIMAL SLEWING, CONTROL OF ANTENNA DISH DYNAMICS, ...

SCHEDULE OF EXPERIMENTAL PHASES

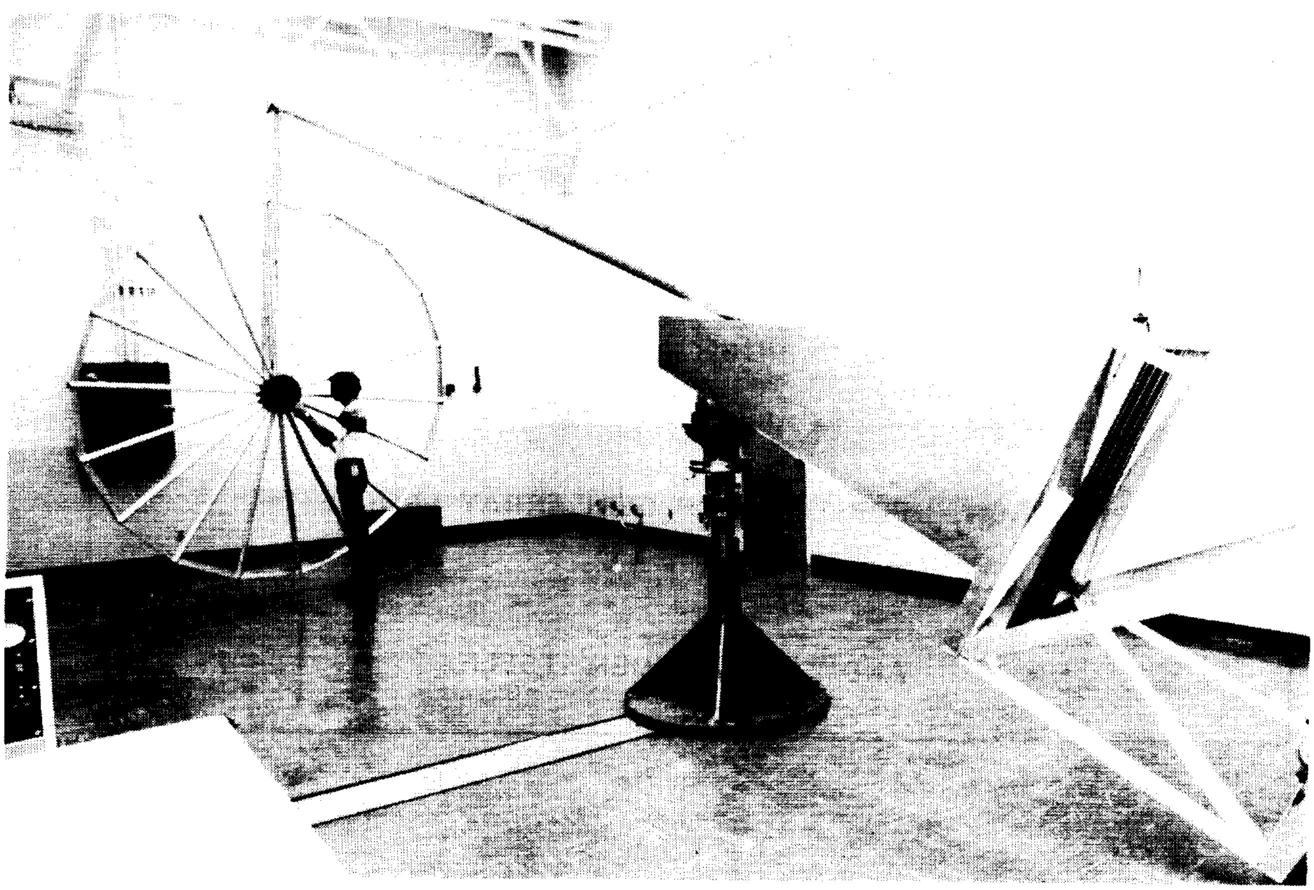
The schedule for carrying out the five phases described in the previous chart is shown below.



PHOTOGRAPH OF THE POC SPECIMEN

Some data on the POC experimental specimen:

Overall Length	29'
Antenna Dish Diameter	10'
Weight (Excluding Air Bearing)	590 lbs
Height	19'



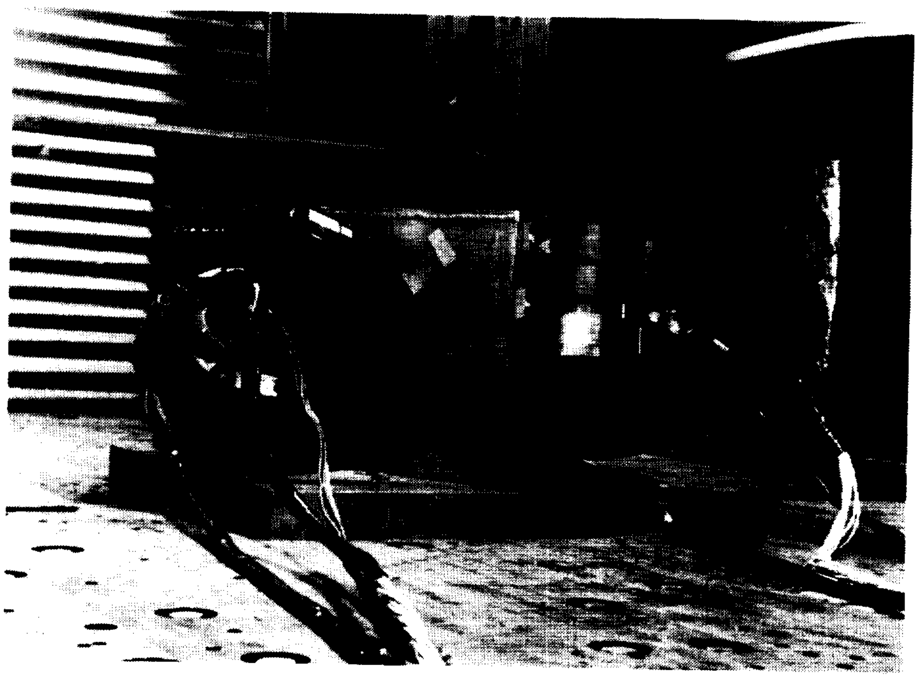
HARDWARE LIST

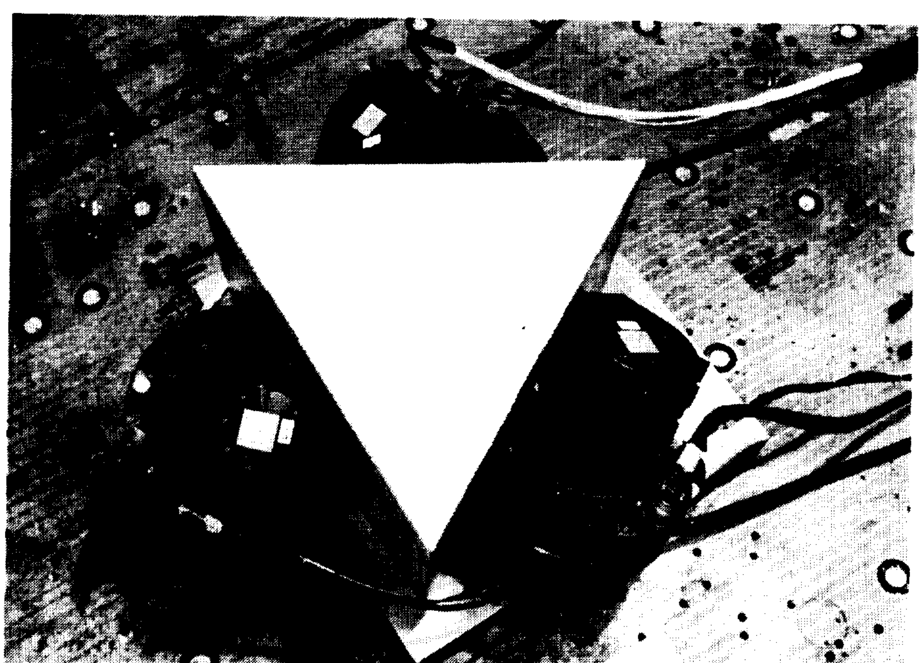
Shown here is a list of the major components used in the POC experiment. The computer plays a dual role; it both implements the control system, and monitors the testing procedures. The controls tests are modifications of standard modal testing procedures.

ACTUATORS:	C.M.G. CLUSTER, PROOF MASS ACTUATORS
SENSORS:	LASER ATTITUDE DETERMINATION RATE GYROS, ACCELEROMETERS
SUSPENSION:	AIR BEARING
COMPUTATION:	PDP 1145 WITH CSPI ARRAY PROCESSOR
	AND THE SPECIMEN ITSELF

PHOTOGRAPHS OF THE CMG CLUSTER

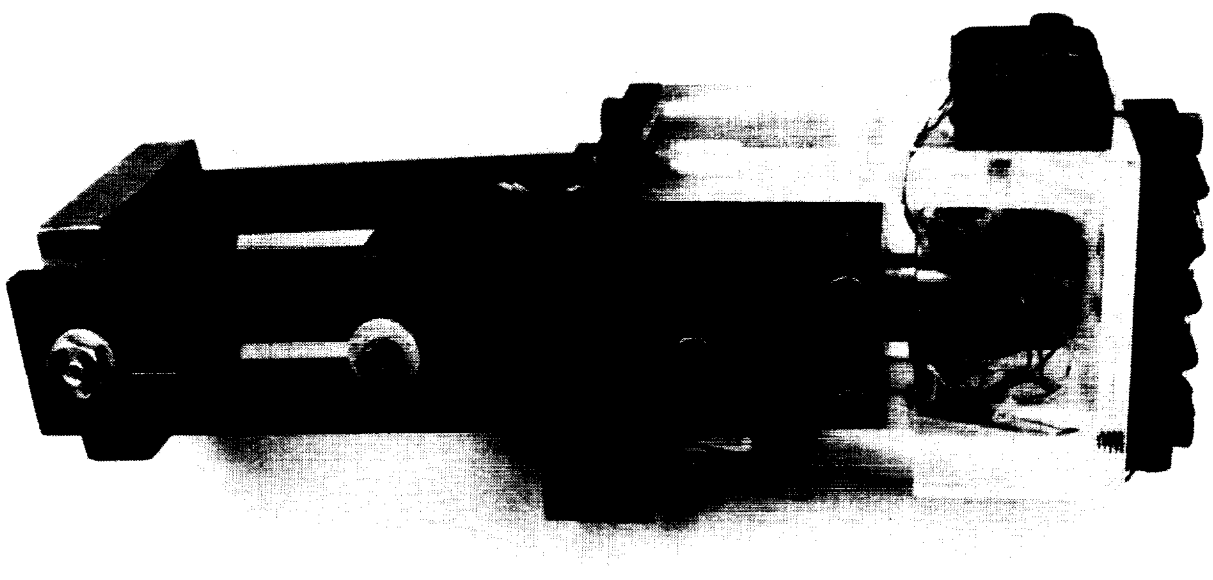
The next two pictures show the CMG cluster. Three CMGs are mounted such that the gimbal axes are symmetrically spaced on the surface of a 30° cone, and intersect at its apex. Each CMG can produce up to one hundred foot-pounds of torque, and has a momentum magnitude of five foot-lb-sec. Each unit weighs about forty pounds, and is approximately 1 1/2 feet long.





PHOTOGRAPH OF A PROOF-MASS ACTUATOR

Ten of these proof-mass actuators will be used to provide distributed actuation in Phases III and IV of the experiment. Each unit is capable of exerting a force of up to 1/2 lb. The force results from the proof-mass being accelerated by the magnetic coil. These devices can be used only for vibration suppression since they are not capable of producing a constant force.



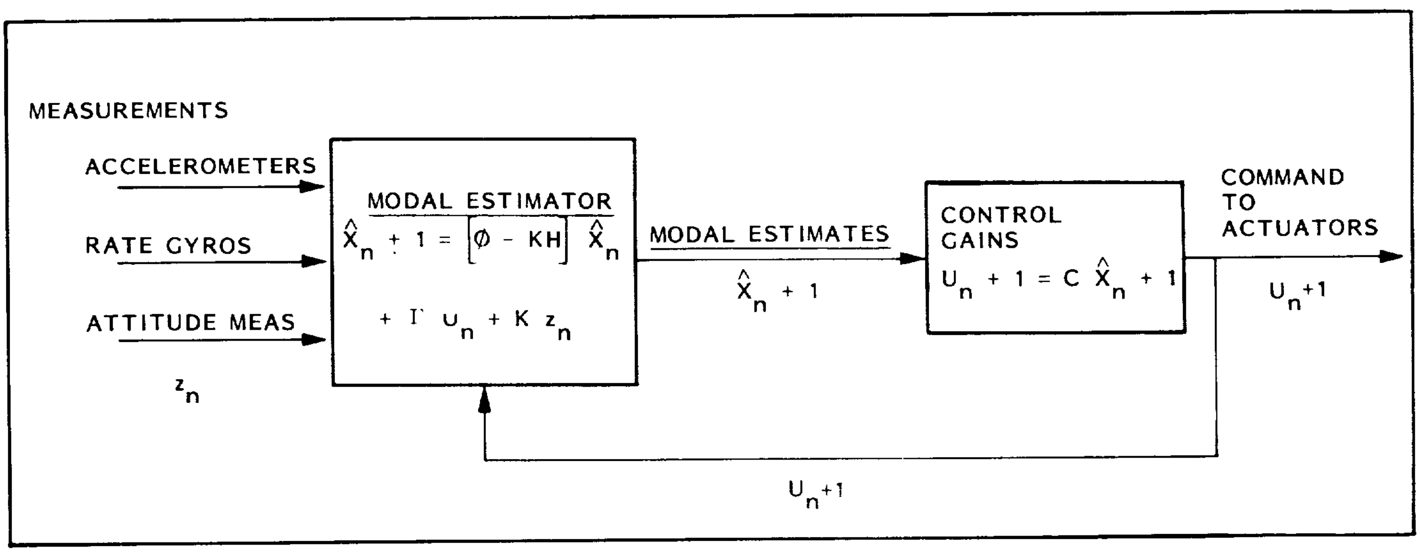
MODAL CHARACTERIZATION RESULTS

These data show how closely the finite element model was able to anticipate the modal frequencies of the specimen. Not shown is data on the agreement of the mode shapes; qualitatively agreement was good for the first five modes, but from then on analysis and experiment seemed to diverge. This uncertainty in the knowledge of the mode shapes could hamper design of the control system; maximum performance cannot be reached until the mode shapes are better determined.

	EXPERIMENTAL MODES	ANALYTICAL MODES (FINITE ELEMENT)
1.	1.50 Hz	1.67 Hz
2.	1.57	1.72
3.	3.01	3.28
4.	5.07	4.50
5.	6.91	6.23
6.	11.49	10.09 10.72
7.	13.02	12.11
8.	14.24	14.95
9.	15.33	15.44
10.	16.90	16.36
11.	16.98	17.29
12.	17.01	19.49
13.	17.61	20.50
14.	19.10	
15.	19.97	

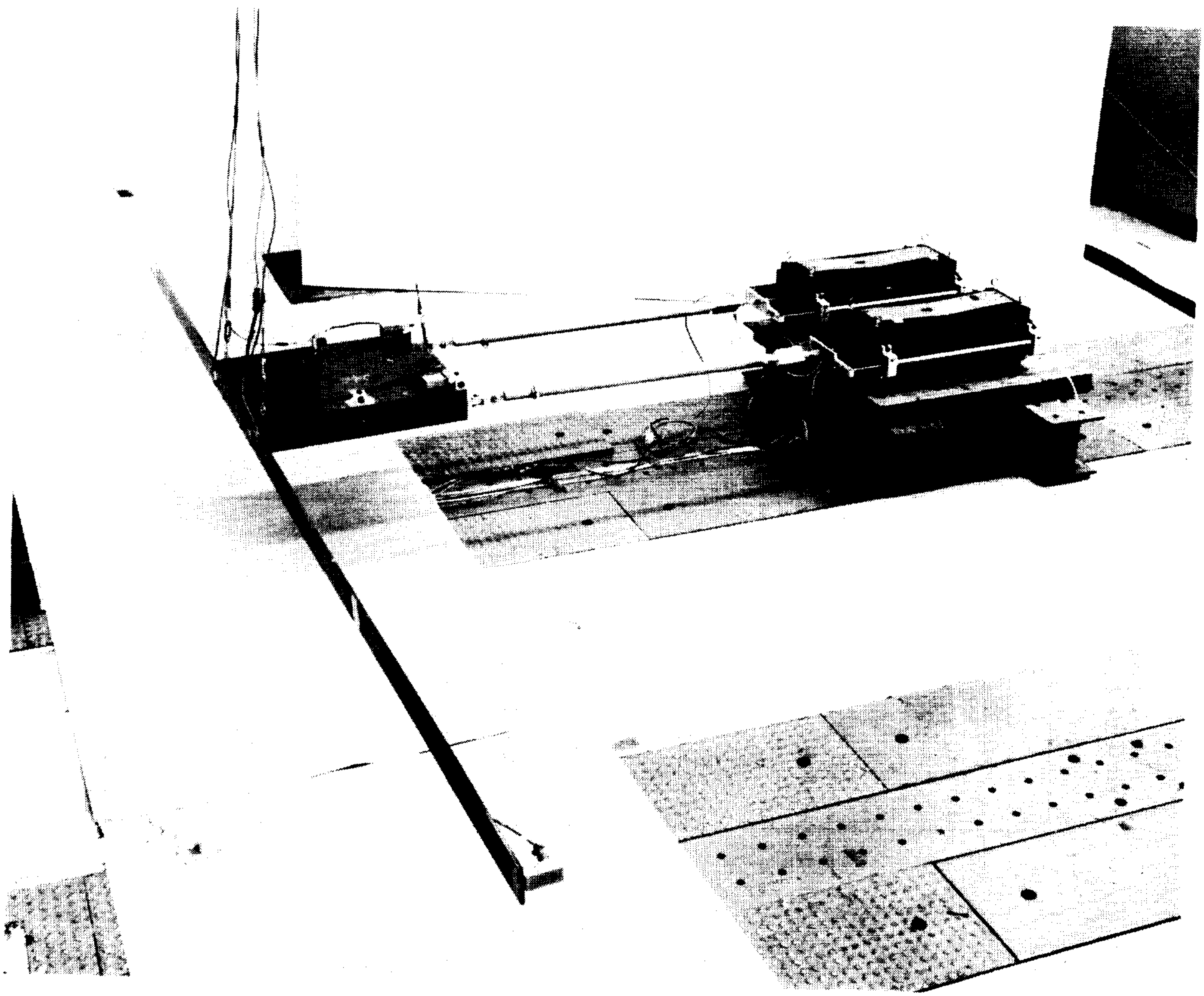
CONTROL SYSTEM SCHEMATIC

Shown here is a schematic of the control system as it will be implemented on the POC experiment. The strategy is to estimate the modal amplitudes using a digital Kalman filter, and then to use these estimates, multiplied by the appropriate gains, to generate the actuator commands. The Kalman filter gains and the control gains are generated using conventional optimal control synthesis procedures.



PHOTOGRAPH OF THE TOYSAT EXPERIMENT

The Toysat was an earlier experiment. We use it here to show the type of results we expect to obtain from the POC experiment. The Toysat consists of a 15 foot flexible beam fastened to the side of a 2 foot square block of aluminum. It is suspended from the ceiling in such a way as to allow free motion in the horizontal plane. Control of the motion of the specimen is provided by two linear actuators, and sensing is provided by accelerometers mounted at the ends of the beam, as well as linear position sensors mounted in tandem with the linear actuators. The control system used was a smaller version of that planned for the POC experiment.



OPEN AND CLOSED LOOP BEHAVIOR

These time histories illustrate that the control system used was indeed able to significantly affect the flexible behavior of the Toysat. During the first four seconds of the test runs, a disturbance was input through the shakers. In the closed loop tests, the control system was on during the disturbance and for the next eight seconds. The control system reduced response during the disturbance, and greatly reduced the settling time after the disturbance was finished.