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SLEWING CONTROL EXPERIMENT FOR A FLEXIBLE PANEL

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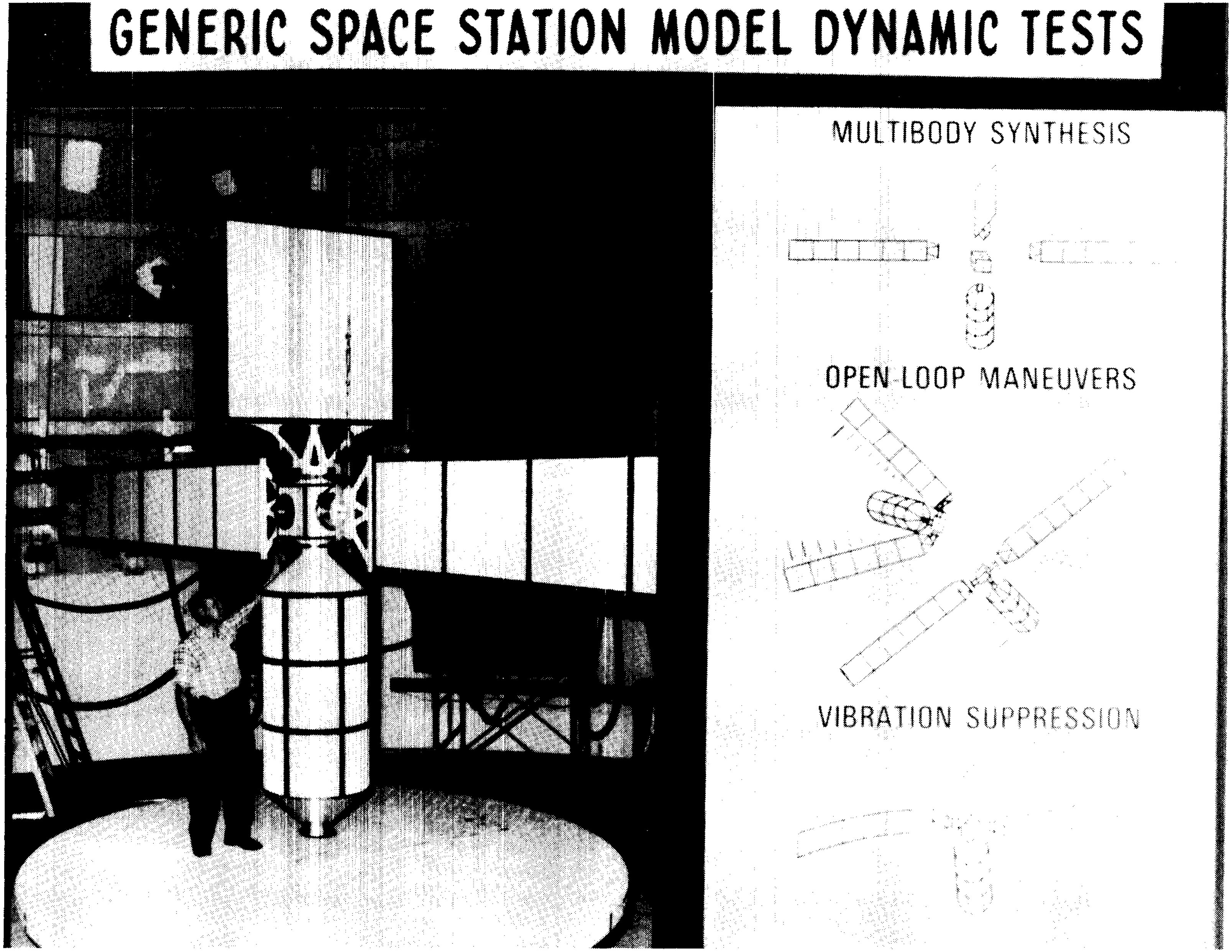
INTRODUCTION

This research is intended to identify technology areas in which better analytical and/or experimental methods are needed to adequately and accurately control the dynamic responses of multibody space platforms such as the Space Station. A generic space station solar panel (ref. 1) is used to experimentally evaluate current control technologies. Active suppression of solar panel vibrations induced by large angle maneuvers is studied with a torque actuator at the root of the solar panel. These active suppression tests will identify the hardware requirements and adequacy of various controller designs (ref. 2).


GENERIC SPACE STATION MODEL DYNAMIC TESTS
MULTIBODY SYNTHESIS
OPEN-LOOP MANEUVERS
VIBRATION SUPPRESSION

RAPID MANEUVERING OF FLEXIBLE STRUCTURES

The objective of the present experiment is to demonstrate slewing of a flexible structure in a single axis while simultaneously suppressing vibrational motion by the end of the maneuver. This experiment is designed to verify theoretical analyses concerning the application of modern control methods to the control of flexible structures (refs. 3 & 4).

RAPID MANEUVERING OF FLEXIBLE STRUCTURES

- OBJECTIVE: TO UNDERSTAND THE SUPPRESSION OF VIBRATIONS IN FLEXIBLE STRUCTURES.

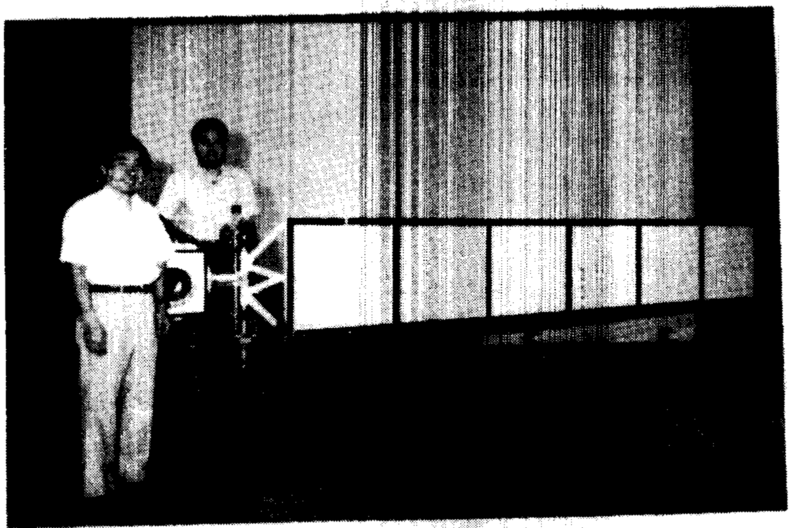
- APPROACH: PERFORM FUNDAMENTAL EXPERIMENTS IN SLEWING OF FLEXIBLE STRUCTURES WHILE SIMULTANEOUSLY SUPPRESSING VIBRATIONAL MOTION AT THE END OF MANEUVER.

EXPERIMENT SET-UP

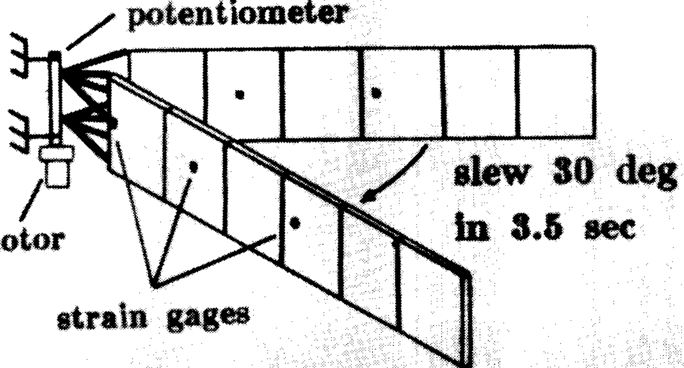
A 13-foot-long flexible solar panel model having a cross section of 2.1 ft x .13 in. is used for experimental validation. The test model is cantilevered in a vertical plane and rotated in the horizontal plane by an electric gearmotor. Instrumentation consists of three full-bridge strain gages to measure bending moments and two angular potentiometers to measure the angle of rotation at the root. The strain gages are located at the root, at twenty-two percent of the panel length, and at the mid-span. Signals from all four sensors are amplified and then monitored by an analog data acquisition system. An analog computer closes the control loop, generating a voltage signal for the gearmotor based on a linear optimal control algorithm with terminal constraints in finite time. The Figure shows an example of results for a 30-degree slew in 3.5 seconds. When no control is used, residual motion is significant, whereas the controller produces the same maneuver with virtually no residual motion.

SLEWING CONTROL SUCCESSFULLY DEMONSTRATED FOR FLEXIBLE SOLAR PANEL

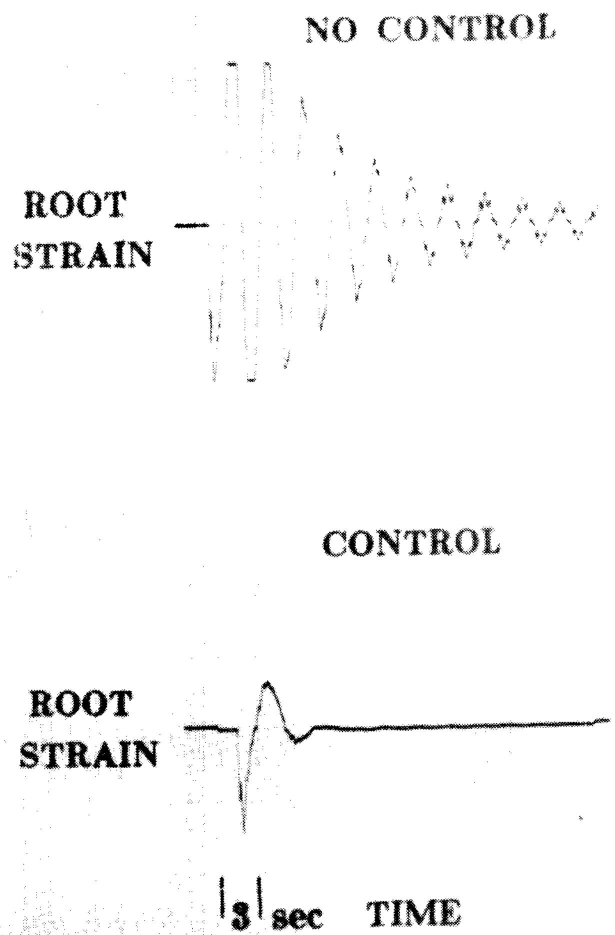
TEST SET-UP



13-foot long aluminum/honeycomb panel



EXPERIMENT



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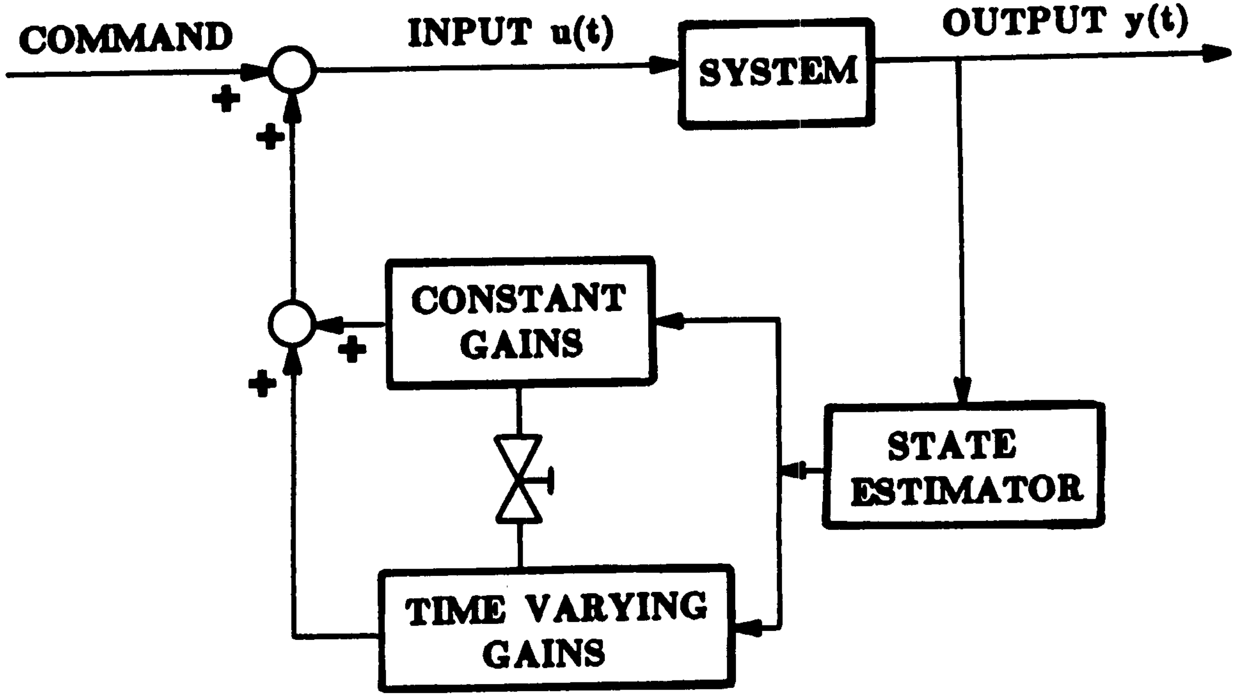
CONTROL STRATEGY FOR TERMINALLY CONSTRAINED MANEUVER

The control design which is used in this experiment is the optimal terminal control law (refs. 3 & 4). The optimal terminal control law is formulated by findind the control input to minimize a cost function which consists of an integral of quadratic forms in the state, control, and control-rate with appropriate weighting matrices, subject to specified terminal constraints. The feedback gains thus derived consists of constant (steady state) and time varying gains. The weighting matrices determine the relative importance of the constant gain and time varying gain.

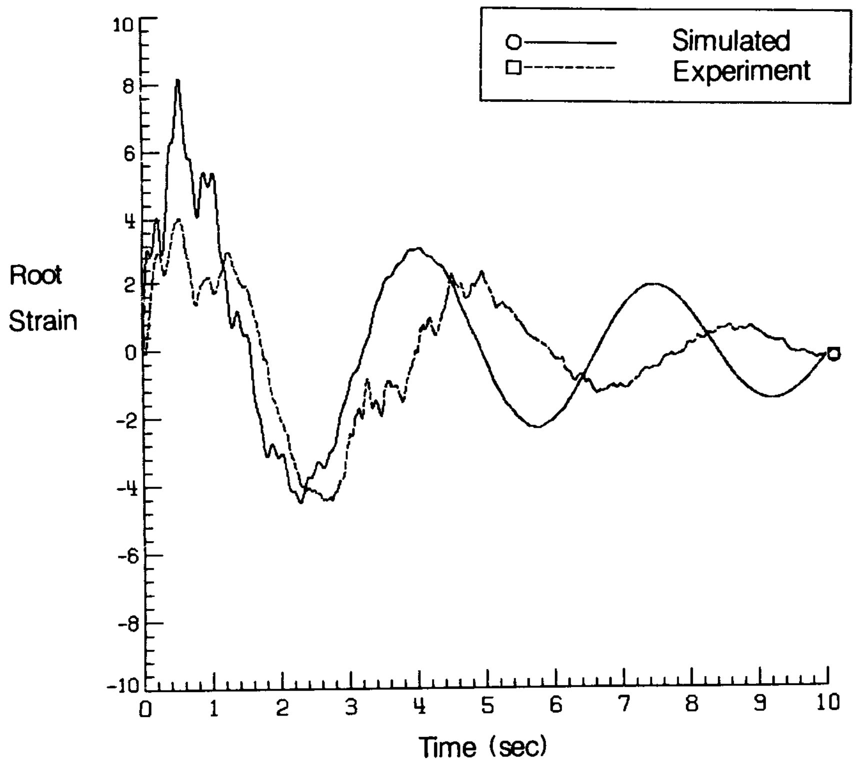
CONTROL STRATEGY FOR TERMINALLY CONSTRAINED MANEUVER



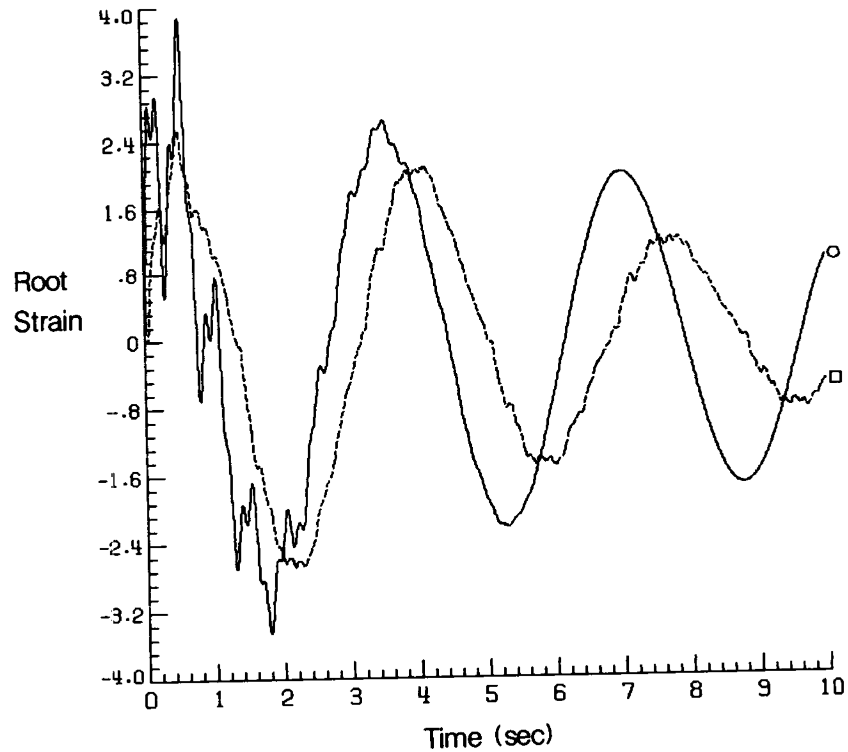
TYPICAL ANALYSIS/TEST COMPARISON

This figure shows the results for 30-degree maneuvers in air and in vacuum. The root strain is shown to illustrate the comparison of the analytical simulation with the experimental results. The solid line represents simulation data, whereas the dashed line represents the experimental data. Reasonable agreement is observed in the transient responses. The ordinate is in millivolts which can be converted to strain by using the conversion factor (ref. 5).

TRANSIENT RESPONSES FOR SIMULATED AND EXPERIMENTAL DATA
(For a 30 degrees maneuver)



a) Air



b) Vacuum

TYPICAL ANALYSIS/TEST COMPARISON (CONTINUED)

The predicted and experimental frequencies and damping values are shown in the Table. In addition to the transient analysis, the laboratory data was analyzed using the Eigensystem Realization Algorithm (ERA) (Refs. 6 & 7). Since the system dynamics including air damping are nonlinear, the data length must be considered in the interpretation of modal parameters. However, examination of modal parameters identified using several different data lengths indicates that no significant variation of results occurs. Harmonic frequencies which reflect nonlinearities of the system dynamics do appear (see ref. 8). As a result, the dynamic behavior for those cases in air can be approximately described by the modal parameters. The predicted first mode frequency in air is lower than measured in the experiment. This is because of the softening effect of the gear train backlash which is not properly modeled if cantilever modes are used in the beam discretization. The same phenomena in vacuum is also observed. In both cases (in air and in vacuum), the analytically predicted damping values are lower than experiment. The differences are attributed to the dissipative effect of the gear train backlash not modeled. A reduction of the peak strain is also observed in vacuum because no air opposes the maneuver.

TYPICAL ANALYSIS/TEST COMPARISON

	DAMPING	FREQUENCY
• ANALYSIS	5%	0.28 HZ
• EXPERIMENT		
IN AIR	16%	0.25 HZ
IN VACUUM	9%	0.27 HZ

TYPICAL ANALYSIS/TEST COMPARISON (CONTINUED)

This figure shows the results for the same maneuver in air and vacuum when the control torque profile is shaped (ref. 5). Good agreement is observed in the transient analysis in vacuum. The experiment data in air depict a residual motion caused by air circulation in the laboratory while conducting the experiment. With the exception of the peak strain values, the curves in the figure agree reasonably. It is believed that the geartrain backlash and deadband effects contribute significantly to the increase of the peak strain value when air is opposing the slew maneuver particularly for the case with torque shaping. The discrepancy is also attributed to modeling errors of the drag forces. The drag coefficient is generally a function of vibration amplitude.

TRANSIENT RESPONSES FOR SIMULATED AND EXPERIMENTAL DATA
(For a 30 degrees maneuver with torque shaping)

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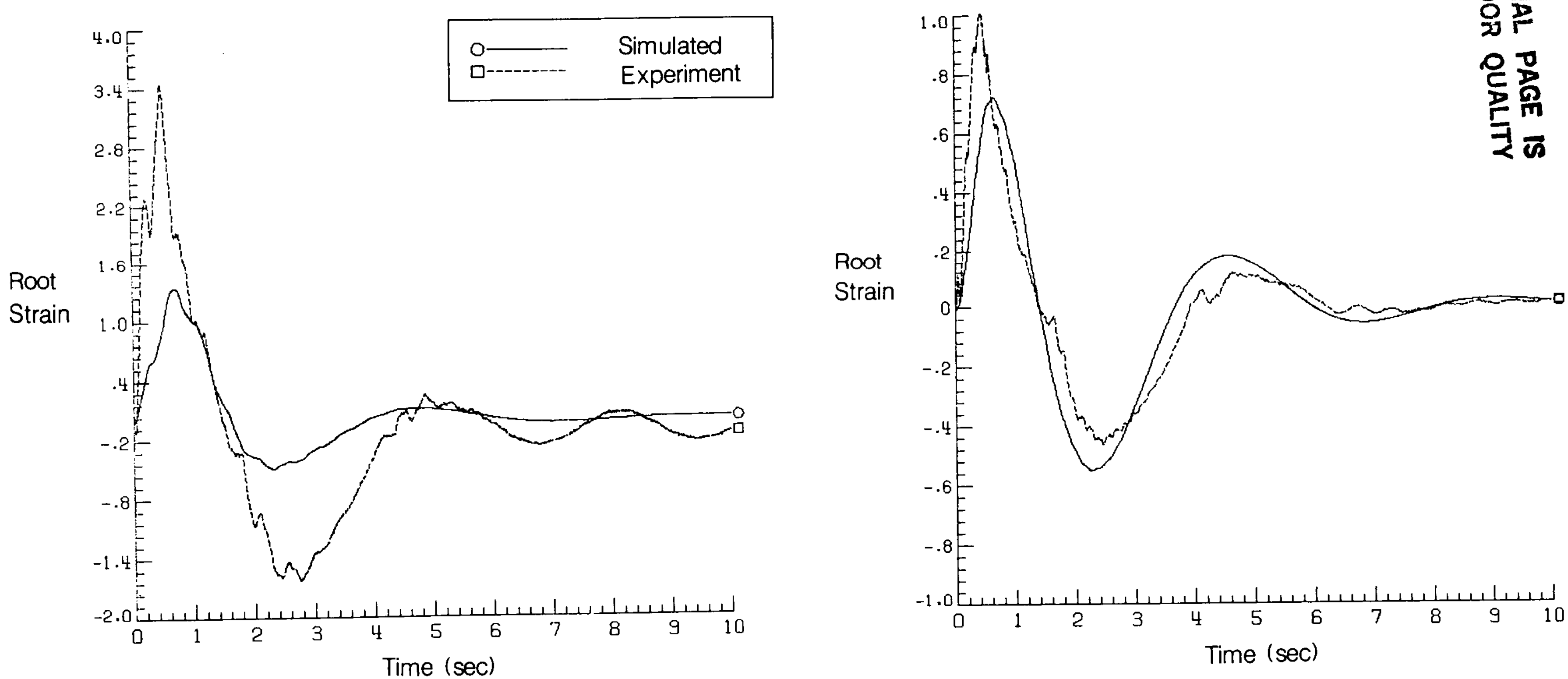

a) Air

b) Vacuum

ACCOMPLISHMENT

Prediction of transient responses, frequencies, and damping ratios is compared with experimental results. Satisfactory agreement was achieved between experimental measurements and theoretical predictions. Nonlinear effects due to large bending deflections during the maneuver did not cause significant changes in performance of the control laws, which were designed using linear control theory. To minimize the excitation of flexible modes, a low-pass filter was used to shape the control torque input. This shaping proved beneficial for fast slewing maneuvers. Damping effects due to atmosphere can be systematically and effectively included in the equations for slewing maneuvers of a flexible panel. By using the analysis technique shown here, one can include air damping in the numerical simulation to extrapolate the characteristics of the system in vacuum. The significance of air damping effects depends on the controller design for flexible structures. The smoother the controller is, the less the effects of air damping will be.

ACCOMPLISHMENT

- FAST SLEWING MANEUVERS WITH VIBRATION SUPPRESSION HAVE BEEN SUCCESSFULLY DEMONSTRATED FOR FLEXIBLE STRUCTURES.

- SATISFACTORY AGREEMENT WAS ACHIEVED BETWEEN EXPERIMENTAL MEASUREMENTS AND THEORETICAL PREDICTION USING A LINEAR CONTROL THEORY

FUTURE PLANS

The hardware will be modified to study the slewing control of multiple solar panels hinged to a rigid body, which produces a kinematically nonlineal dynamic system for large angle maneuver. Three actuators are required to slew the system which has three rigid body axes.

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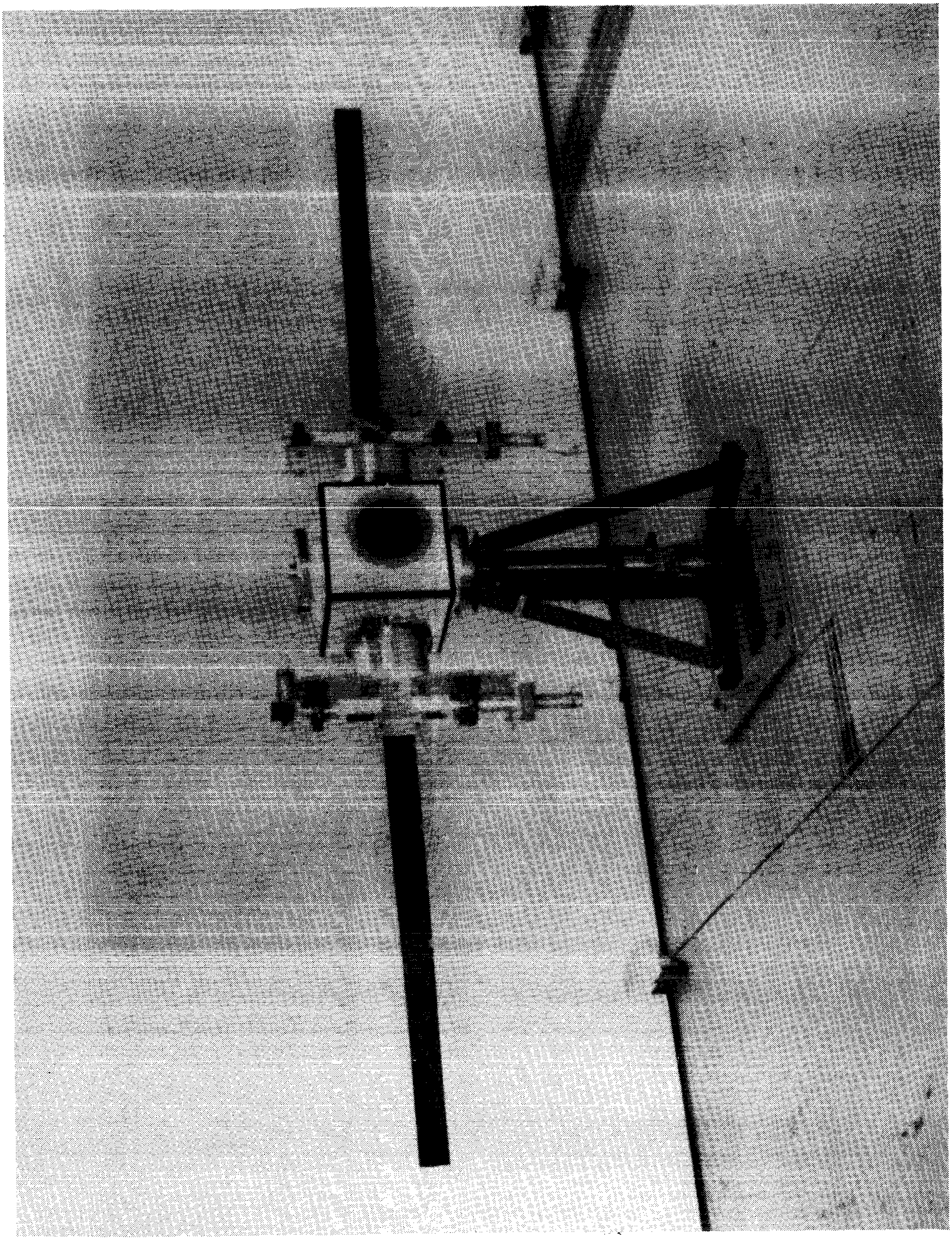

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