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RESEARCH IN SLEWING AND TRACKING CONTROL

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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 and the Radiometer Spacecraft. A generic space station model (ref. 1) is used to experimentally evaluate current control technologies and a radiometer spacecraft model is used to numerically test a new theoretical development for nonlinear three-axis maneuvers (ref. 2). Active suppression of flexible-body vibrations induced by large-angle maneuvers is studied with multiple torque inputs and multiple measurement outputs. These active suppression tests will identify the hardware requirements and adequacy of various controller designs.

OUTLINE

- **Rapid three–body maneuvering experiments**

- **Analytical development for nonlinear three–axis maneuvers**

RAPID THREE-BODY MANEUVERING EXPERIMENTS

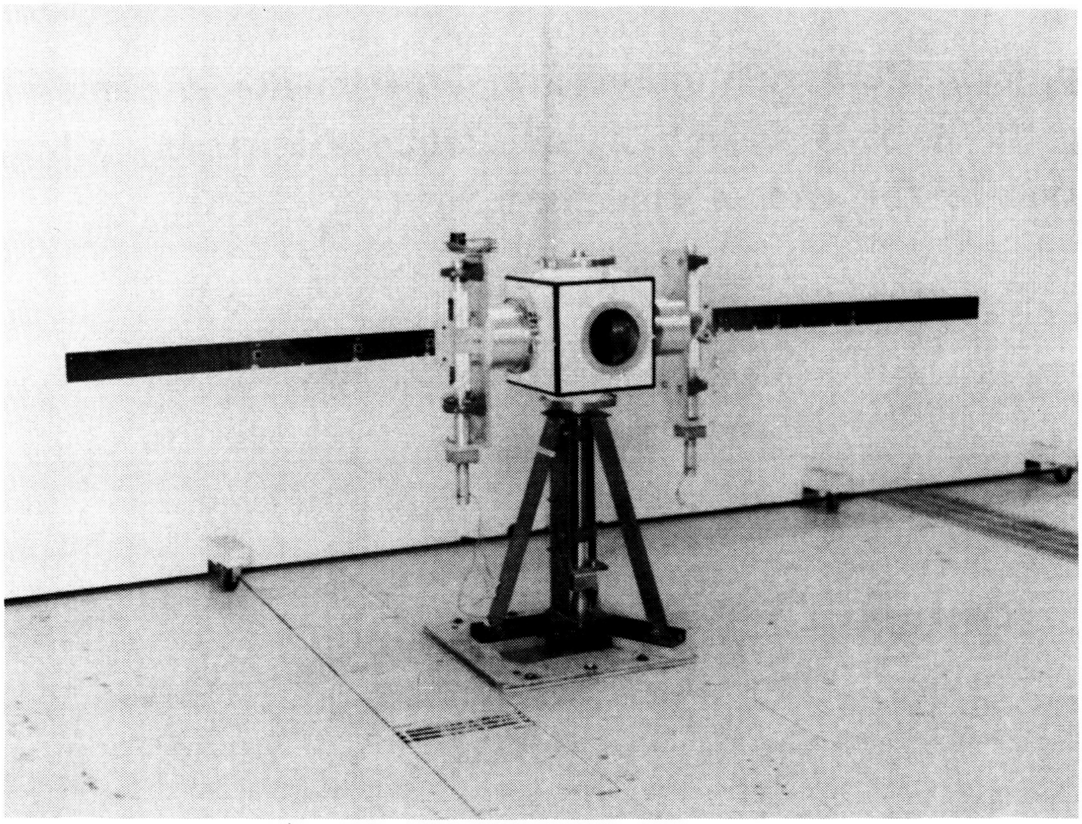
The objective of the present experiment is to demonstrate slewing of flexible structures in multiple axes while simultaneously suppressing vibrational motion at the end of the maneuver. This experiment is designed to verify theoretical analyses concerning the application of modern control methods (refs. 3 & 4) for linear systems to the control of nonlinear systems (refs. 5).

- **Objective: To understand the suppression of vibrations in flexible structures due to large–angle multi–axis maneuvers.**

- **Approach: Perform fundamental experiments in rapid slewing of a three–body flexible system while suppressing vibrational motion at the end of maneuver.**

EXPERIMENT SETUP

Two flexible steel panels hinged to a rigid hub are used to study the slewing control for experimental validation of modern control theory. The hub is rotated in the horizontal plane by an electric gearmotor and its rotational angle is measured by a potentiometer. Instrumentation for each individual panel consists of an electric gearmotor, three full-bridge strain gages to measure bending moments and an angular potentiometer to measure the angle of rotation at the root. The electric gearmotor provides the torque at the root of the panel in the horizontal plane. The strain gages are located at the root, at twenty-two percent of the panel length, and at the mid-span. As a result, the system has three gearmotors as inputs, and six strain gages and three potentiometers as outputs. Signals from all outputs are amplified and then monitored by an analog data acquisition system. An analog computer closes the control loop, generating voltage signals for the three gearmotors based on a linear optimal control algorithm (refs. 6 & 7).



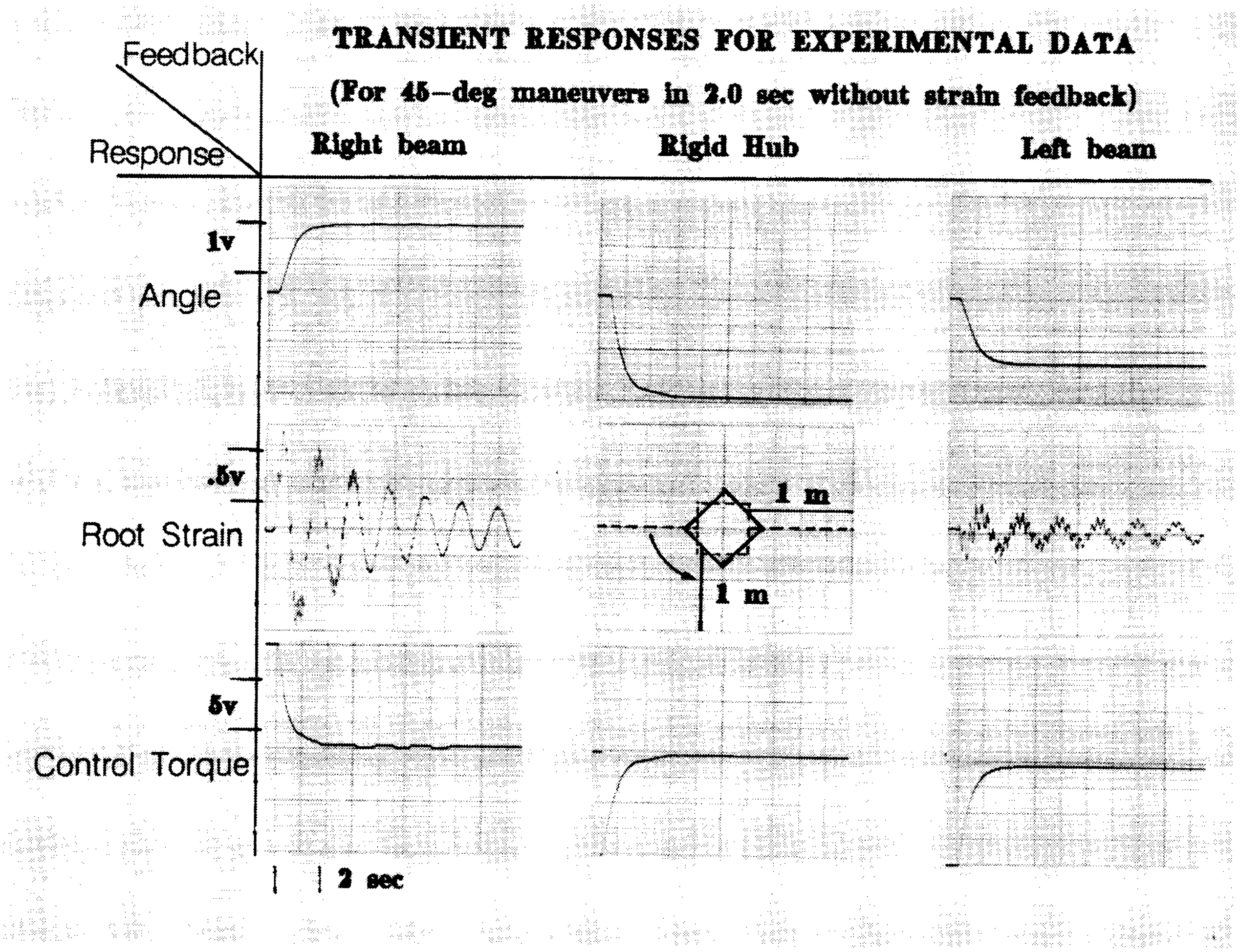
CONTROL STRATEGY FOR LARGE ANGLE MANEUVER

The control designs which use simple closed-loop feedback algorithms are considered for implementation. The basic strategy is to develop means of applying the linear control theory to the nonlinear dynamic system. The control designs are based on a linear dynamic system obtained by using the feedback linearization procedure developed in ref. 3 to isolate the kinematic nonlinearities in the state matrix and then properly treat them as the external force disturbances. The linear dynamic system includes the major portion of the couplings between the rigid hub rotation and the flexible panel motions. It has been proven that this control design is stable under certain constraints of the control gains. With this control strategy, the control procedure can be easily implemented and the three actuators work cooperately to accomplish the large-angle maneuvering and simultaneously suppress the vibrational motions.

- **Define performance requirements such as slewing rate**
- **Derive a three–body dynamic model including actuator dynamics**
- **Treat nonlinear terms as disturbances**
- **Compute direct output feedback gains**
- **Check stability of the closed–loop nonlinear system**

TYPICAL TEST RESULTS

This figure shows the results for 45-degree maneuvers in air. No strain feedback is conducted. The root strain is shown to illustrate the experimental results. The solid line in the center figure represents the final position of the system, whereas the dashed line represents the initial position.



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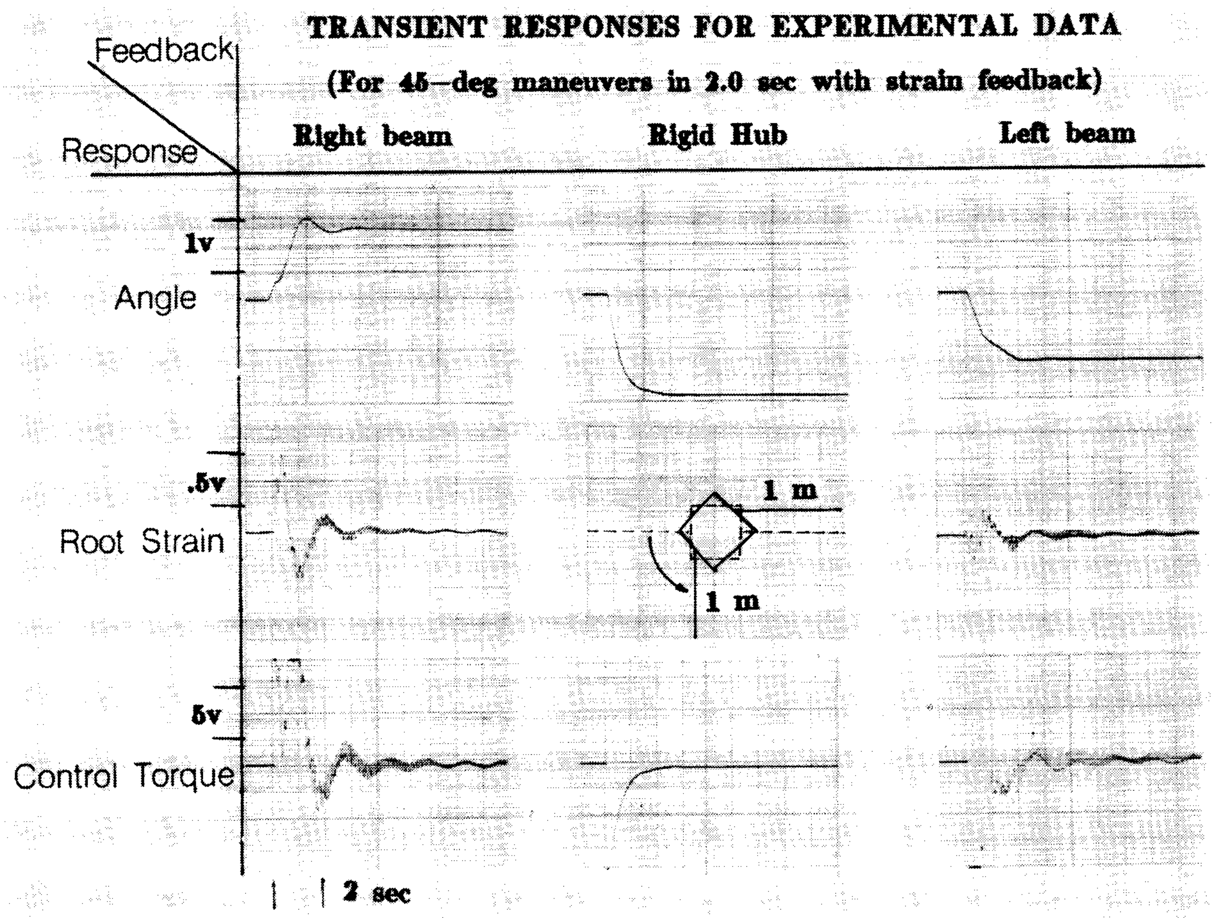
TYPICAL TEST RESULTS (CONTINUED)

This figure shows the results for 45-degree maneuvers with strain feedback. The root strain is shown to illustrate the experimental results. The solid line in the center figure represents the final position of the system, whereas the dashed line represents the initial position. Significant reduction of the root strain responses is observed because of the strain feedback. The experiment data depict a residual motion caused by air circulation in the laboratory while conducting the experiment. Nonlinear effects due to kinematic nonlinearity and large bending deflections during the maneuver did not cause significant changes in performance of the control laws, which were designed using linear control theory.



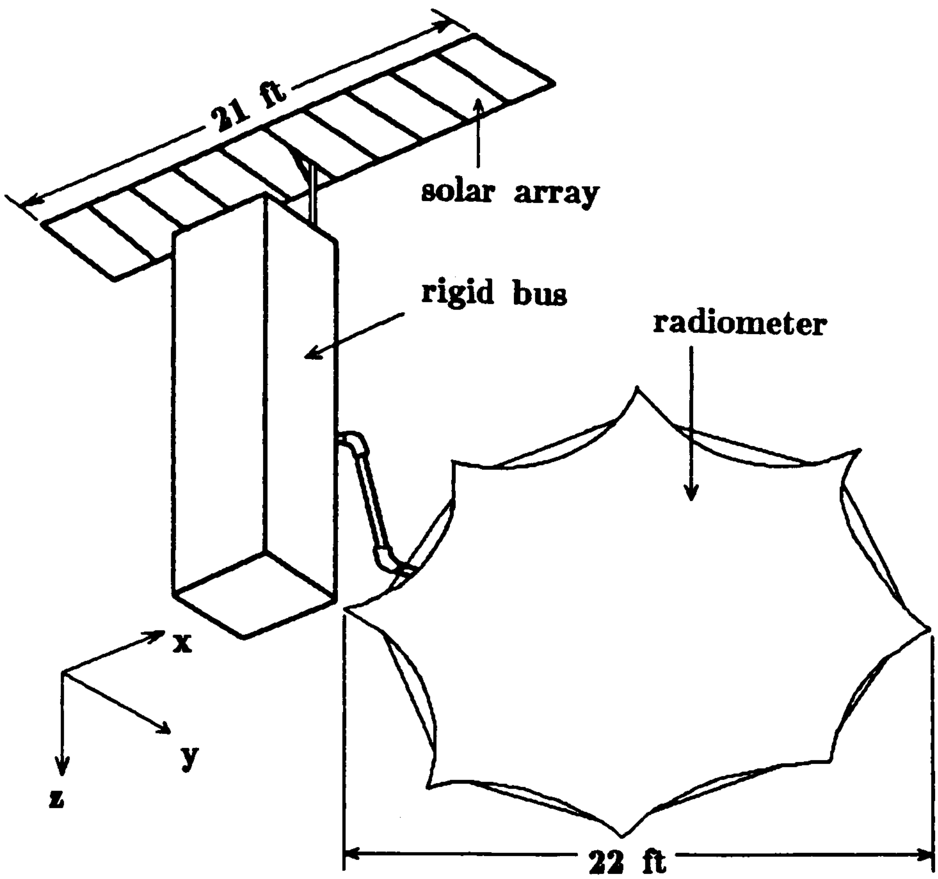
NONLINEAR THREE-AXIS MANEUVERS FOR FLEXIBLE SPACECRAFT

The following figures present a new approach for general nonlinear three-axis slewing maneuvers for flexible spacecraft. The approach developed here is to find the optimal solution for the rigid body model, and then to apply this open-loop rigid body optimal control to fully flexible spacecraft with a perturbation feedback controller. The perturbation feedback controller controls several flexible modes in addition to the rigid body modes, and the feedback gains are computed using the flexible plant linearized about the rigid body nominal solution at several points along the maneuver (ref. 2).

- **Use a rigid body nominal solution for the open–loop maneuver**
  - **Compute single–axis starting guess**
  - **Apply continuation method**
- **Use a closed–loop perturbation feedback for vibration suppression**
  - **Linearize flexible plant about nominal solution**
  - **Compute perturbation gains**
  - **Interpolate gains between time–points**
- **Control smoothing**

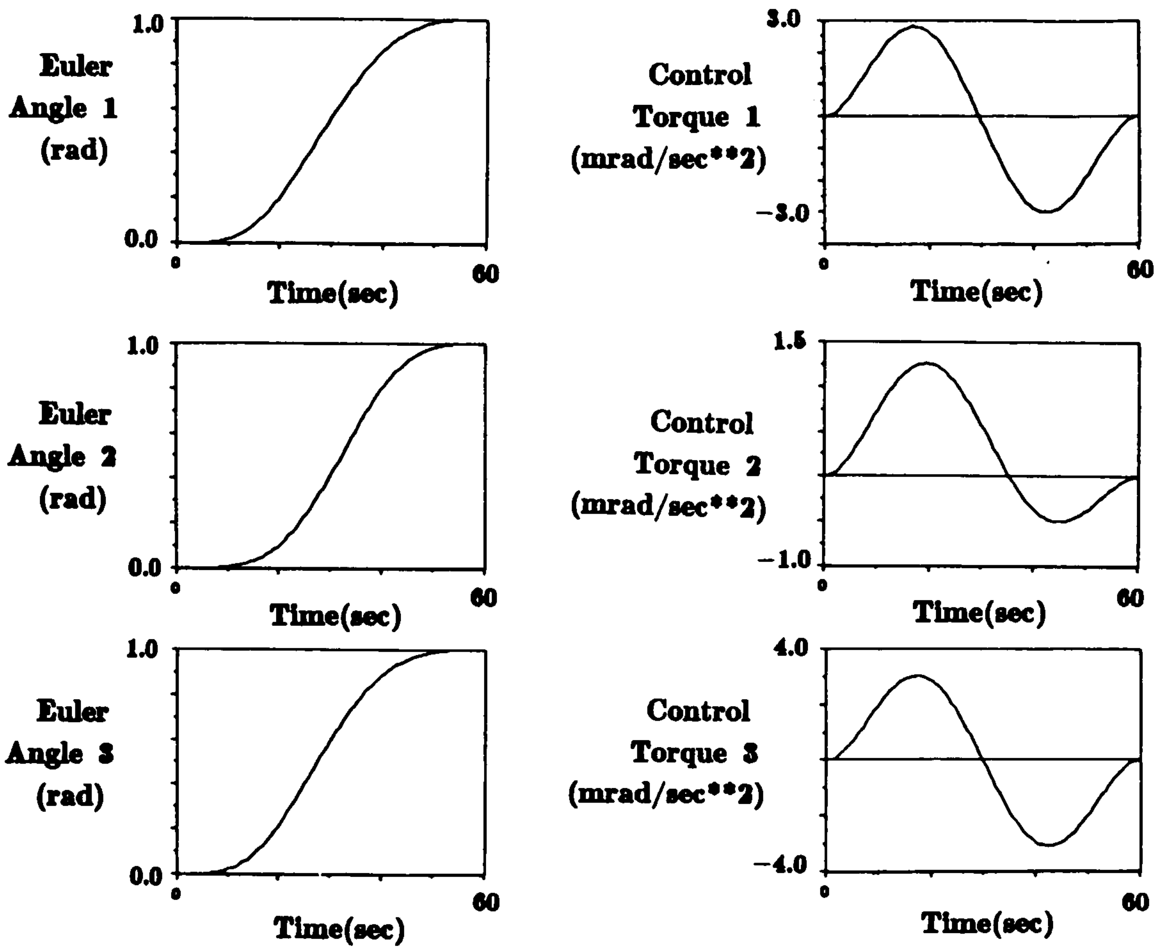
RADIOMETER SPACECRAFT MODEL

The spacecraft model used for the example maneuvers is based on a satellite model similar to the N-ROSS satellite, which consists of a more or less rigid bus and several flexible appendages including radiometer and solar array. The spacecraft bus is assumed to be rigid in this study, whereas the radiometer and the solar array are assumed to be flexible. The flexible appendages are each assumed to have five elastic degrees of freedom, and 0.1% damping.



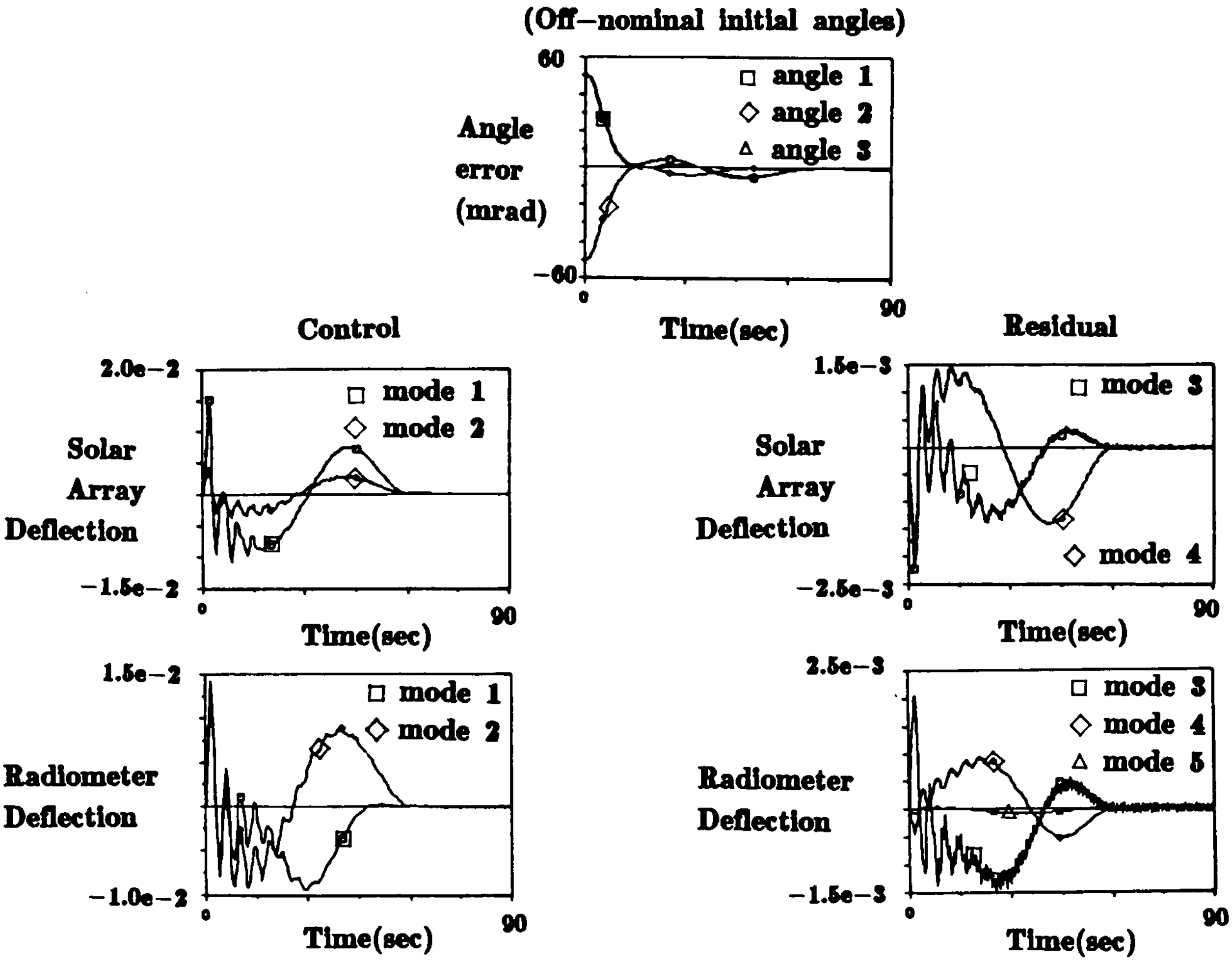
EXAMPLE MANEUVER - RIGID-BODY NOMINAL SOLUTION

A 60 second rest-to-rest maneuver with angular displacement of 1 radian about each axis was simulated. The break frequency is chosen to be $2\pi/60$ rad/sec. For the choice of this break frequency, the resulting maneuver had controls with smooth profiles.



EXAMPLE MANEUVER - PERTURBATION FEEDBACK

The 60 second rest-to-rest maneuver with angular displacement of 1 radian about each axis was simulated. The flexible plant was linearized about the rigid body nominal solution at 12 second intervals. The two lowest solar array modes and the two lowest radiometer modes were chosen for inclusion in the feedback formulation. The other higher frequency modes represent residual modes. All modes are assumed to have 0.1% damping. The break frequency for the perturbation controller was chosen to be half the frequency of the highest controlled mode, so as to minimize the excitation of the residual modes. The error in the initial angle is chosen to be 5% of the total angular displacement about each Euler axis. The controlled modal amplitudes and residual amplitudes are plotted separately. All the modal amplitudes are very small by the end of the maneuver.



CONCLUDING REMARKS

- **Fast three–body slewing maneuvers with vibration suppression have been successfully demonstrated for flexible structures.**

- **Nonlinear three–axis maneuvers for large flexible systems are developed and numerically tested.**

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