N89-13469

SLEWING AND VIBRATION CONTROL OF THE SCOLE

JIGUAN GENE LIN

CONTROL RESEARCH CORPORATION
LEXINGTON, MA 02173

OUTLINE

I. INTRODUCTION

II. STRUCTURAL VIBRATIONS IN SCOLE EXCITED BY **TIME-MINIMIZED RAPID SLEWING**

-- BANG-PAUSE-BANG (BPB) CONTROL (800 LB)

-- BANG-BANG (BB) CONTROL (0, 80, 25 LBS)

HOW BAD? ALWAYS THAT BAD?

NO FORCE MEANS LEAST EXCITATION?

III. ACTIVE DAMPING OF BPB-EXCITED VIBRATIONS USING **HIGH-PERFORAMANCE MODAL DASHPOTS**

DIRECT VELOCITY OUTPUT FEEDBACK REALLY CANNOT CONTROL EXCESSIVE VIBRATIONS EFFECTIVELY, QUICKLY?

IV. COMMENTS

V. CONCLUSIONS

VI. RECOMMENDATIONS

- SCOLE PRIMARY CONTROL TASK IS:

  RAPIDLY SLEW OR CHANGE THE LINE-OF-SIGHT (LOS), AND

  SETTLE OR DAMP STRUCTURAL VIBRATIONS TO A REQUIRED DEGREE

- THE OBJECTIVE IS:

  MINIMIZE THE TIME REQUIRED TO SLEW AND SETTLE,

  UNTIL LOS REMAINS WITHIN A SPECIFIED ANGLE.

- 2-STAGE APPROACH:

  FIRST: SLEW THE WHOLE STRUCTURE LIKE A RIGID BODY,

  -- IN A MINIMUM TIME,

  -- UNDER THE LIMITED CONTROL MOMENTS AND FORCES

  THEN: DAMP THE EXCITED STRUCTURAL VIBRATIONS

- SOME PREVIOUS RESULTS ON STAGE-1 DESIGN

CASE	STRATEGY (LB-FT) →	MOMENT (LB) →	FORCE (DEG) →	LOS ERROR (SEC) →	SLEW TIME
F10	BB	10,000	0	.150	12.604
F11	**BPB**	**10,000**	**800**	**.086**	**4.892**
F12	BB	10,000	800	.097	3.756

- OBJECTIVE OF CURRENT STUDY

  STAGE-2 DESIGN: ACTIVE CONTROL OF EXCITED VIBRATIONS

Structural Vibrations Excited by
Bang-Bang-Type Rapid Slew Maneuvers

Force (lb)	Moment (lb-ft)	Strategy (sec)	Slew Time (sec)	LOS Error (deg)	Deflect. (ft)	Att. Dev. (deg)
800	10,000	.867 (B) 3.158 (P) .867(-B)	4.892 (Note 1)	89.8 or 133.3	+114 -113	+88.35 -86.96
0	same	6.307 (B) 6.307(-B)	12.614	6.25	+5.06 -5.18	+3.83 -4.02
80	same	4.416 (B) 4.416(-B)	8.832	24.7	+20.59 -10.83	+15.98 -8.31
25	same	5.479 (B) 5.479(-B)	10.959	0.51	+0.25 -0.30	+0.16 -0.30

Note 1. Time of application is 1.734 sec, only 35.32% of the slew time.

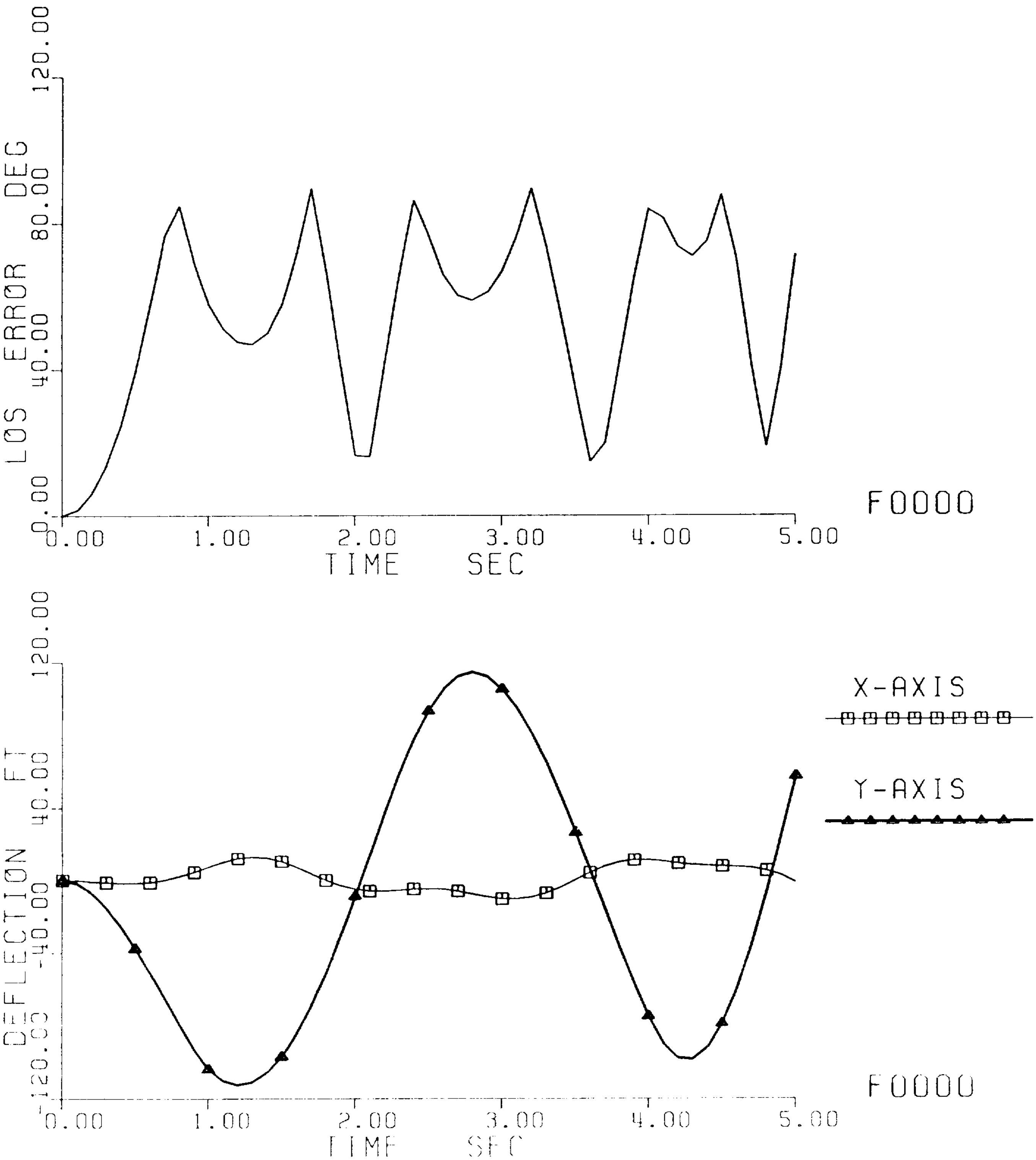


Fig. 3-1 Vibratory responses to Rapid Time-minimized Bang-Pause-Bang Slew;
a. Line-of-sight error and Mast tip deflection.

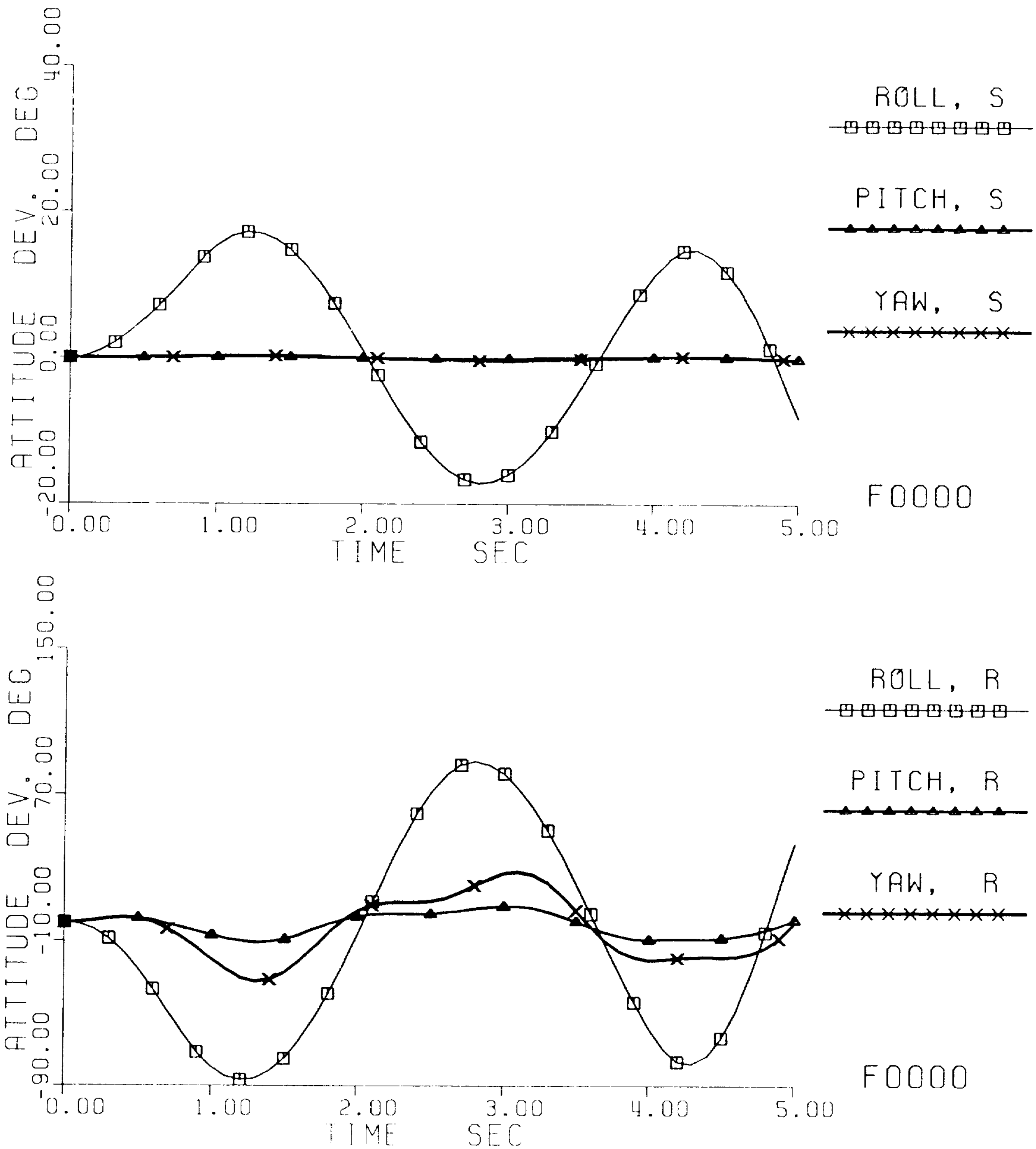
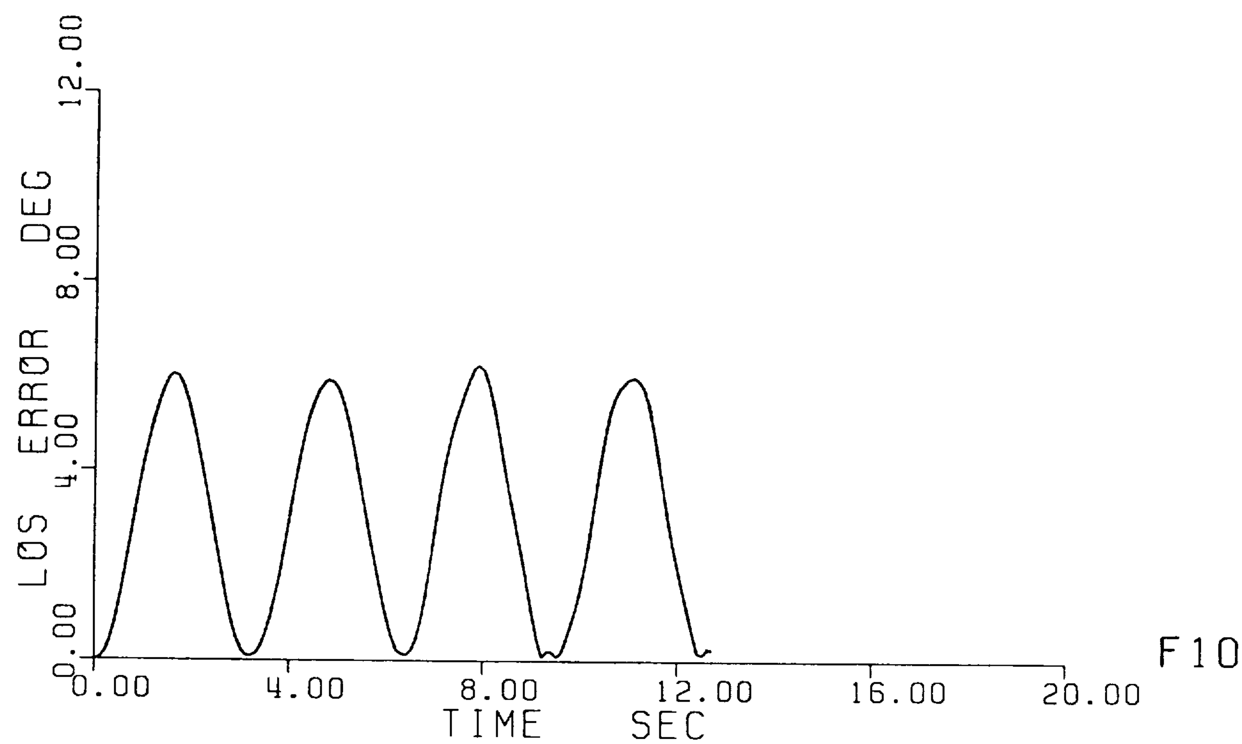


Fig. 3-1 Vibratory responses to Rapid Time-minimized Bang-Pause-Bang Slew;
b. Attitude deviations at the Shuttle (S) and the Reflector (R) ends.



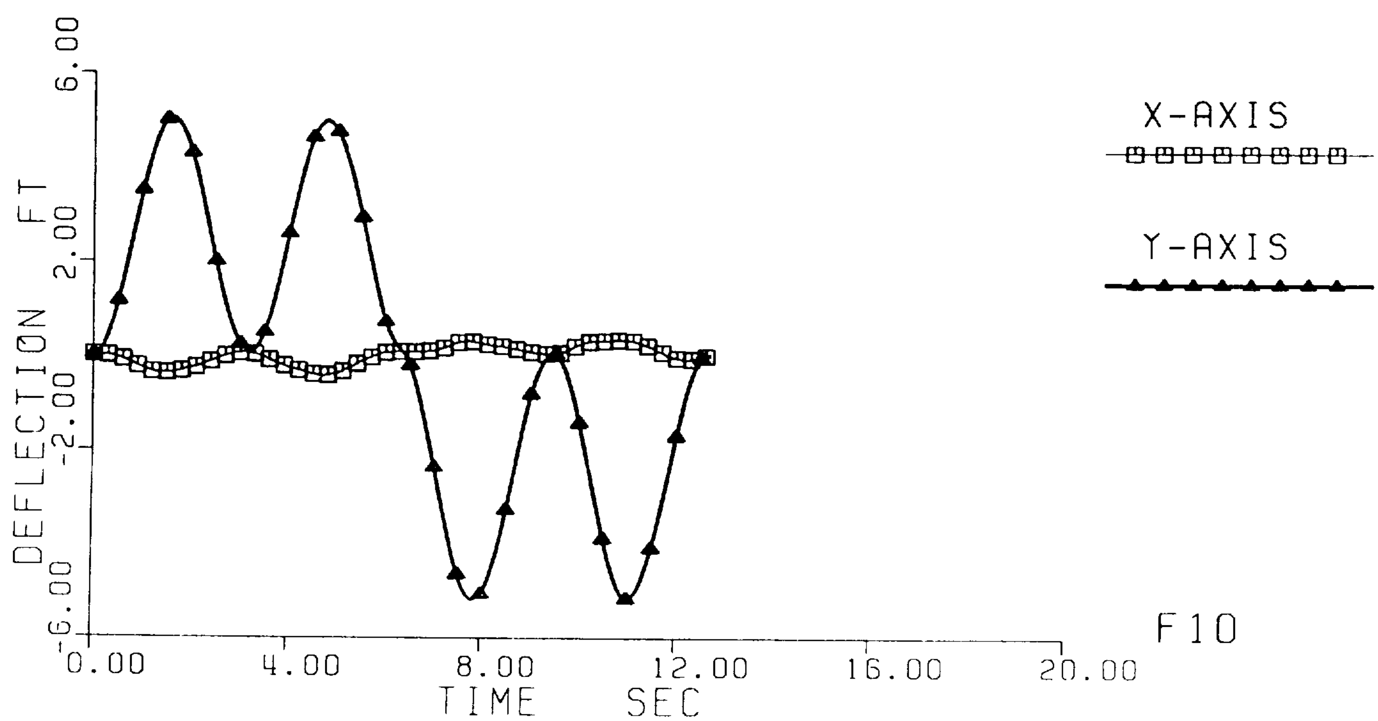


Fig. 3-2 Vibratory responses to Rapid Time-minimized Bang-Bang Slew: 0 lb;
a. Line-of-sight error and Mast tip deflection.

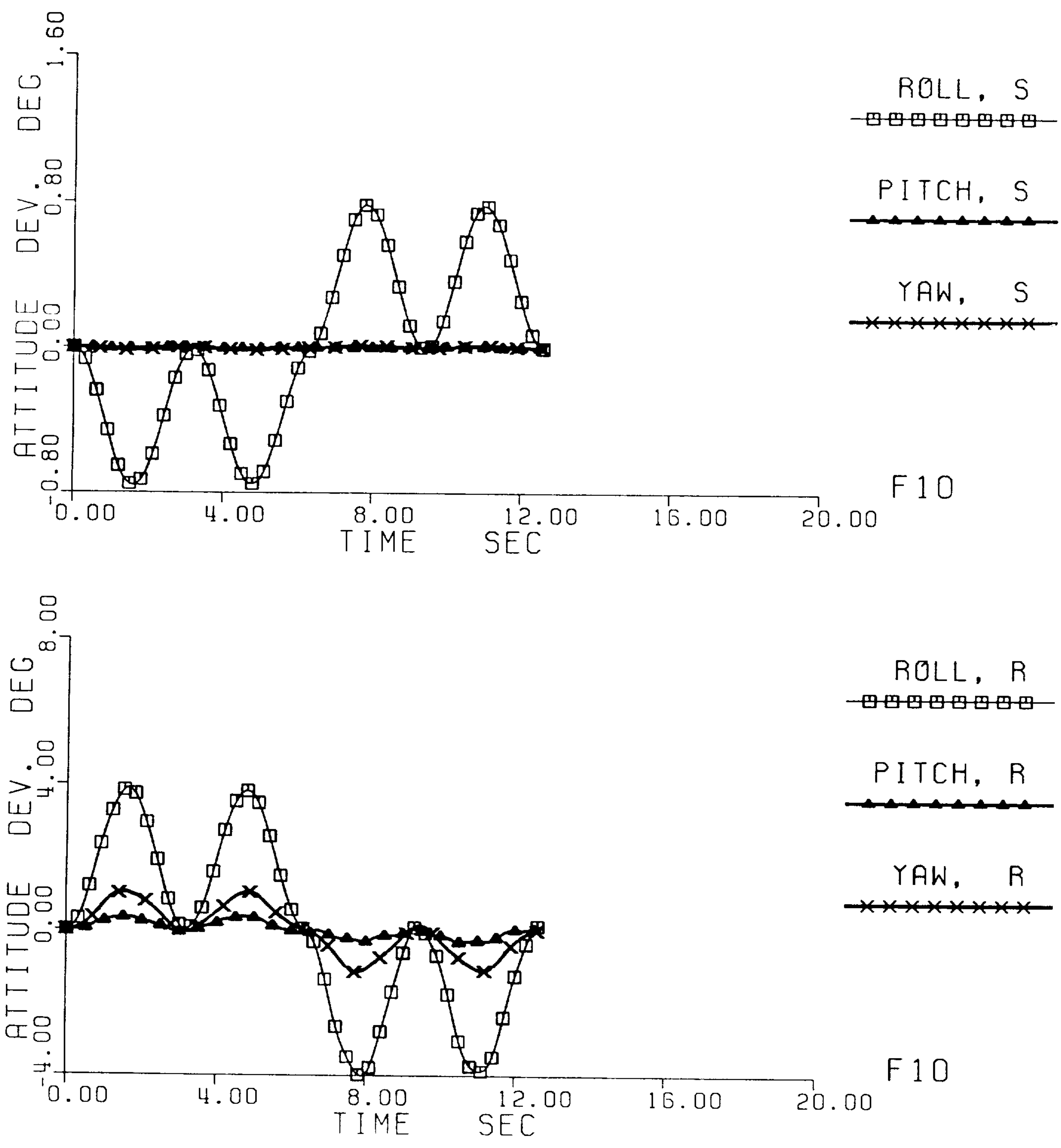


Fig. 3-2 Vibratory responses to Rapid Time-minimized Bang-Bang Slew: 0 lb;
b. Attitude deviations at the Shuttle (S) and the Reflector (R) ends.

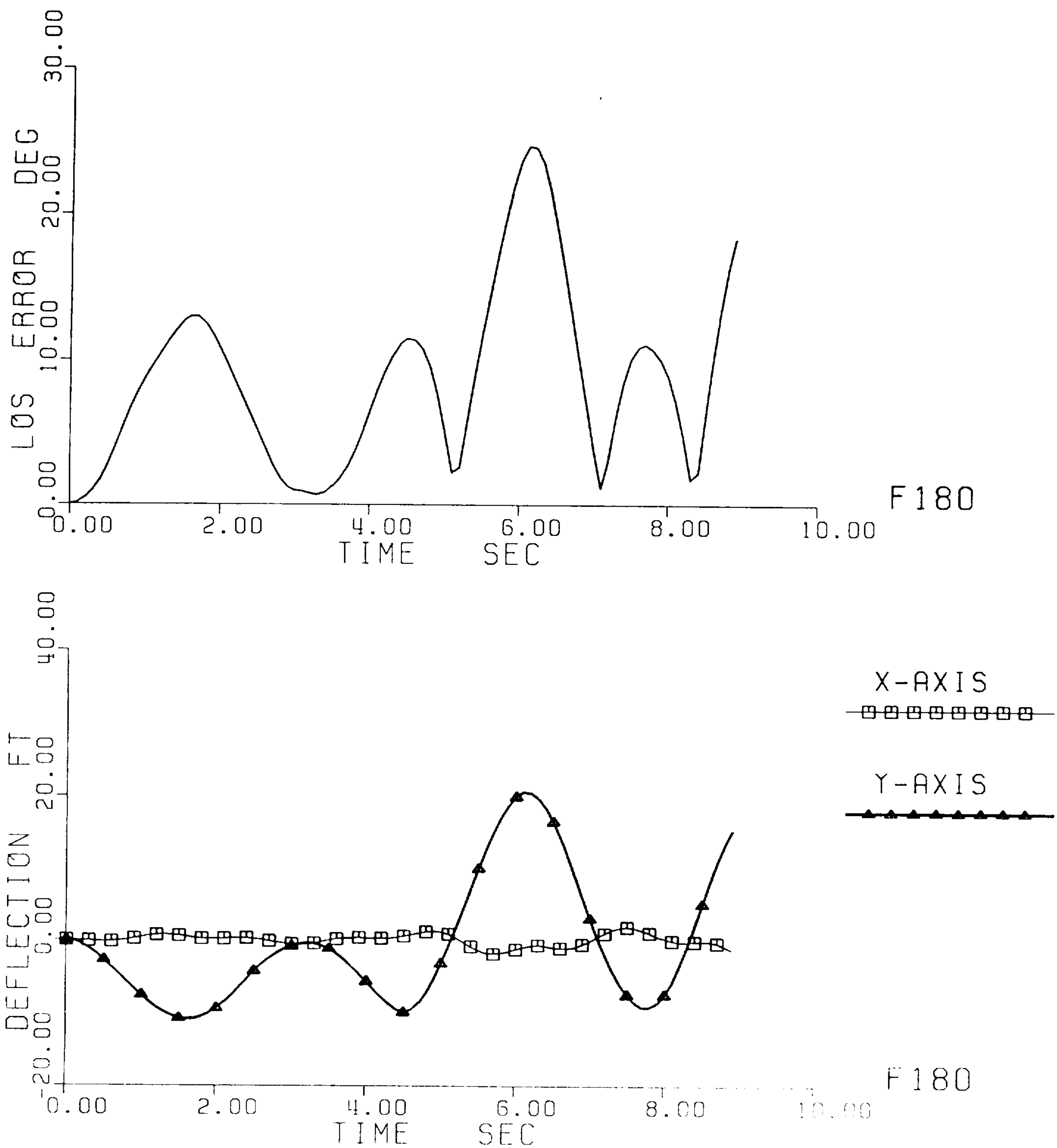


Fig. 3-3 Vibratory responses to Rapid Time-minimized Bang-Bang Slew: 80 lb;
a. Line-of-sight error and Mast tip deflection.

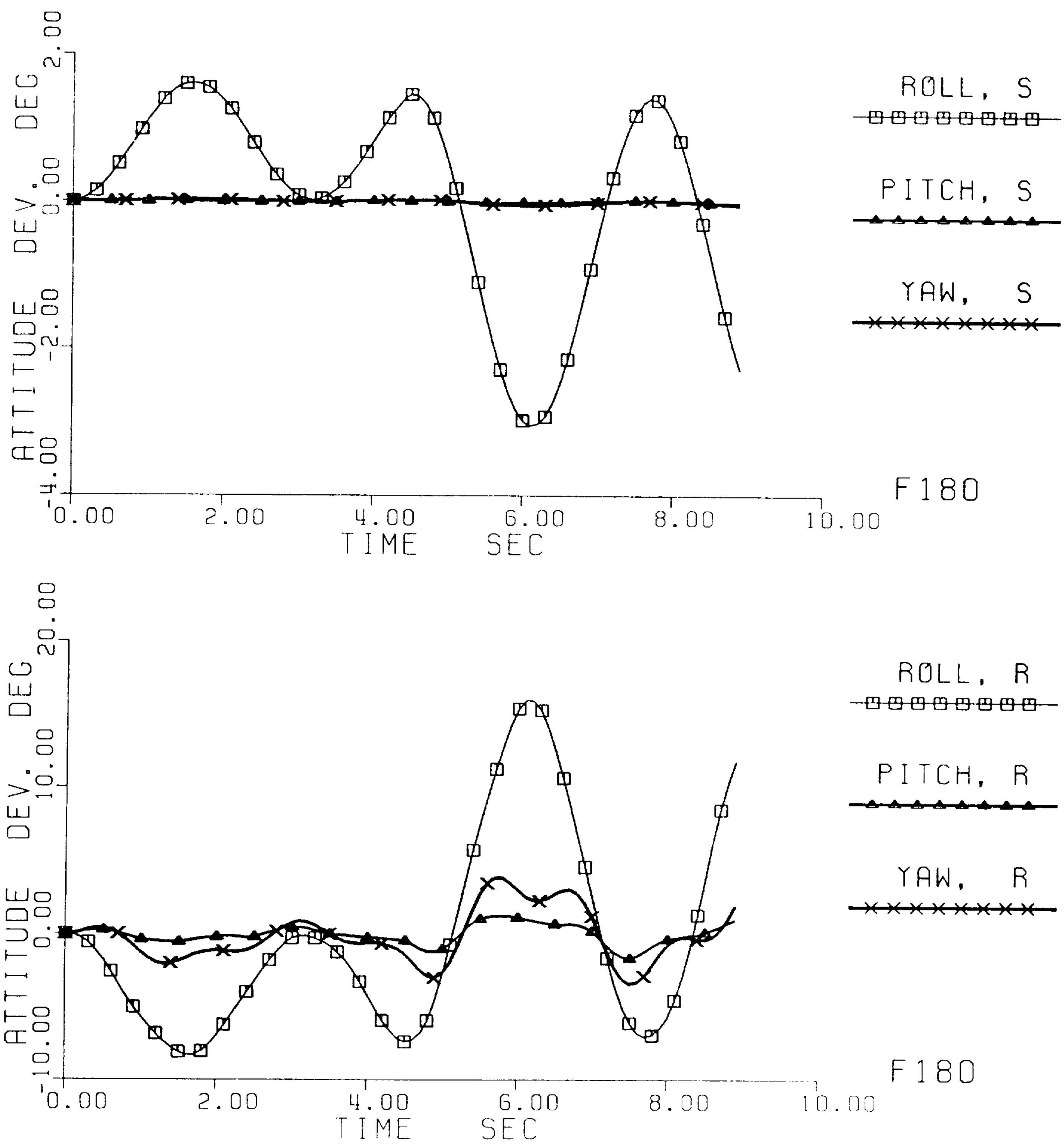


Fig. 3-3 Vibratory responses to Rapid Time-minimized Bang-Bang Slew: 80 lb;
b. Attitude deviations at the Shuttle (S) and the Reflector (R) ends.

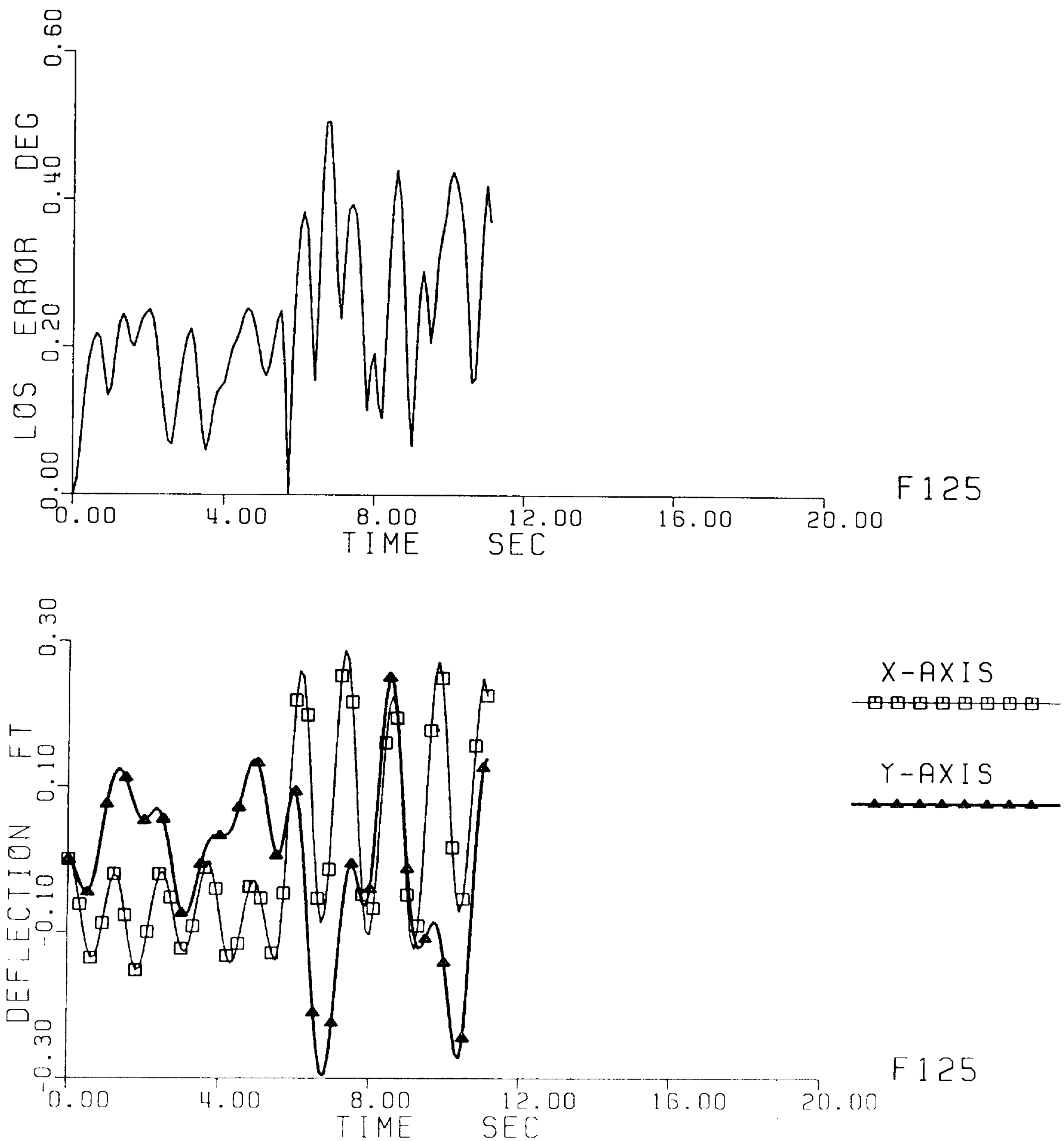


Fig. 3-4 Vibratory responses to Rapid Time-minimized Bang-Bang Slew: 25 lb;
a. Line-of-sight error and Mast tip deflection.

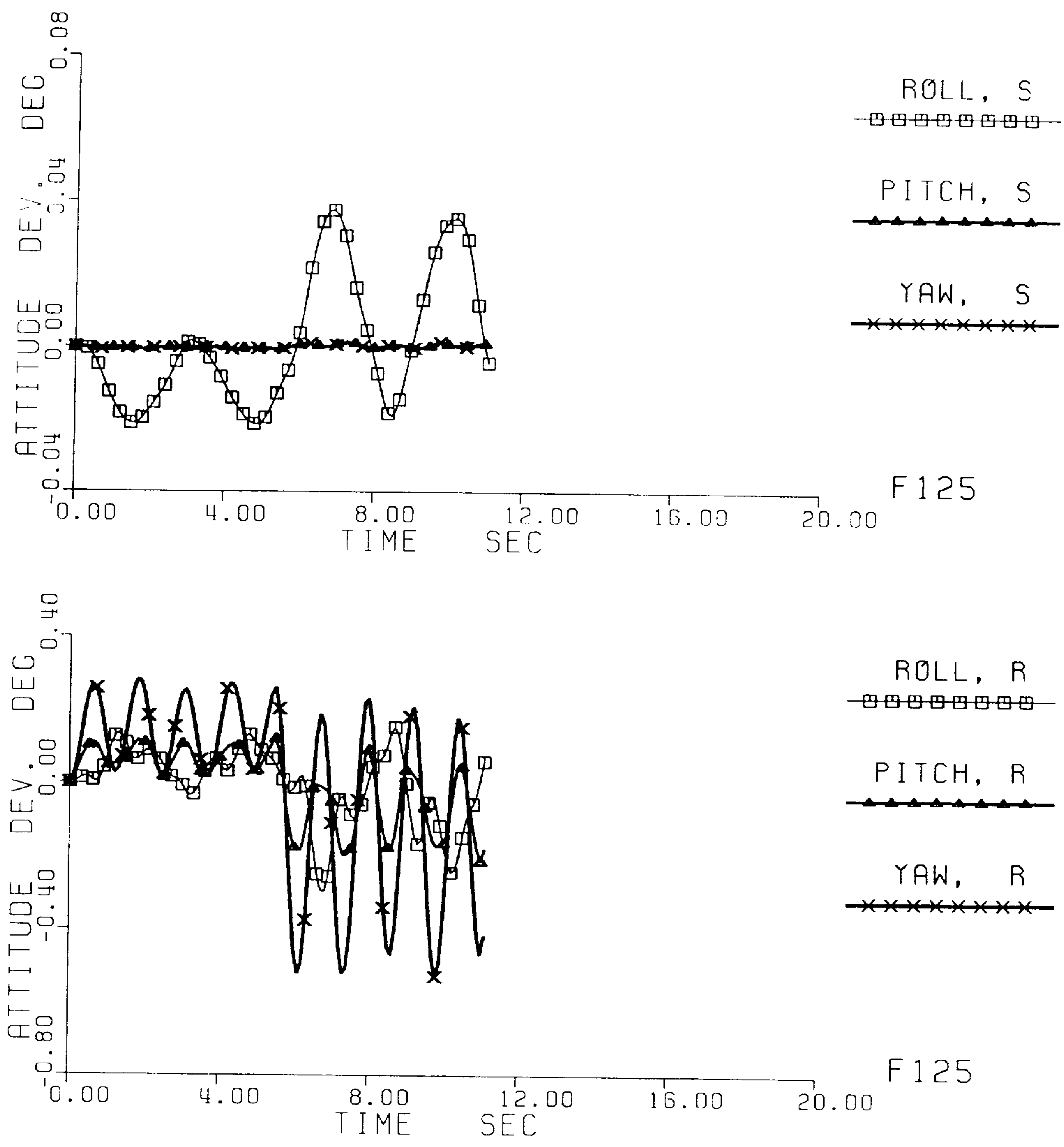


Fig. 3-4 Vibratory responses to Rapid Time-minimized Bang-Bang Slew: 25 lb;
b. Attitude deviations at the Shuttle (S) and the Reflector (R) ends.

- Using no forces on Reflector DOES NOT mean least excitation!

- If LOS error is the only concern, Stop using 800lb force;
  Use 25lb (Vernier thruster level) instead.
  -- But time is equally important!!!

- Additional time of various length is still required
  for damping out the excited vibrations.

- **VIBRATION CONTROL CHALLENGE:**

Can excessive vibrations,
such as excited by the 800lb rapid slewing,
be effectively suppressed to a reasonable level
quickly, say, in 5 sec?

MODAL-DASHPOT DESIGN MD1

PART 1: LINEAR VELOCITY FEEDBACK

$$\begin{bmatrix} U_7 \\ U_8 \end{bmatrix} = -\,G_{LVR} \begin{bmatrix} Y_{15} \\ Y_{16} \end{bmatrix}$$

$$\begin{bmatrix} U_7 \\ U_8 \end{bmatrix} = F_4 = \begin{bmatrix} \text{APPLIED FORCE ON REFLECTOR IN } \mathbf{X}\text{-}\mathbf{DIRECTION} \\ \text{APPLIED FORCE ON REFLECTOR IN } \mathbf{Y}\text{-}\mathbf{DIRECTION} \end{bmatrix}$$

$$\begin{bmatrix} Y_{15} \\ Y_{16} \end{bmatrix} = \begin{bmatrix} \text{RATE OF } \mathbf{XZ}\text{-DEFLECTION AT REFLECTOR END} \\ \text{RATE OF } \mathbf{YZ}\text{-DEFLECTION AT REFLECTOR END} \end{bmatrix}$$

$$G_{LVR} = \begin{bmatrix} .58420630E{+}01 & .43392044E{+}00 \\ .42038249E{+}00 & .69796355E{+}01 \end{bmatrix}$$

ADDITIONAL DAMPING RATIO DESIGNED = 0.6737, MODE 2

= 0.6, MODE 1

2% SETTLING TIME OF 3 SEC IS DESIGNED FOR MODE 2

Part 2: Angular Velocity Feedback

$$\begin{bmatrix} U_4 \\ U_5 \\ U_6 \end{bmatrix} = - G_{AVR} \begin{bmatrix} Y_{10} \\ Y_{11} \\ Y_{12} \end{bmatrix}$$

$$\begin{bmatrix} U_4 \\ U_5 \\ U_6 \end{bmatrix} = M_4 = \begin{bmatrix} \text{applied moment on Reflector about } \mathbf{X\text{-axis}} \\ \text{applied moment on Reflector about } \mathbf{Y\text{-axis}} \\ \text{applied moment on Reflector about } \mathbf{Z\text{-axis}} \end{bmatrix}$$

$$\begin{bmatrix} Y_{10} \\ Y_{11} \\ Y_{12} \end{bmatrix} = \begin{bmatrix} \text{rate of Reflector } \mathbf{Roll} \text{ attitude deviation} \\ \text{rate of Reflector } \mathbf{Pitch} \text{ attitude deviation} \\ \text{rate of Reflector } \mathbf{Yaw} \text{ attitude deviation} \end{bmatrix}$$

$$G_{AVR} = \begin{bmatrix} .24172707E+04 & .16653096E+03 & .45158162E+03 \\ .15734103E+03 & .21781213E+04 & -.72768193E+03 \\ .13433660E+04 & -.22055215E+04 & .42951681E+04 \end{bmatrix}$$

Additional damping ratio designed = 0.03, Modes 3,4,5

Inherent damping ratio assumed = 0.003 all modes

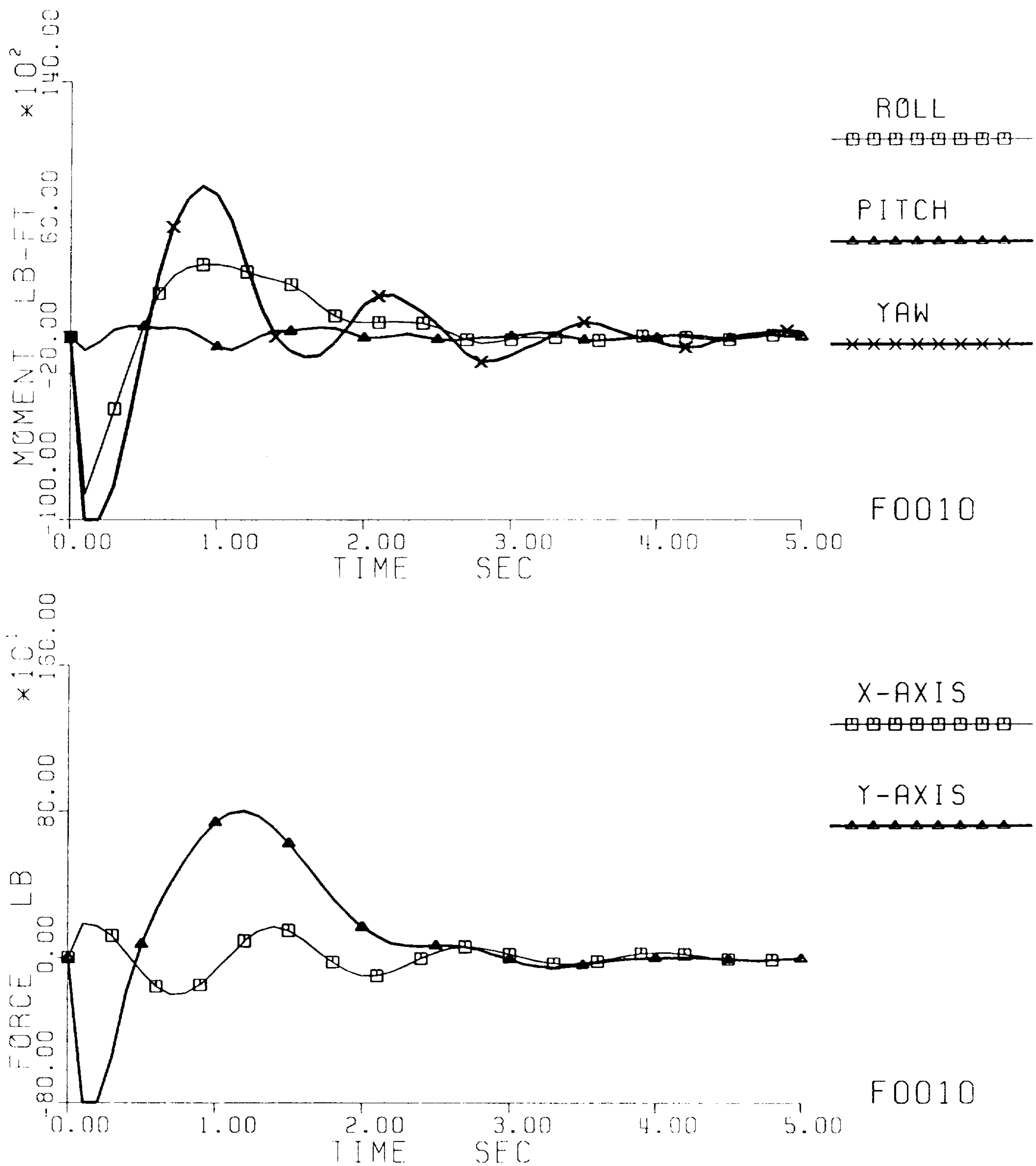


Fig. 6-1 Simulation results of vibration control design MD1;
a. Histories of applied moments and forces at the Reflector.

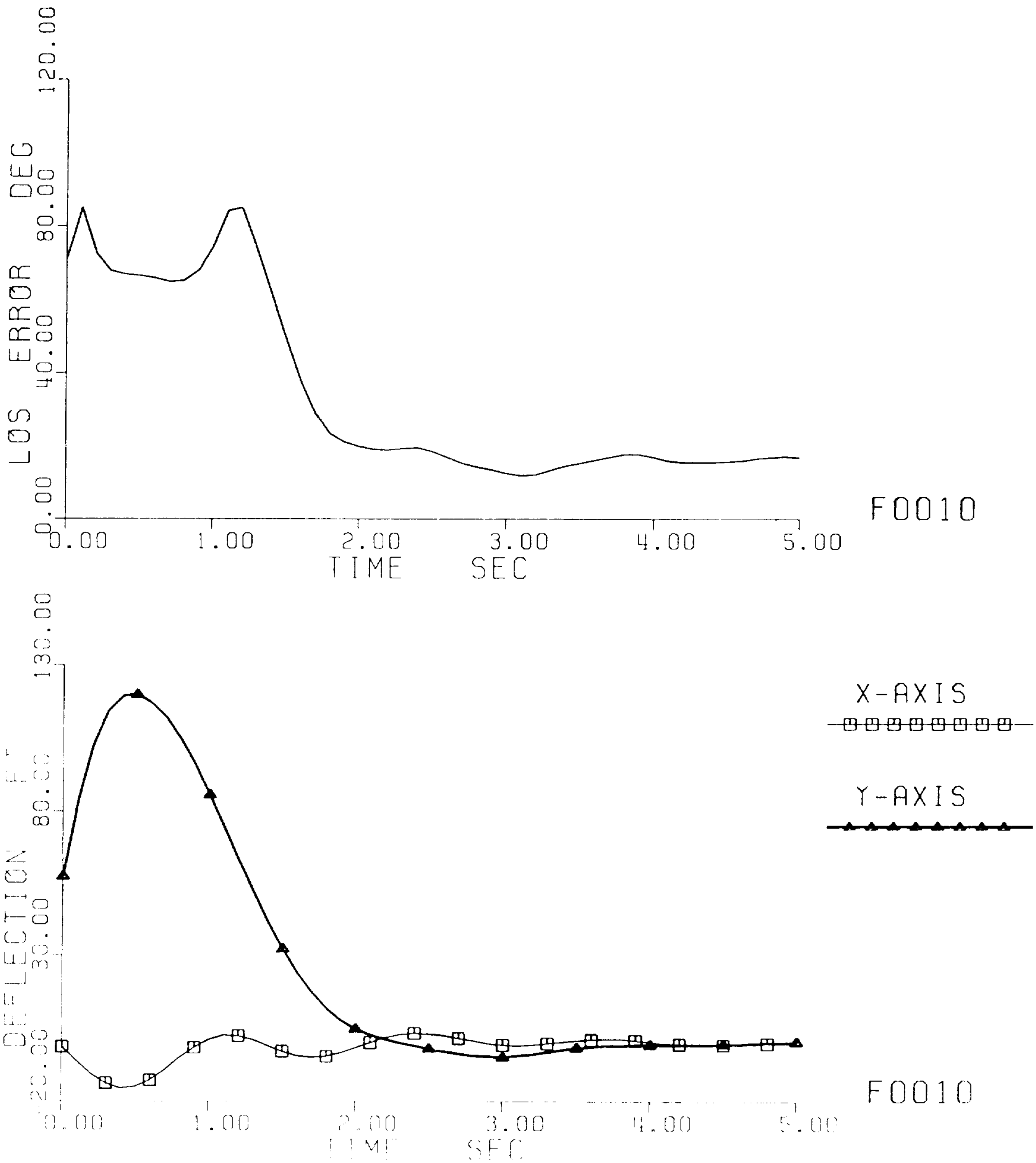


Fig. 6-1 Simulation results of vibration control design MD1;
b. Histories of line-of-sight error and Mast tip deflection.

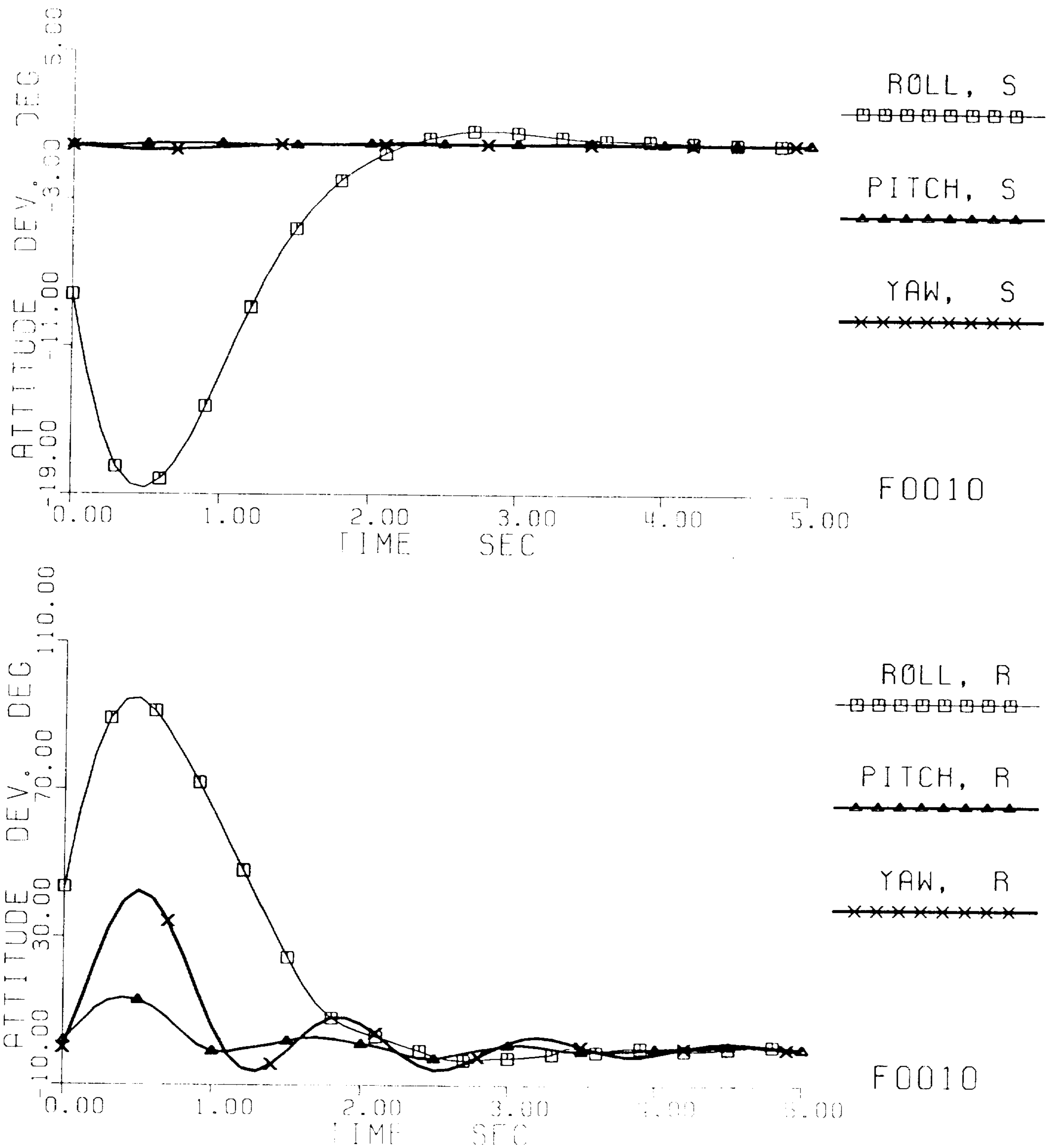


Fig. 6-1 Simulation results of vibration control design MD1;
c. Histories of attitude deviations at Shuttle (S) and Reflector (R) ends

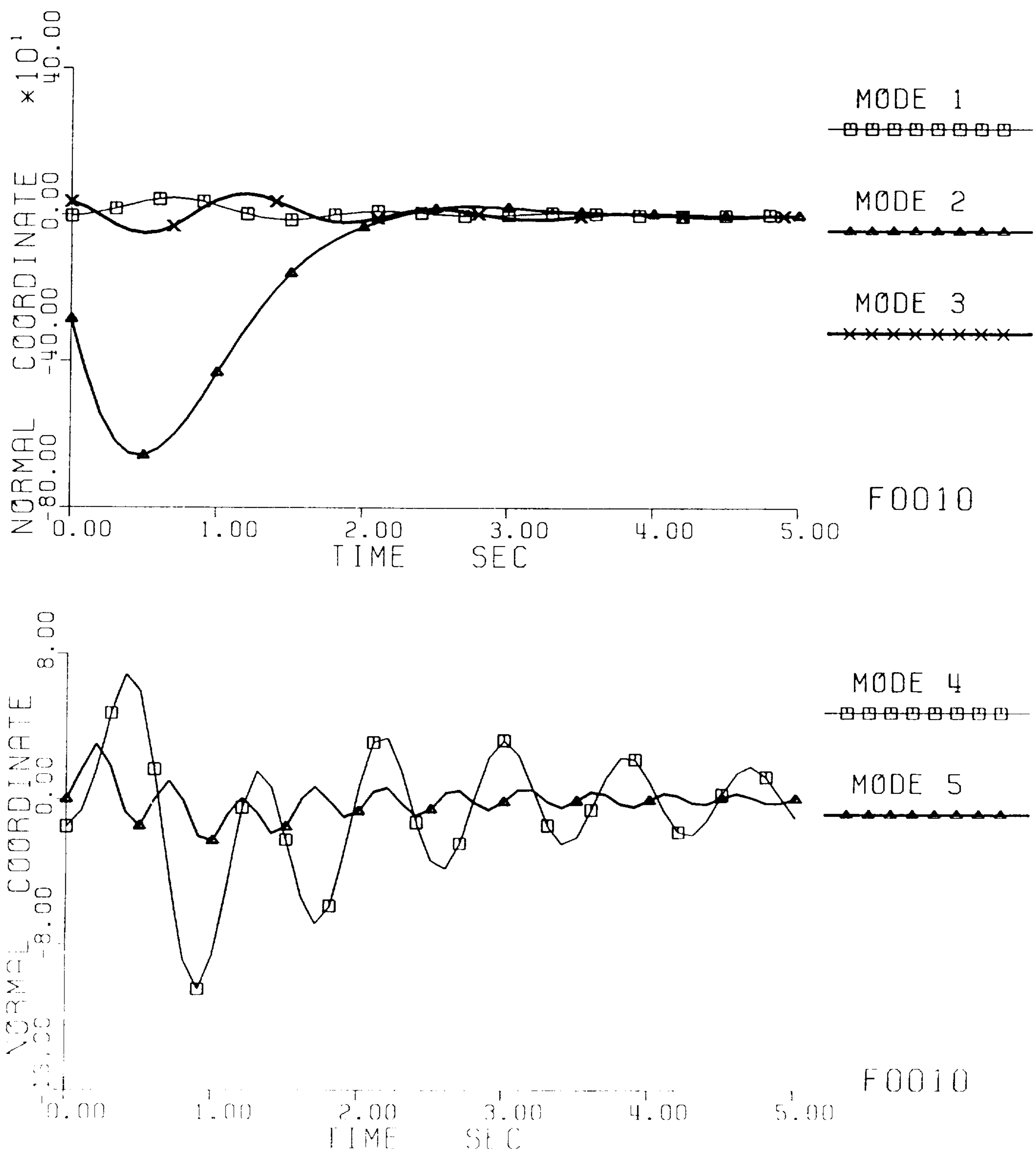


Fig. 6-1 Simulation results of vibration control design MD1;
d. Histories of normal coordinates of the 10 modes.

SUMMARY -- MD1

LOS ERROR $< 18.46^{0}$ $T = 2.5$ SEC

$< 17.46^{0}$ $T > 2.5$ SEC

$\doteq 11.79^{0}$ $T = 3.1$ SEC

DEFLECTION $\leq \pm 5$ FT $T \doteq 2$ SEC

$\leq \pm 0.5$ FT $T = 4.2$ SEC

2% SETTLING TIME ≤ 2.9 SEC

LAST PEAK REFLECTOR ATTITUDE DEVIATION:

ROLL $\doteq 0.460^{0}$

PITCH $\doteq 0.546^{0}$

YAW $\doteq 1.360^{0}$

SUMMARY -- **MD1A**

ADDITIONAL DAMPING RATIO RE-DESIGNED = 0.6, MODE 2
CORRESPONDING 2% SETTLING TIME FOR MODE 2 IS 3.38 SEC

$$G_{LVR} = \begin{bmatrix} .58420557E+01 & .45784262E+00 \\ .42061494E+00 & .62209375E+01 \end{bmatrix}$$

LOS ERROR $\leq$ 16.66^{0} (↓) $T \geq 1.8$ SEC

$\doteq$ 9.57^{0} (↓) $T = 3.1$ SEC

DEFLECTION $\leq$ $\pm$ 7.35 FT (↑) $T = 1.3$ SEC

$\leq$ $\pm$ 0.75 FT (↑) $T = 3.7$ SEC

2% SETTLING TIME $\doteq$ 3 SEC

LAST PEAK REFLECTOR ATTITUDE DEVIATION:

ROLL $\doteq 0.714^{0}$ (↑)

PITCH $\doteq 0.582^{0}$

YAW $\doteq 1.399^{0}$

COMMENTS

- THE MODAL DASHPOT DESIGN MET THE VIBRATION CONTROL CHALLENGE FAIRLY WELL: **EFFECTIVE, FAST SUPPRESSION OF EXCESSIVE VIBRATIONS**

- FOR COMPLETE SUPPRESSION AND PRECISION POINTING AFTER THE QUICK SUPPRESSION,

  EITHER: INCREASE THE MODAL DASHPOT FEEDBACK GAINS

  OR: SWITCH TO INTEGRATED DESIGN OF **LQG/LTR** AND **MODAL DASHPOTS**

- DIRECT VELOCITY OUTPUT FEEDBACK CONTROLLERS NEED NOT BE OF "LOW AUTHORITY", LOW PERFORMANCE.

  -- ADDITIONAL DAMPING RATIO CAN BE DESIGNED TO BE AS HIGH AS TO THE OPTIMAL VALUE 0.707, IF NEACESSARY; INSTEAD OF RESTRICTING TO ONLY ABOUT 0.1

- NO MORE HIGH-GAIN PROBLEMS OF ORIGINAL CANAVIN DEDIGN

- SPILLOVER IS MINIMAL: PERFORMANCE DEGRADATION UN-NOTICEABLE

  SPILLOVER IS BENEFICIAL: CONCOMITANT ACTIVE DAMPING OF UNMODELED MODES

- SYSTEMATIC DESIGN METHOD FOR MODAL DASHPOTS WORKS!

CONCLUSIONS

- 2-STAGE APPROACH IS FEASIBLE AND PROMISING FOR RAPID SLEWING AND PRECISION POINTING OF SCOLE

- NOT ALL BANG-BANG TYPE OF TIME-MINIMIZED SLEW MANEUVERS WILL EXCITE LARGE STRUCTURAL VIBRATIONS IN SCOLE

- MODAL DASHPOTS CAN BE A CONCENTRATED HIGH-POWER VIBRATION CONTROL, AS WELL AS THE USUAL
  DIFFUSE ("BROAD-BAND"), LOW-POWER ("LOW-AUTHORITY") CONTROL

RECOMMENDATIONS

- LIMIT THE MAGNITUDE OF APPLIED FORCES ON REFLECTOR TO
  EITHER 25 LB
  -- LEVEL OF VERNIER THRUSTERS ON THE REAL SPACE SHUTTLE
  OR 150 LB
  -- LEVEL EQUIVALENT TO THE COLD-GAS JETS OF LABORATORY SCOLE

- TO COMPLETE STAGE 2, ADD AN INTEGRATED DESIGN OF
  LQG/LTR (LINEAR-QUADRATIC-GAUSSIAN/LOOP-TRANSFER-RECOVERY)
  AND **MODAL DASHPOTS**

- VALIDATE THE 2-STAGE APPROACH USING THE SCOLE LABORATORY FACILITY WITH A COMPREHENSIVE SEQUENCE OF INTEGRATED DESIGNS AND EXPERIMENTS COUPLING NONLINEAR RIGID-BODY MOTIONS WITH FLEXIBLE-BODY DYNAMICS