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TECHNICAL REPORT RL-76-11

## MULTIPLE ROCKET LAUNCHER CHARACTERISTICS AND SIMULATION TECHNIQUE

Dean E. Christensen  
Ground Equipment and Material Directorate  
US Army Missile Research, Development and Engineering Laboratory  
US Army Missile Command  
Redstone Arsenal, Alabama 35809

February 1976

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br><br>This report provides an insight into the mallaunch associated with multiple firings of free flight rockets from a mobile platform. The effects of resonance with the structure and firing rate are presented. As the mass of the load decreases (as rockets are fired), the launcher's structural frequency changes and passes through this resonant condition.<br><br>(Abstract continued) |                       |                                                             |

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(Abstract concluded)

An analog simulation program was developed to demonstrate this resonant condition. It is included in Appendix A. This program has been developed and is presented as a tool for future use. It will be useful in the development of a General Support Rocket System.

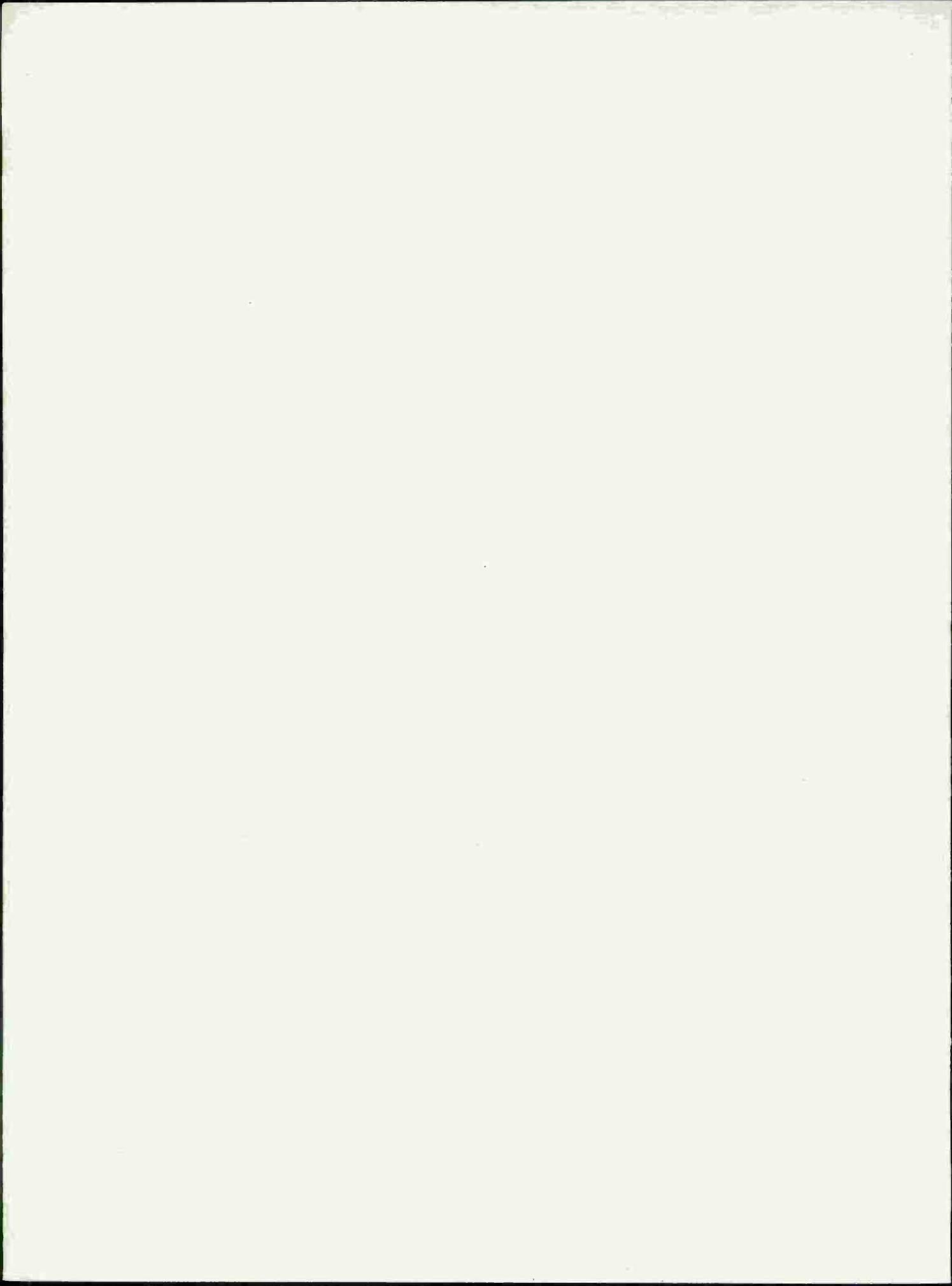
Curves presented show typical mallaunch values due to thrust misalignment and malaim magnitudes associated with multiple firings.

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## I. INTRODUCTION

The art of launching many free rockets from a single mobile platform dates into early history. As warfare progressed, the need for increased mobility became paramount. Light weight requirements dictated new launching approaches. In the past two decades many attempts have been made to define and quantitize impact errors associated with the launching and flight of free rockets. This report is another attempt to place this art into the realm of science.

Many arguments have been presented on ways to separate the dispersion error into those arising from launch versus those incurred during flight. This report will discuss and enumerate those errors which are known to arise during the launching sequence.

An analog simulation program is presented in Appendix A. This program only contains the pitch plane motions of the launcher and rockets, however provisions are included for yaw and roll. The forcing functions are thrust misalignment and exhaust gas impingement. The number of rockets to be fired and the number per row are selected along with a firing rate. Typical results obtained with this program are presented in Section III.

## II. DISCUSSION

Many factors effect the trajectory and impact dispersion of free rockets. There is a practical limit on how well many of these factors can be controlled during production. The cost of the rockets (which are the high density items in the system) rises rapidly as these factors are reduced. These factors include rocket static and dynamic mass unbalance, thrust alignment to the flight axis, and total impulse repeatability of the motors.

Other factors can be controlled in the design and fabrication of the launcher. These include the ability to aim, rocket to rocket alignment, launcher rigidity to fire rate compatibility, detent concept and release mechanism, hysteresis and structural damping, and the method used to induce spin to the rockets. Spin drive systems which require torques to be reacted through the launcher to the ground are an additional error source. Spin systems which utilize the rocket's exhaust gas allows more flexibility in the launcher design.

Figure 1 shows factors involved in the analysis and design of a launcher. Many models and simulations have been derived and performed to relate the inputs to the outputs.

Another factor which plays an important role in the accuracy of the system is the design philosophy of the rocket. From aerodynamic considerations, an optimum length to diameter ratio and a given spin rate are desirable. However, from a dynamic view, a long slender rocket presents problems by allowing flexible body modes to become significant, especially if high spin rates are required. While the rocket is constrained on the launcher body bending strain energy is stored in the rocket. This bending is produced by mass imbalance, rocket spin, thrust misalignment and mass set back forces. At launch or sometime during the flight, this energy is released and body bending vibration begins (Figure 2). The time at which this release of energy occurs will effect the trajectory and impact, especially if it occurs during the burning phase of the rocket motor. This phenomenon was first proposed in 1969. Early in 1975 the free flight rocket firings again raised the question of flexible body effect. Current work is progressing in this area.

Figure 3 is the system's engineering approach towards the design of a rocket/launcher combination which has been used for preliminary design. The basic design goals for a launcher are as follows:

- 1) Adequate base structure.
- 2) Proper trunnion locations.
- 3) Optimum stiffness, damping, inertias, and mass placements.
- 4) Adequate clearances to insure a clean launch.
- 5) Proper load balance to minimize aim changes.
- 6) Reloading access.
- 7) Adequate alignment and straightness of the launcher guidance device.
- 8) Proper type of launch device (rail, tube, etc.)
- 9) Minimize rocket induced launcher reactions.
- 10) Provide adequate launch attitudes and rates.

The simulation program described in Section III is a tool devised to assist in attaining some of these goals. The program relates launcher mass and stiffness to rocket exhaust, thrust misalignment, and firing rate.

### III. SIMULATION

An analog simulation for multiple rocket launching is being constructed. This report contains the work being accomplished in this effort. To date only the pitch plane motions have been modeled. The timing and forcing functions can be used for the inclusion of yaw and roll. The technique is the main object of study at this time. As

proposals for multiple rocket launchers become available, a tool for their comparison will be needed. Concepts will vary to such an extent that assumptions and approximations will always be required to fit any simulation program in existence. In some cases modifications to the model and/or program will be required. The only constant in the approach will be the basic techniques or building blocks. These are contained in Appendices A and B.

As in any analog simulation, the event timing is an important element. Digital logic has been utilized to complete this function and to control the analog components. An iterative "error feedback" approach has been used to uncouple the equations of motion. This technique evolved from some control system work performed by the author. Figure 4 shows the timing and logic used in the firing of one rocket. It is repeated for each rocket launched in the sequence. Case I is when the rocket is fully engaged on the launcher with two points of contact. Case II is the tip-off phase where the forward support is disengaged and the rear support engaged. Case III is the free flight portion of the trajectory of the previously fired missile, its position is recorded until the next rocket is fired.

A plotting routine was devised which allows for the recording of the missile rates and displacements at a given position in the flight trajectory. For the examples shown, this position was taken as the instant that the rearward support was released. Figures 5 through 7 depict these values. Figure 8 shows the launcher motion, and it is clearly evident where resonance build-up occurs. At this point the launch position shifts from one side of a cycle to another. This accounts for the general shape of the curves in Figures 4 through 8. Random thrust-misalignment accounts for the band of values for any given rocket in the sequence.

The most important features of this simulation program is that it runs in real time. The operator can select with thumb wheel settings the total number of rockets he wishes to fire, the number per row on the launcher, and the firing interval between rockets. The launcher and transport vehicles stiffness or natural frequency can be changed by turning a potentiometer dial. The analog program has considerably more flexibility than its digital counterpart. A digital solution to a multiple firing simulation would be impossible from economic considerations. Minutes of real time would be required to be tracked by numerical integration methods. The complexity of the differential equations requires these numerical solutions. The initial conditions for each rocket depend upon the end states of the previously fired round. Any attempt at a numerical solution will require several simplifying assumptions which will degrade the solution to questionable usefulness.

#### IV. CONCLUSIONS

Resonance can be expected to occur between the firing rate and the launcher's frequency at some time during the ripple launching of a complete load of rockets from a multiple launcher. This condition will add to the mallaunch and malaim of the rockets.

To eliminate or minimize this condition it is recommended that an investigation of the effects of a variable firing rate during a single ripple be conducted. This should be accomplished with an analog program which has been expanded to contain yaw. The basic building blocks for this program are contained in Appendices A and B.

# LAUNCHER ANALYSIS

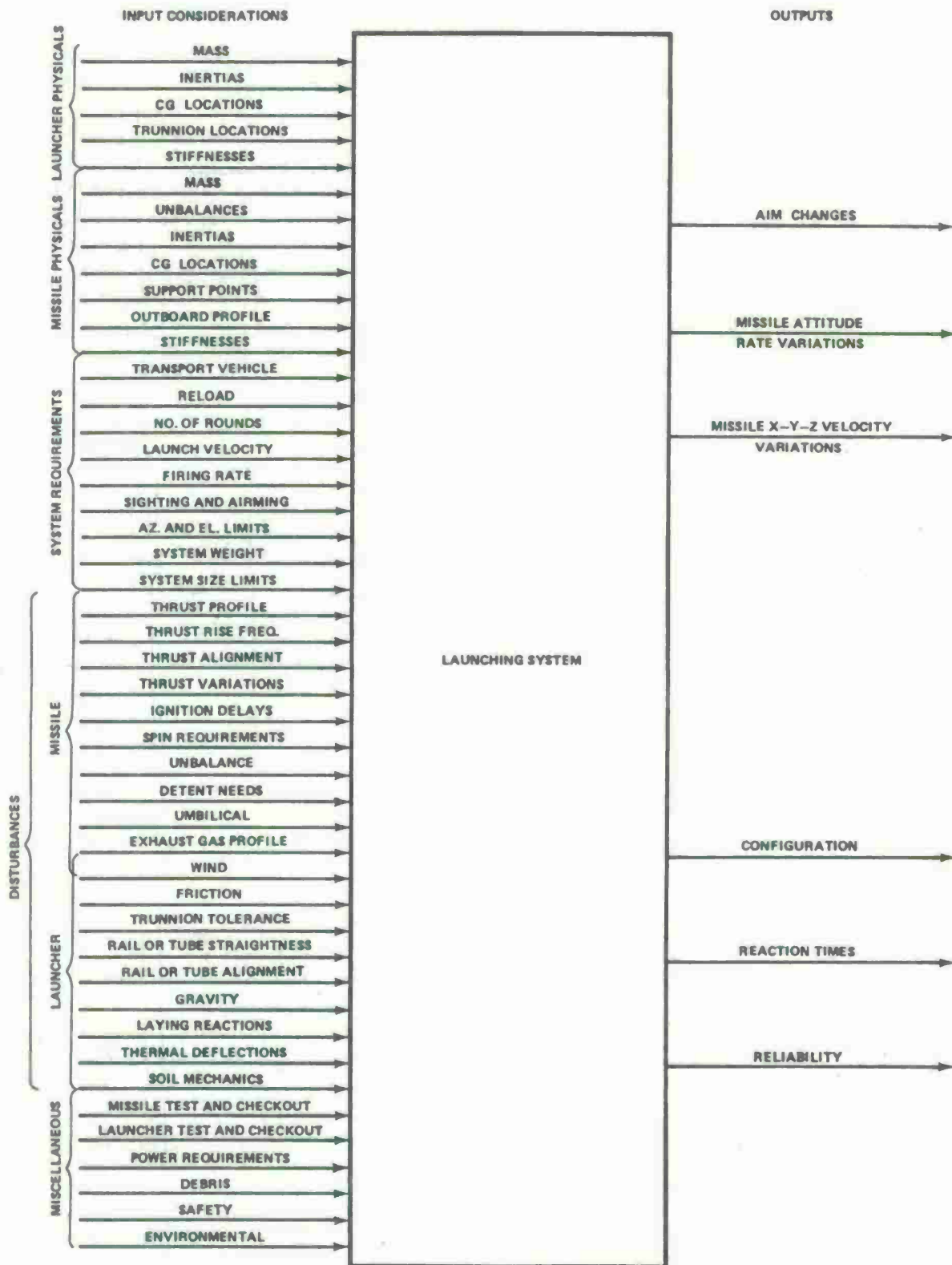
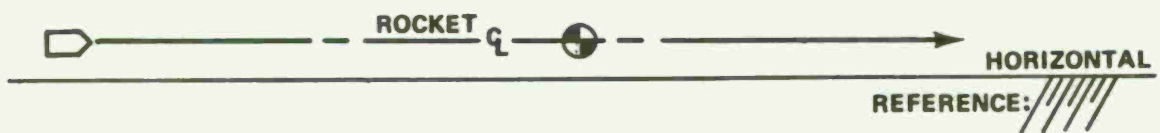
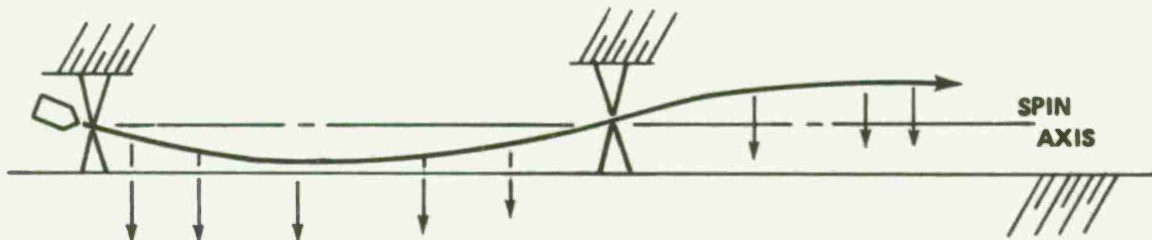


Figure 1. Launcher analysis.

**CASE 1. NO FORCES PRESENT**



**CASE 2. ALLOW GRAVITY TO ACT:  
TWO SUPPORT POINTS:**



**CASE 3. ADD THE CENTRIFUGAL FORCE DUE TO SPIN**

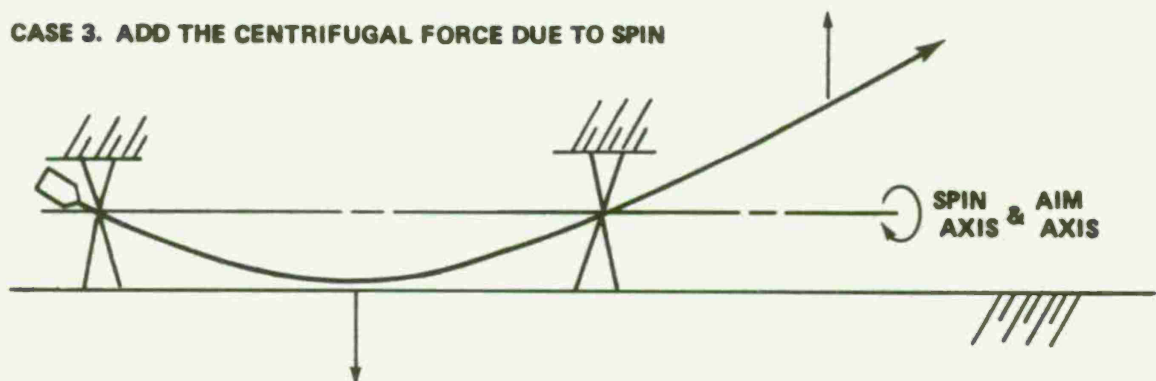
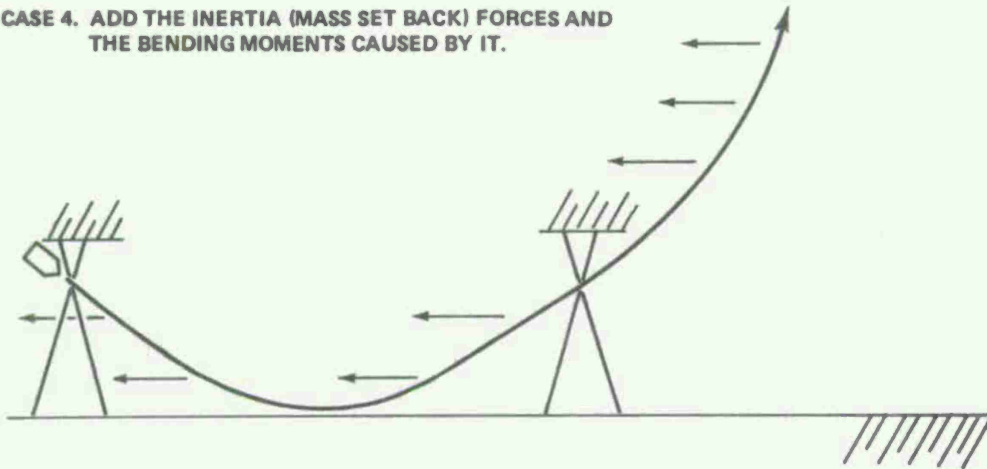
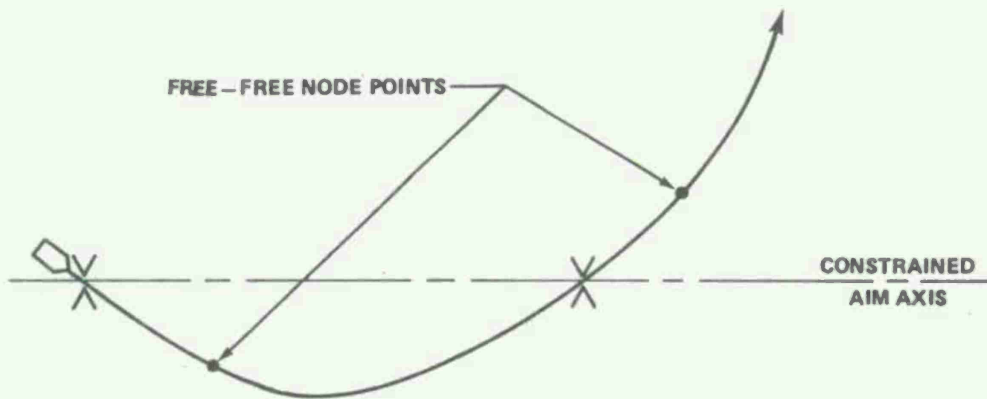


Figure 2. Deformed history of a spinning rocket.

CASE 4. ADD THE INERTIA (MASS SET BACK) FORCES AND THE BENDING MOMENTS CAUSED BY IT.



CASE 5. SUPERIMPOSE THE FREE-FREE NODE POINTS ON THE DEFLECTED SHAPE.



CASE 6. FREE - FREE OSCILLATIONS OR VIBRATION AFTER RELEASE FROM THE CONSTRAINTS:

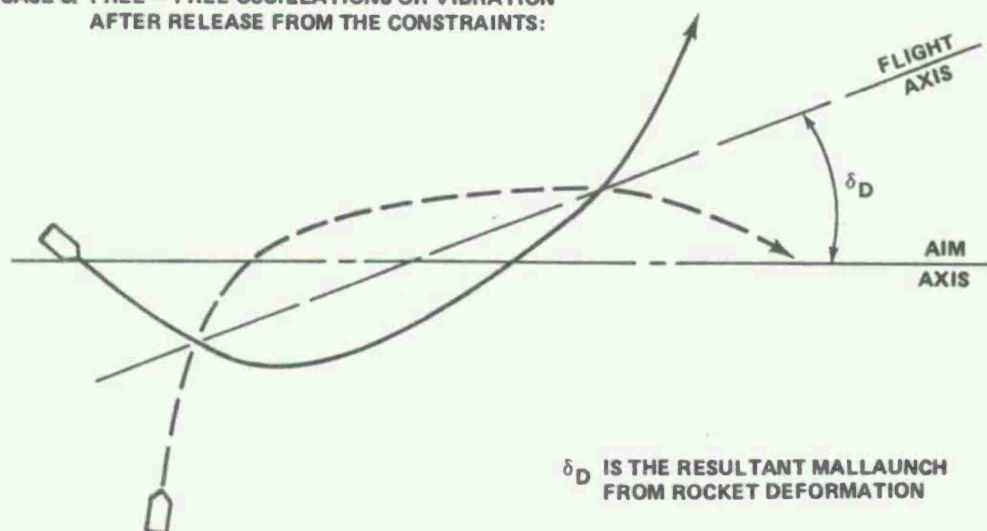


Figure 2. (Concluded).

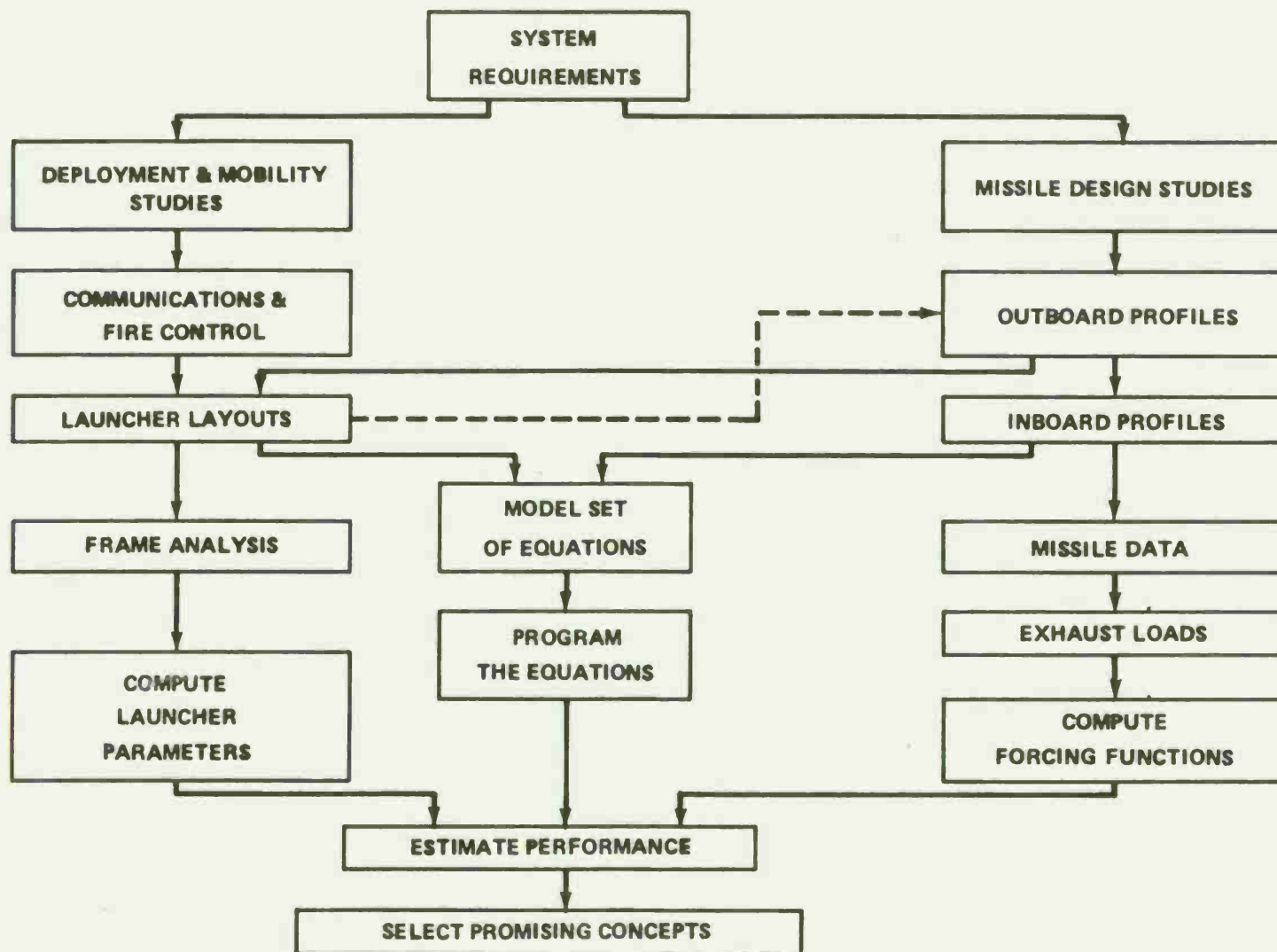


Figure 3. Missile - launcher interface (system's engineering).

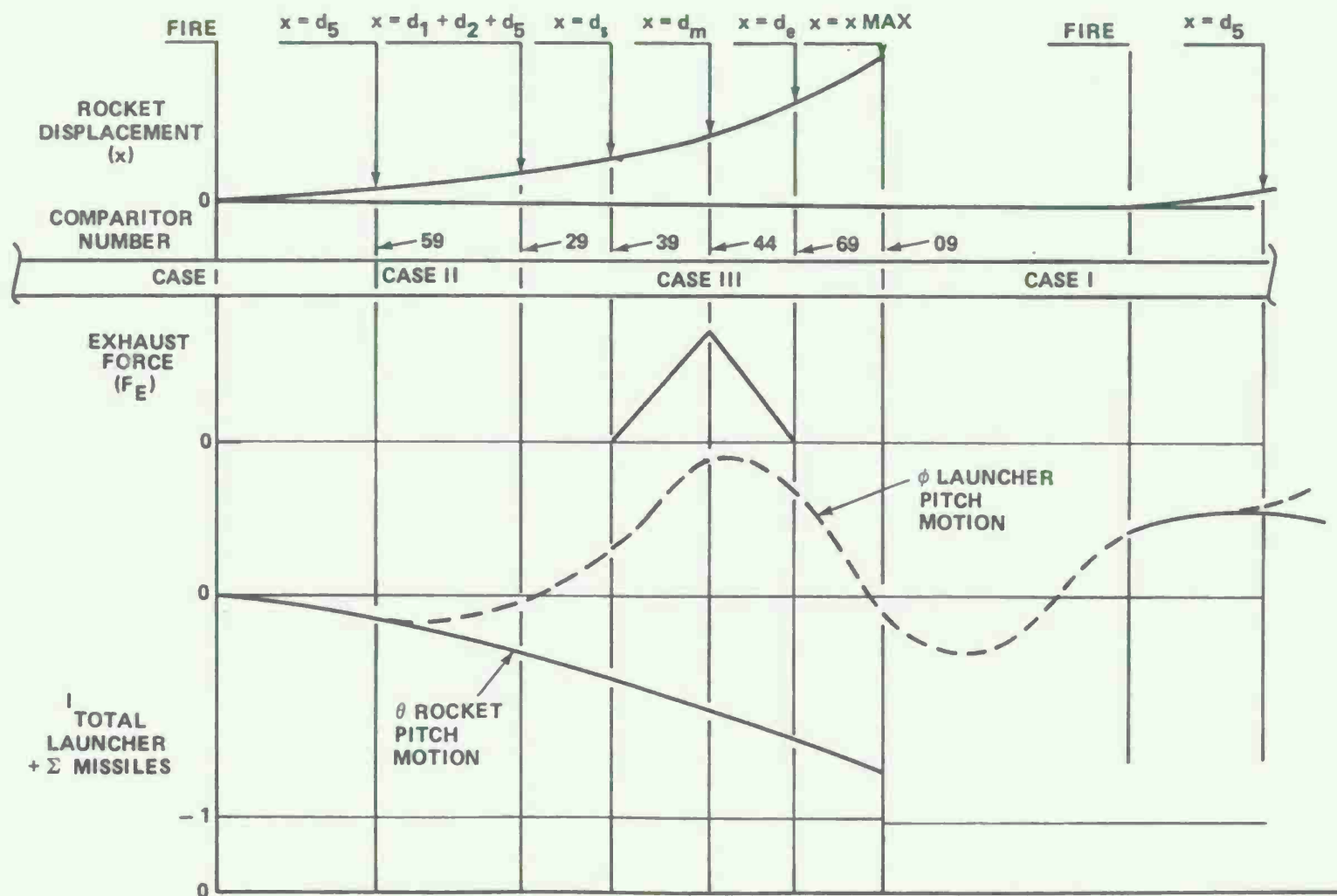


Figure 4. Timing and logic for one rocket fired in the sequence.

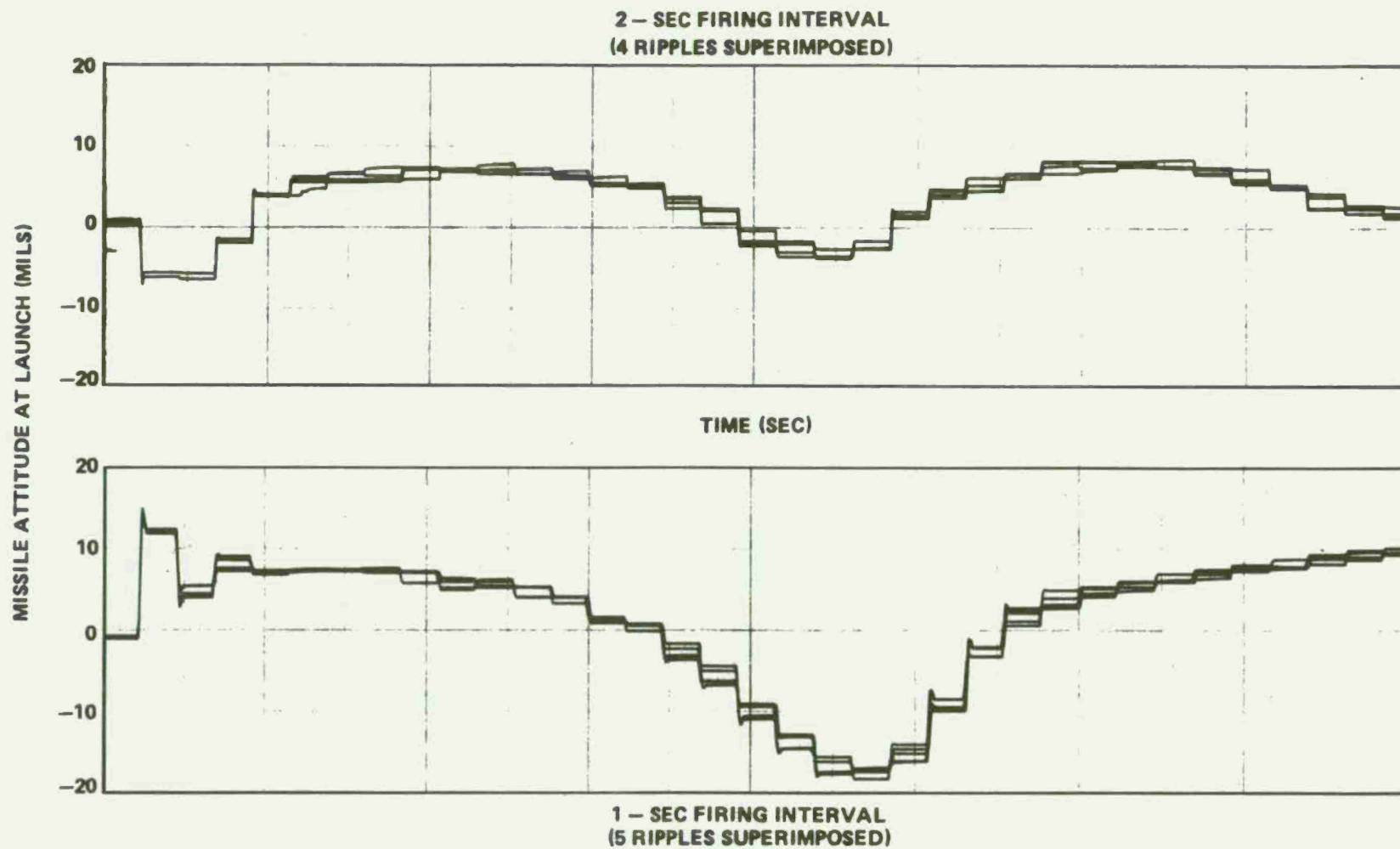


Figure 5. Missile pitch attitude at launch.

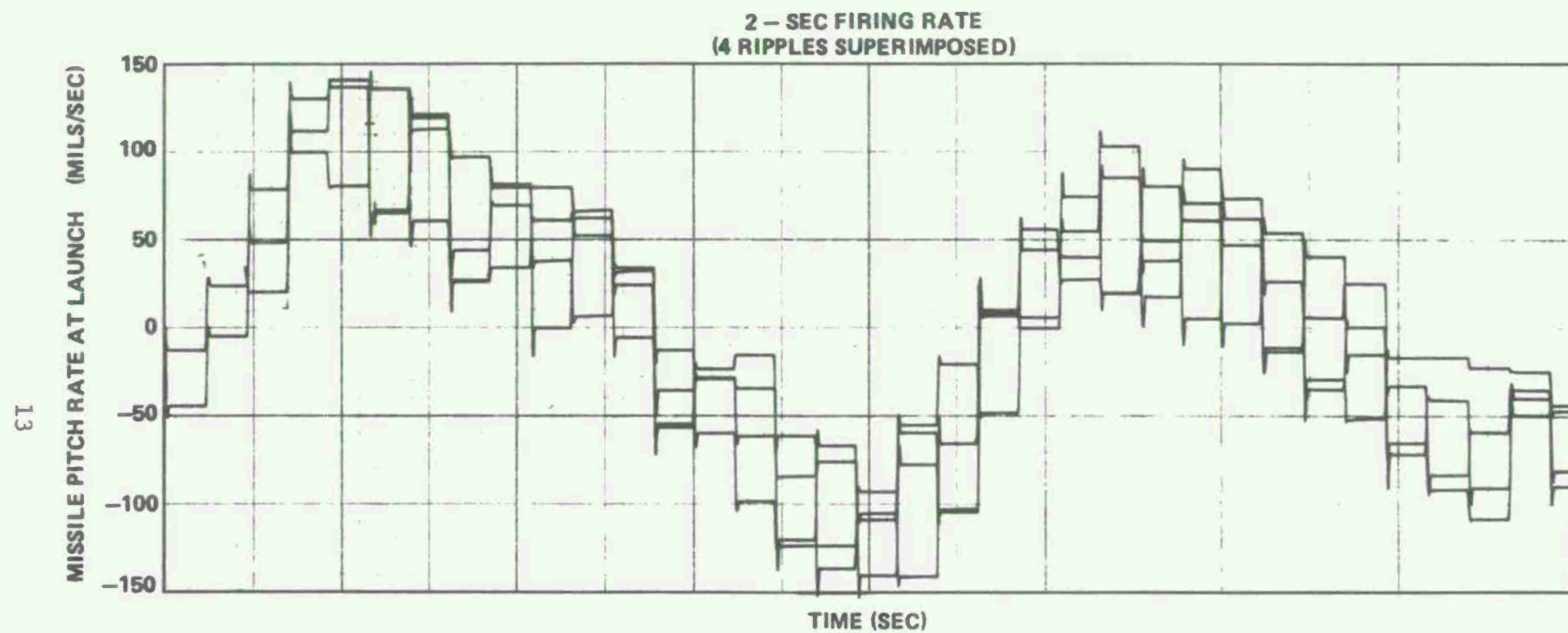


Figure 6. Missile pitch rate at launch - 2 second firing interval.

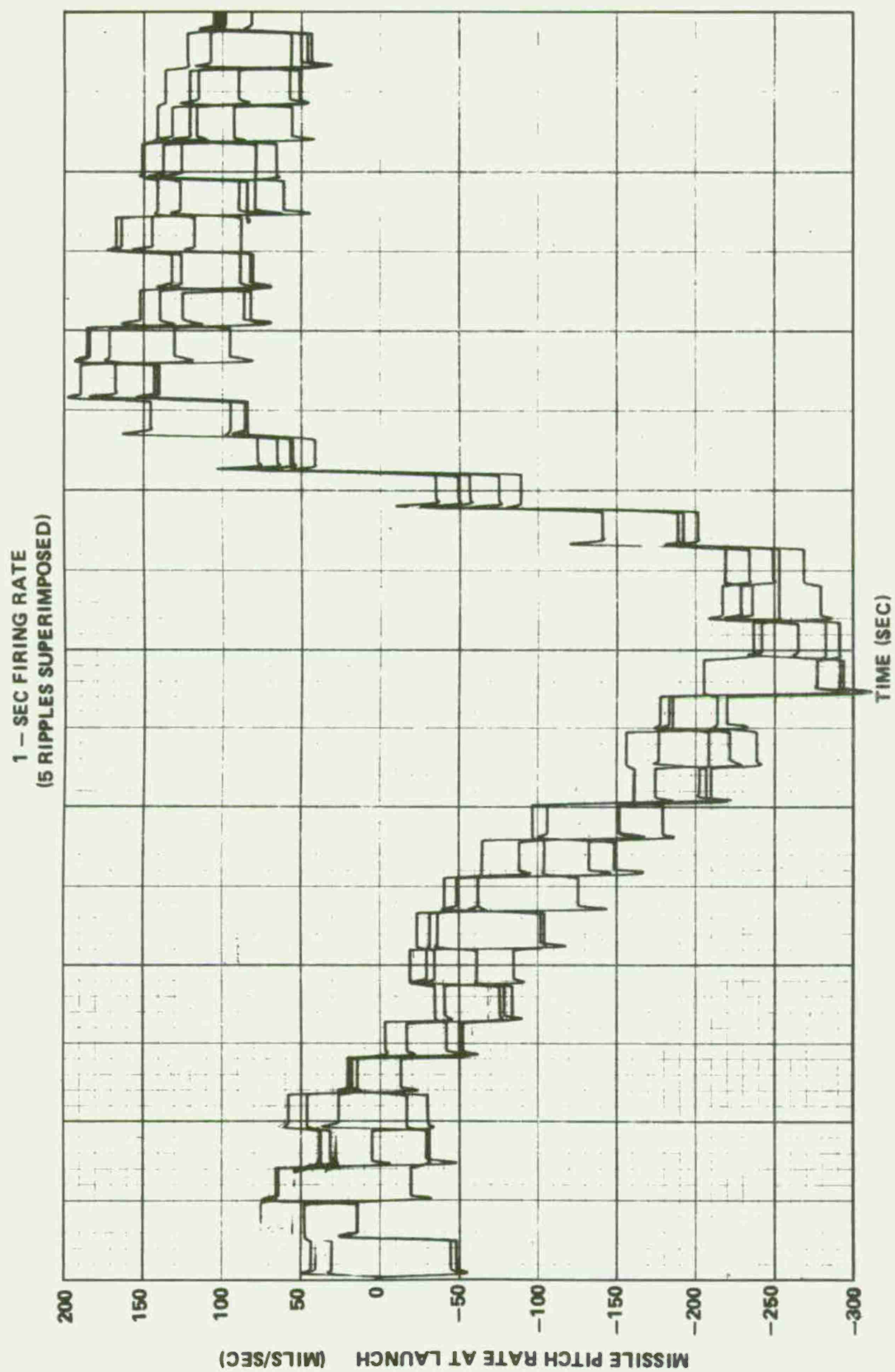


Figure 7. Missile pitch rate at launch - 1 second firing interval.

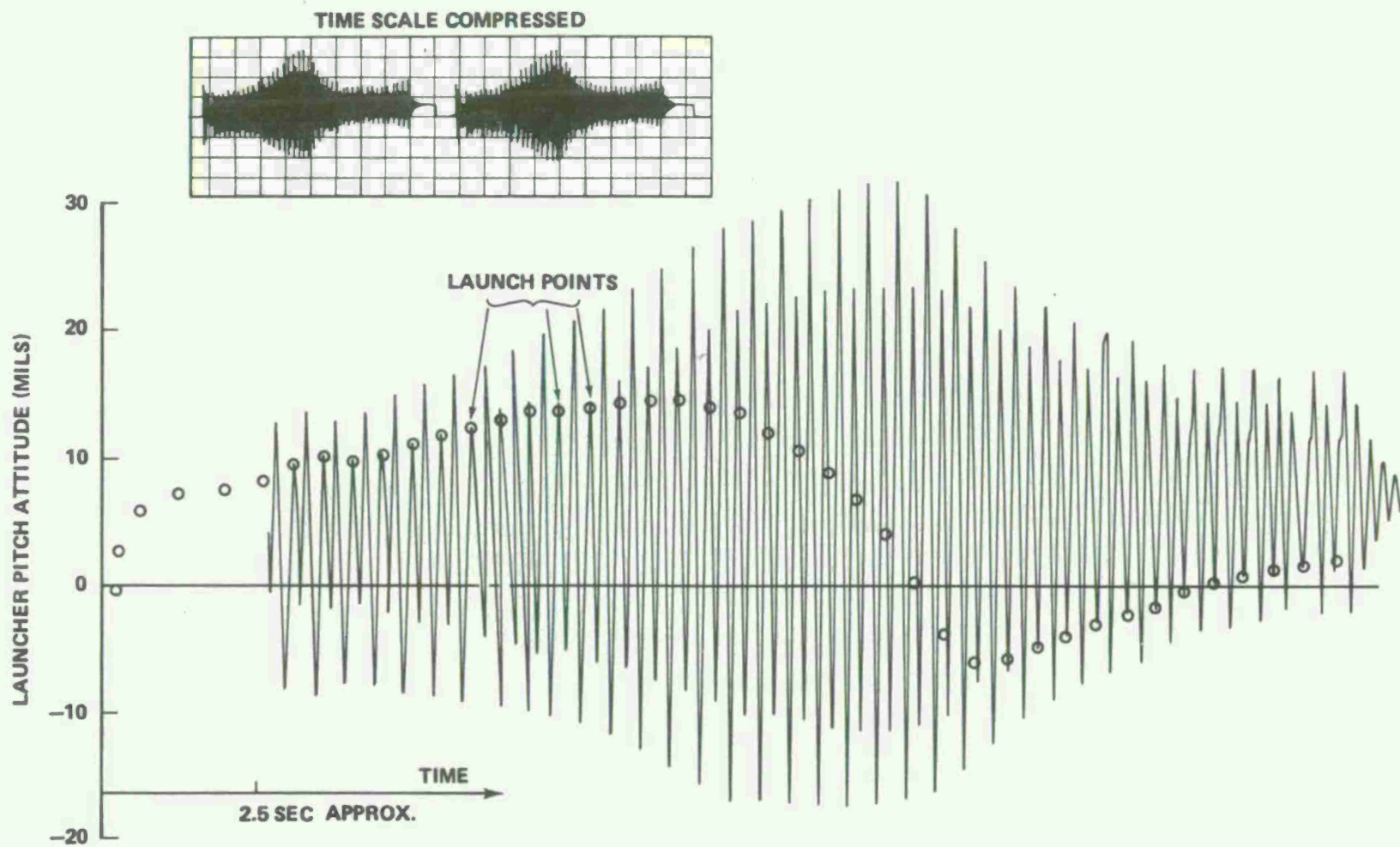
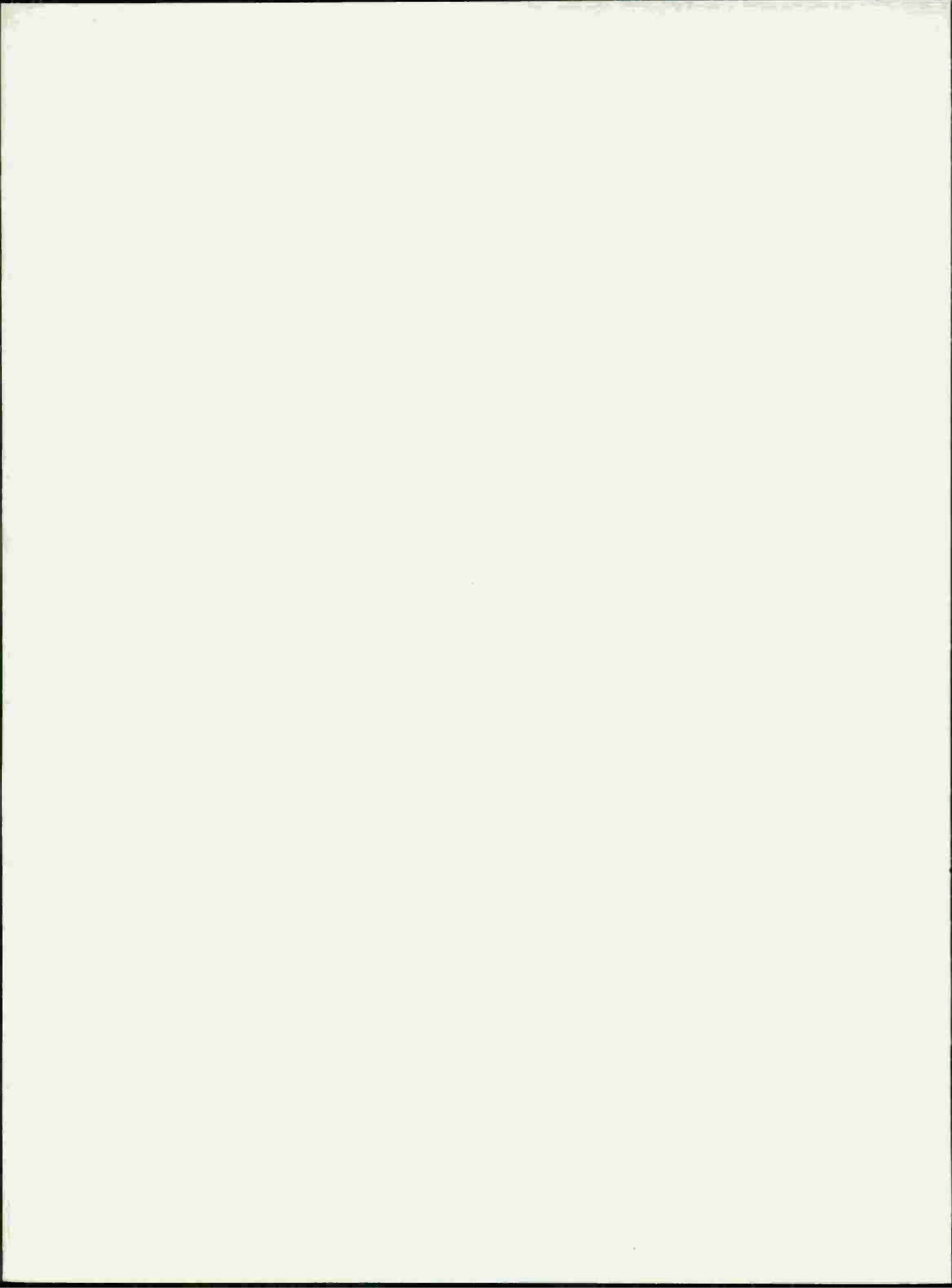
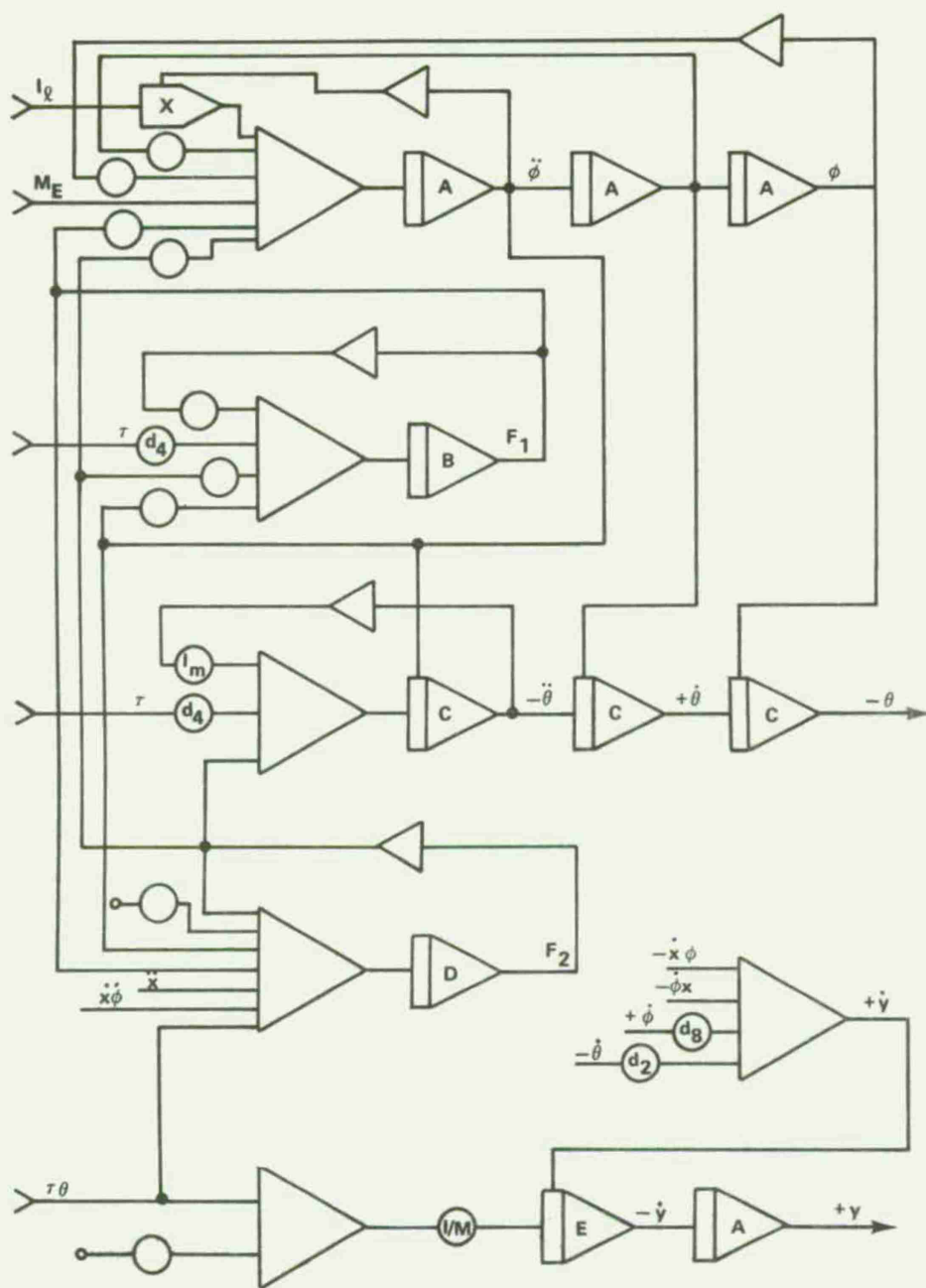


Figure 8. Launcher motion versus time.



## **Appendix A**

### **ANALOG PROGRAMS INCLUDING DIGITAL CONTROL LOGIC**



INTEGRATOR MODES

|          | A  | B  | C  | D  | E  |
|----------|----|----|----|----|----|
| CASE I   | OP | OP | IC | OP | IC |
| CASE II  | OP | IC | OP | OP | IC |
| CASE III | OP | IC | OP | IC | OP |

Figure A-1. General analog approach.



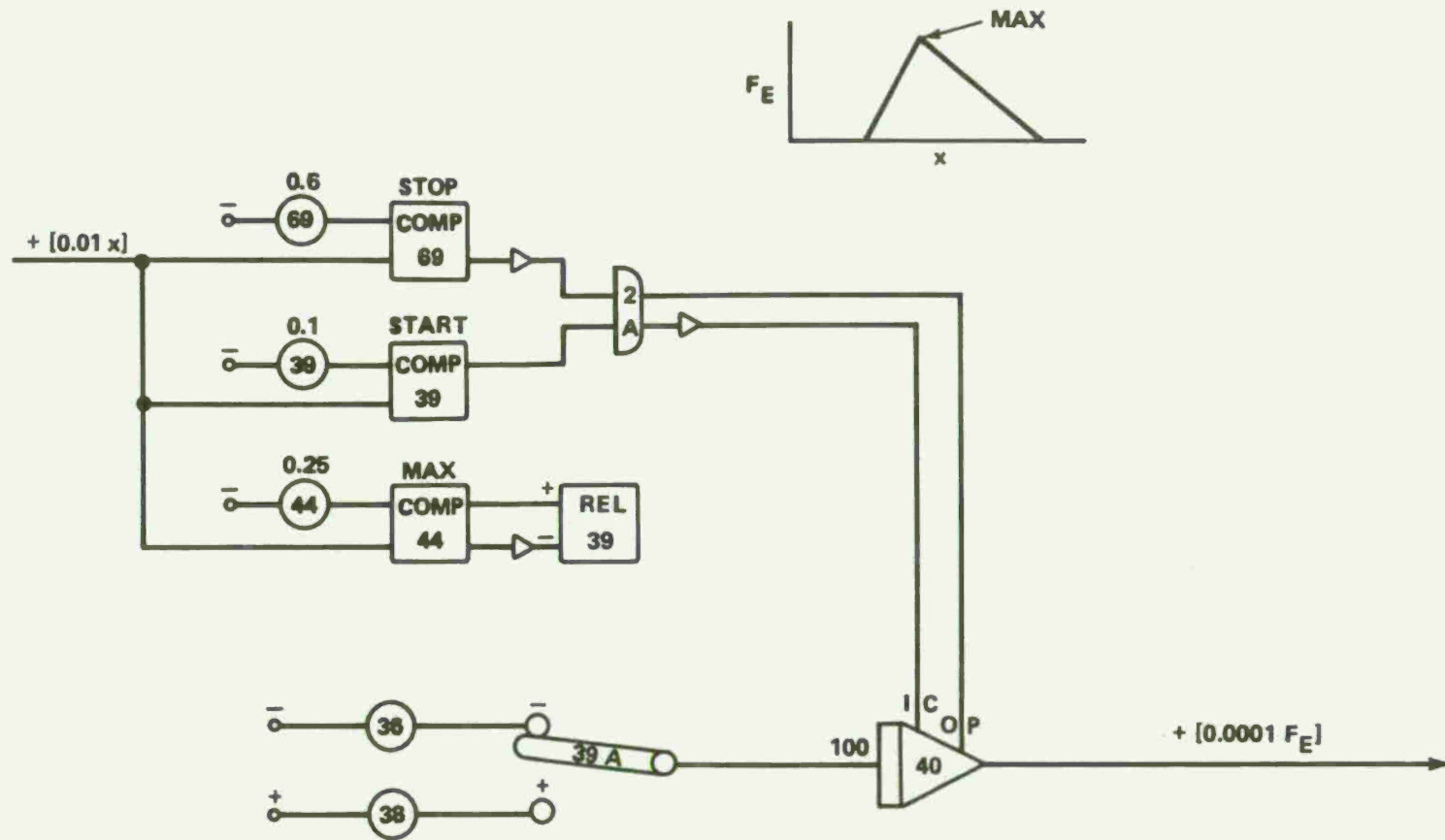


Figure A-3. Exhaust gas impingement force.

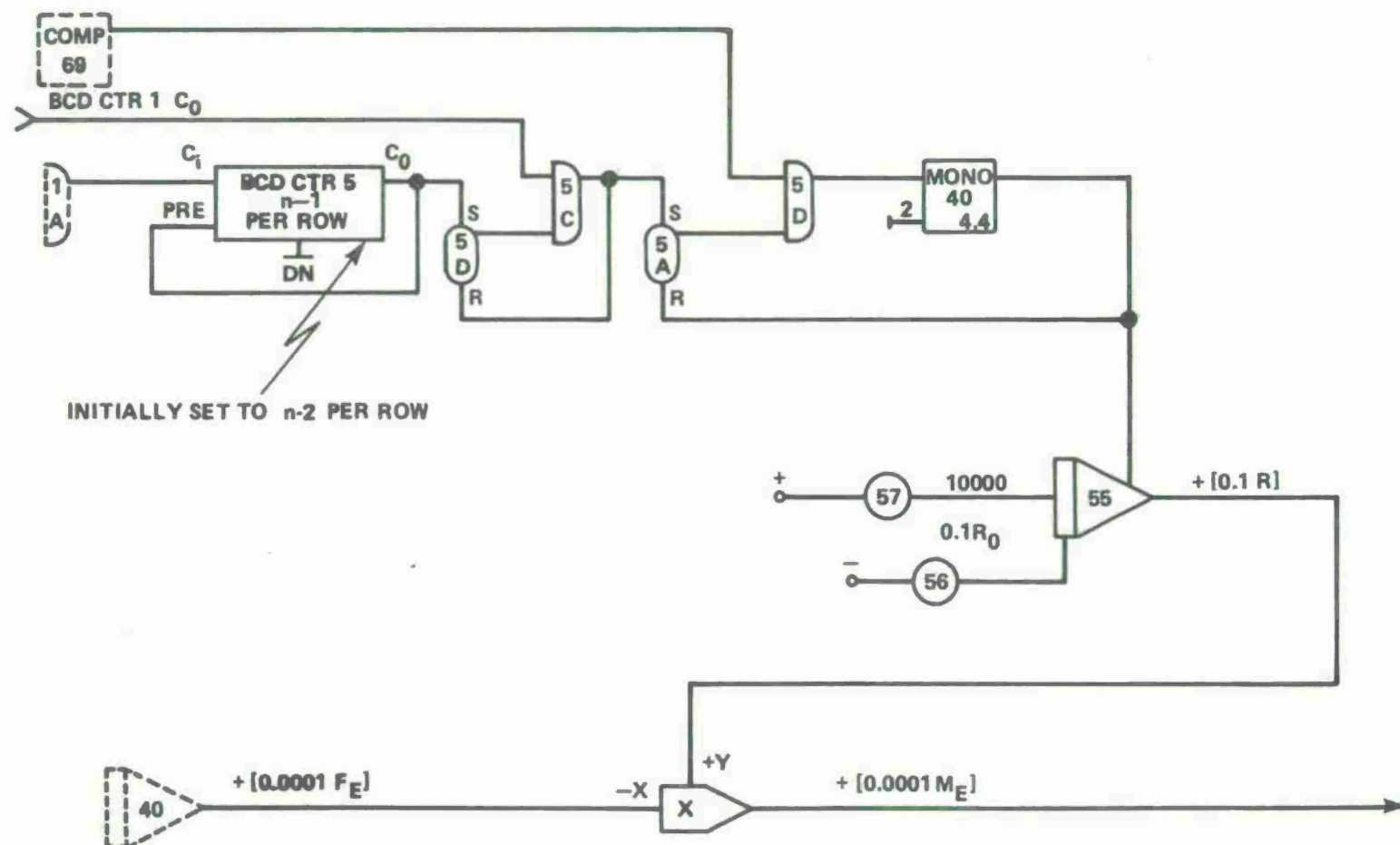


Figure A-4. Exhaust gas impingement moment arm and moment generation (pitch motion).

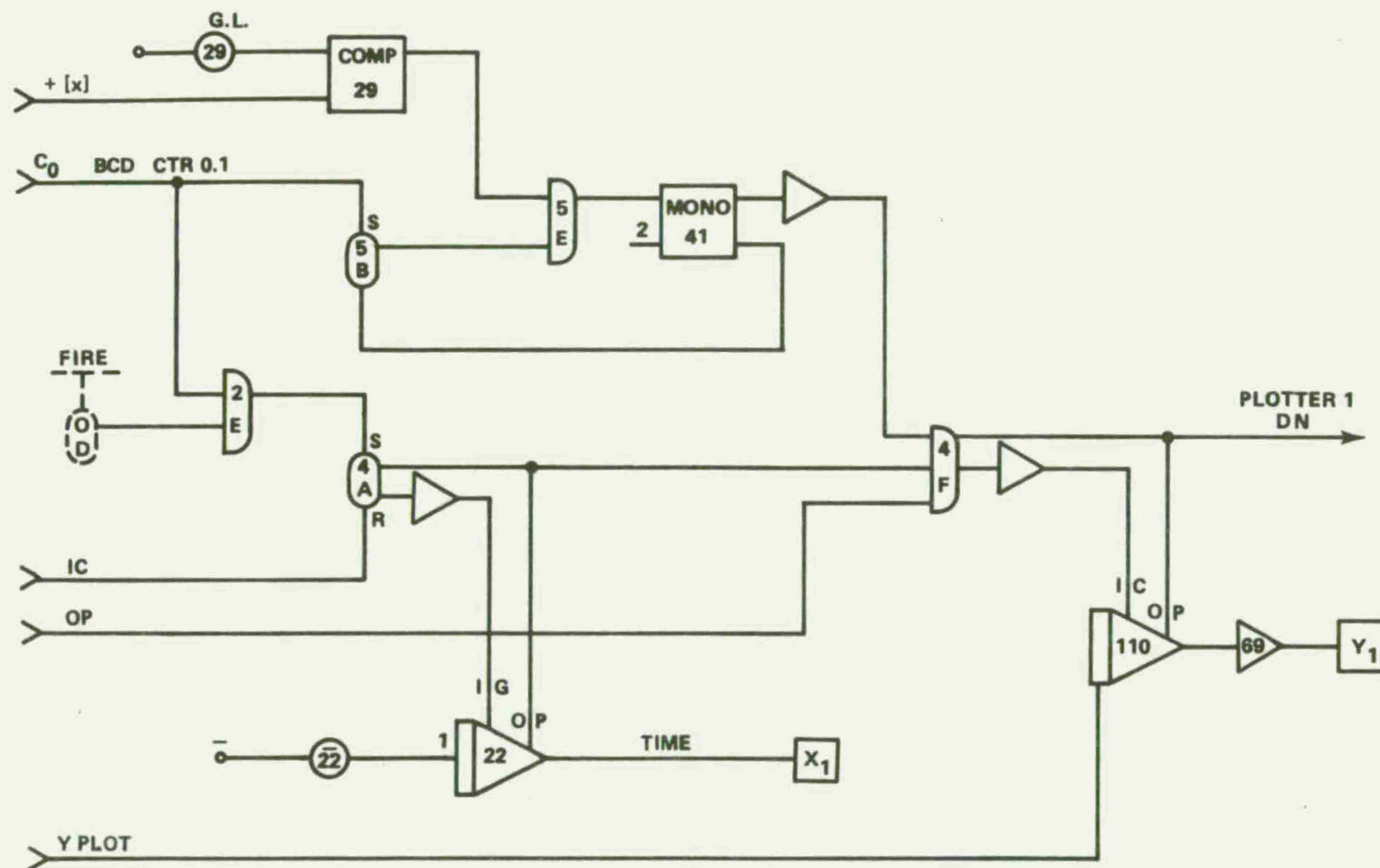


Figure A-5. Plotting values at end of guidance.

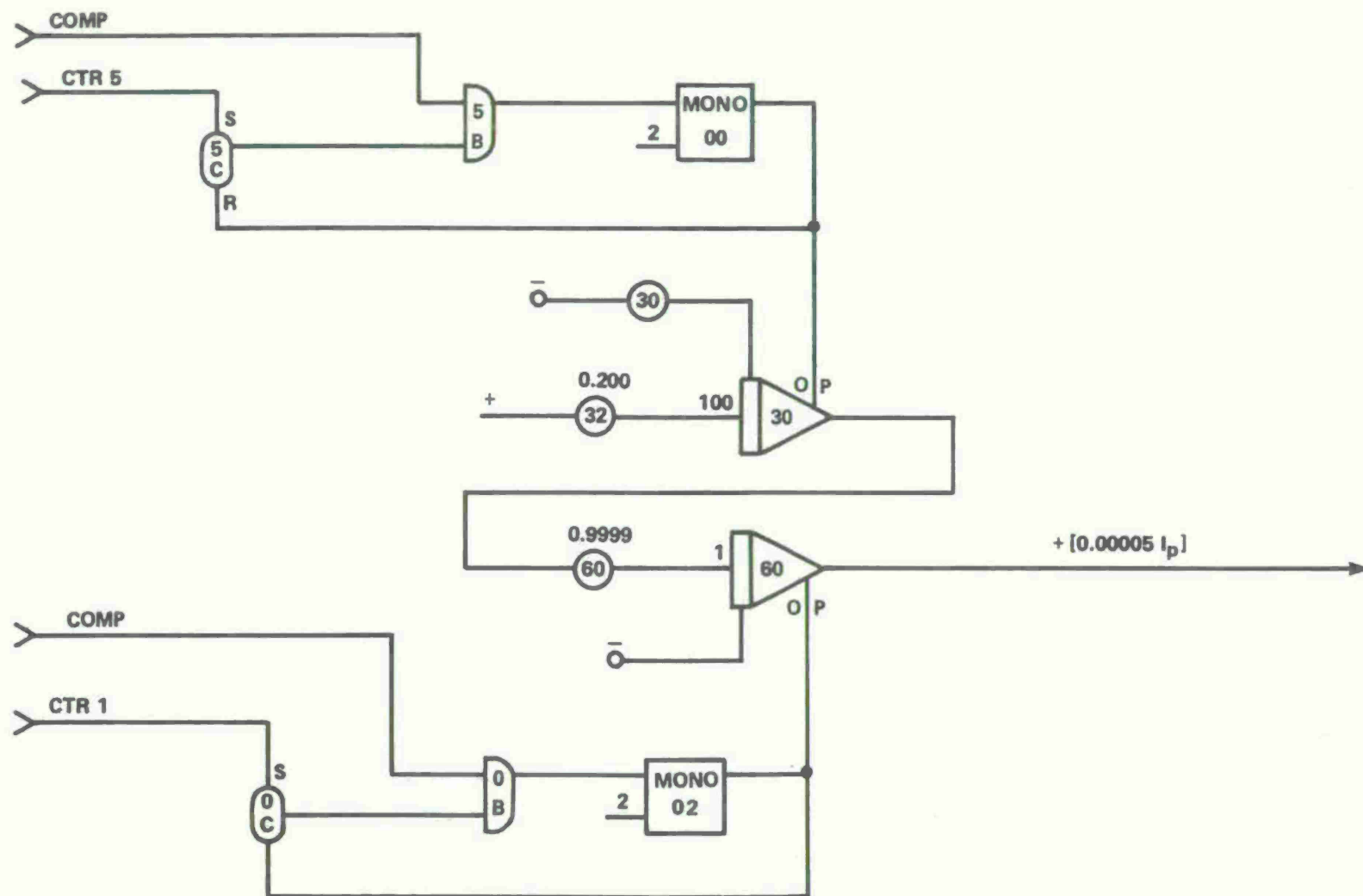


Figure A-6. Total pitch mass moment of inertia minus the missile to be launched.

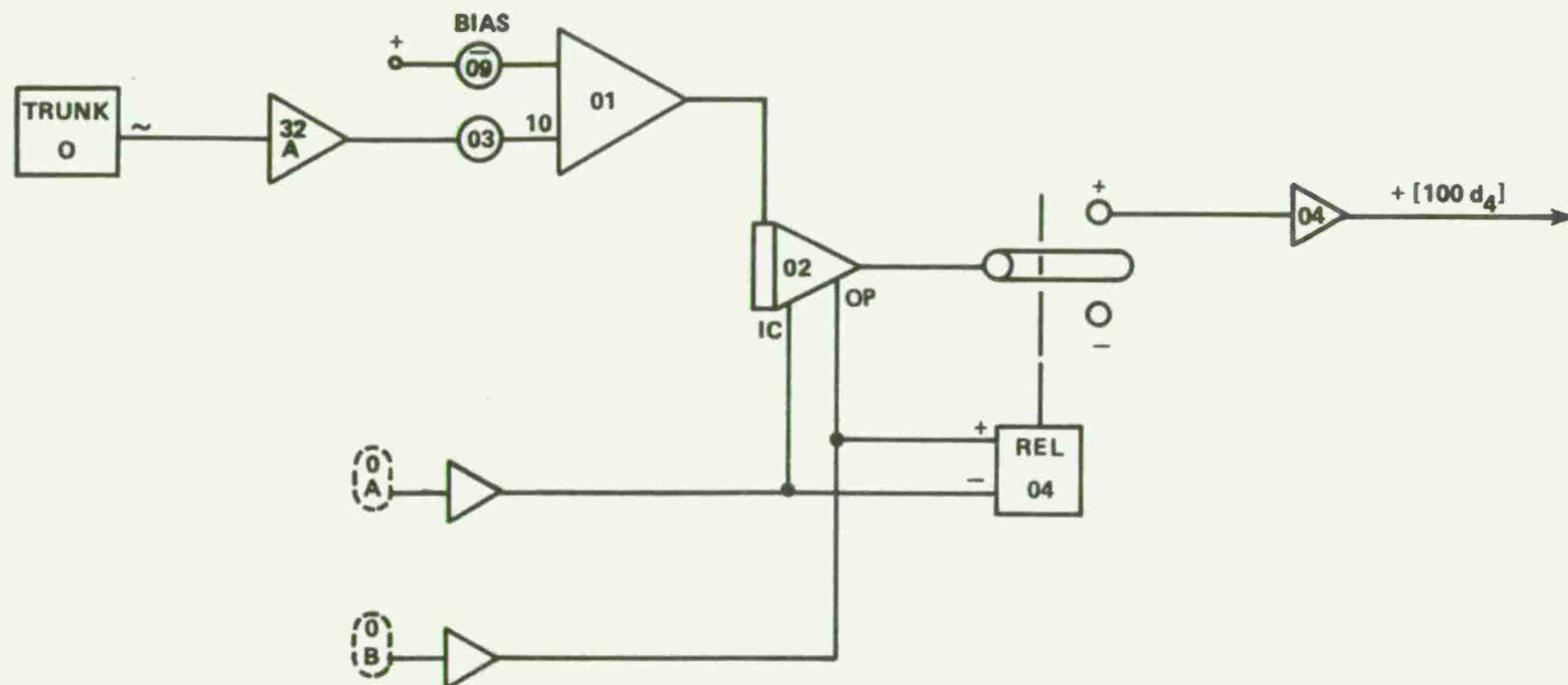


Figure A-7. Variable thrust misalignment ( $d_4$ ) (random).

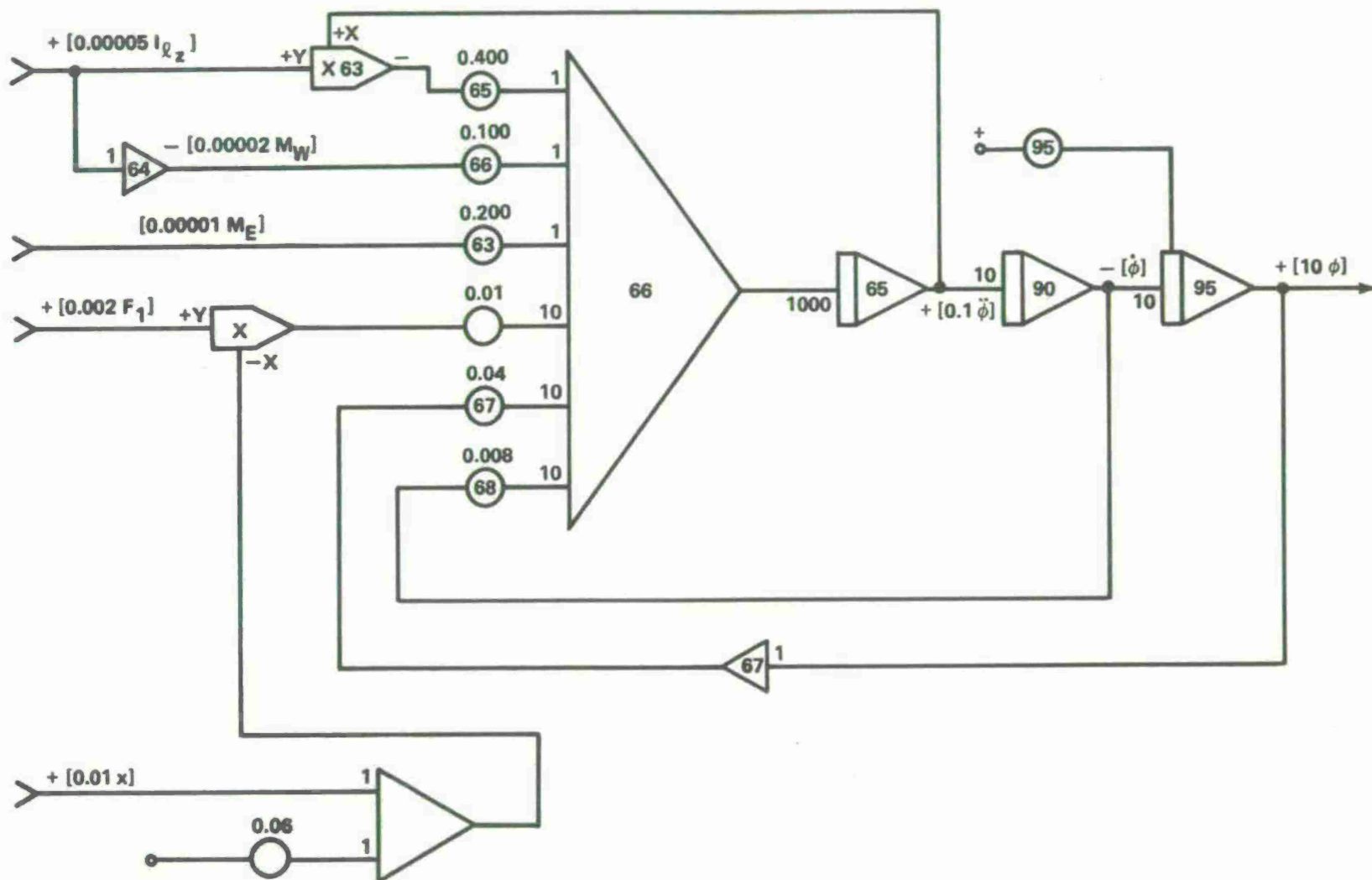


Figure A-8. Launcher pitch motion.

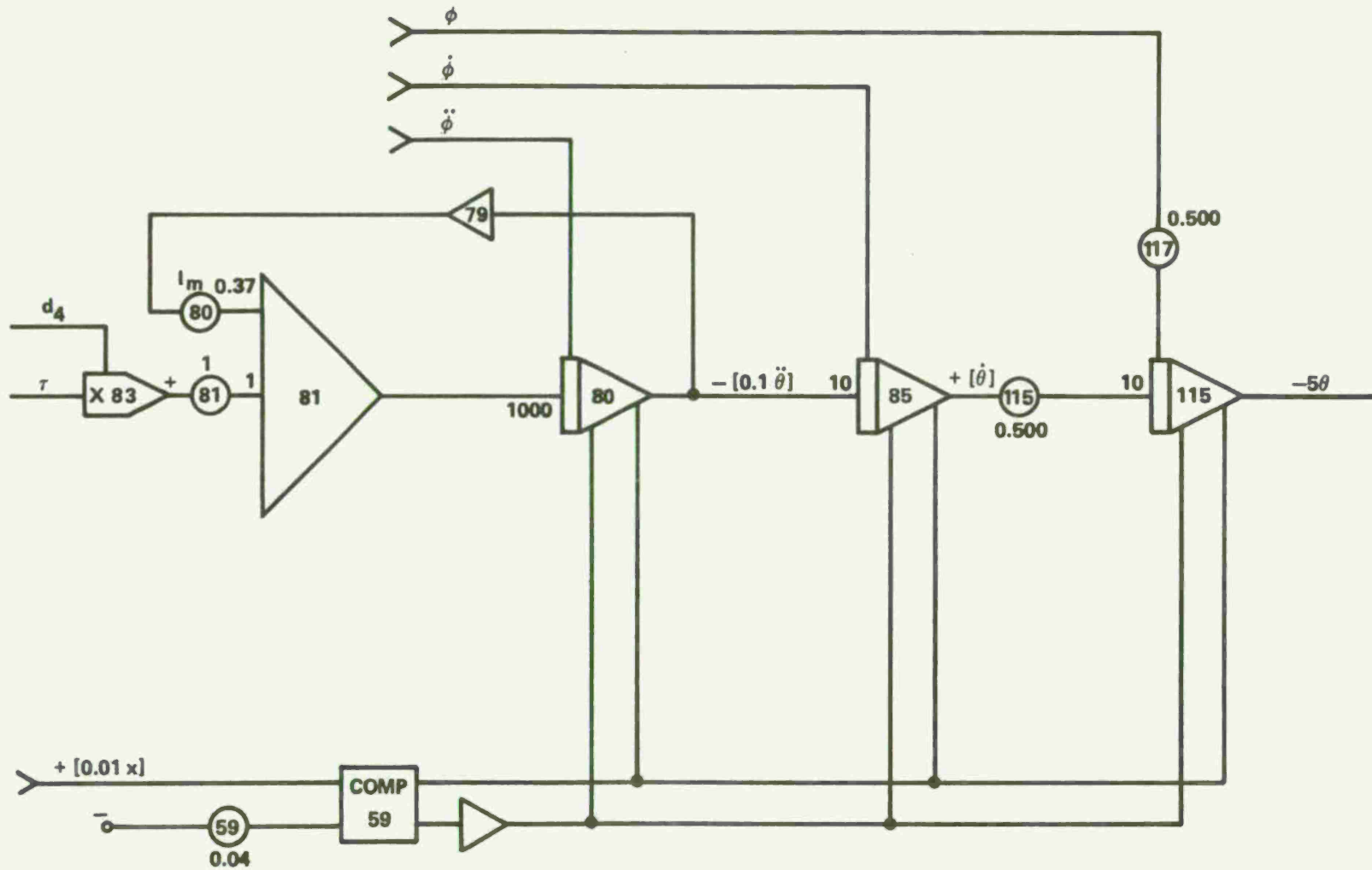
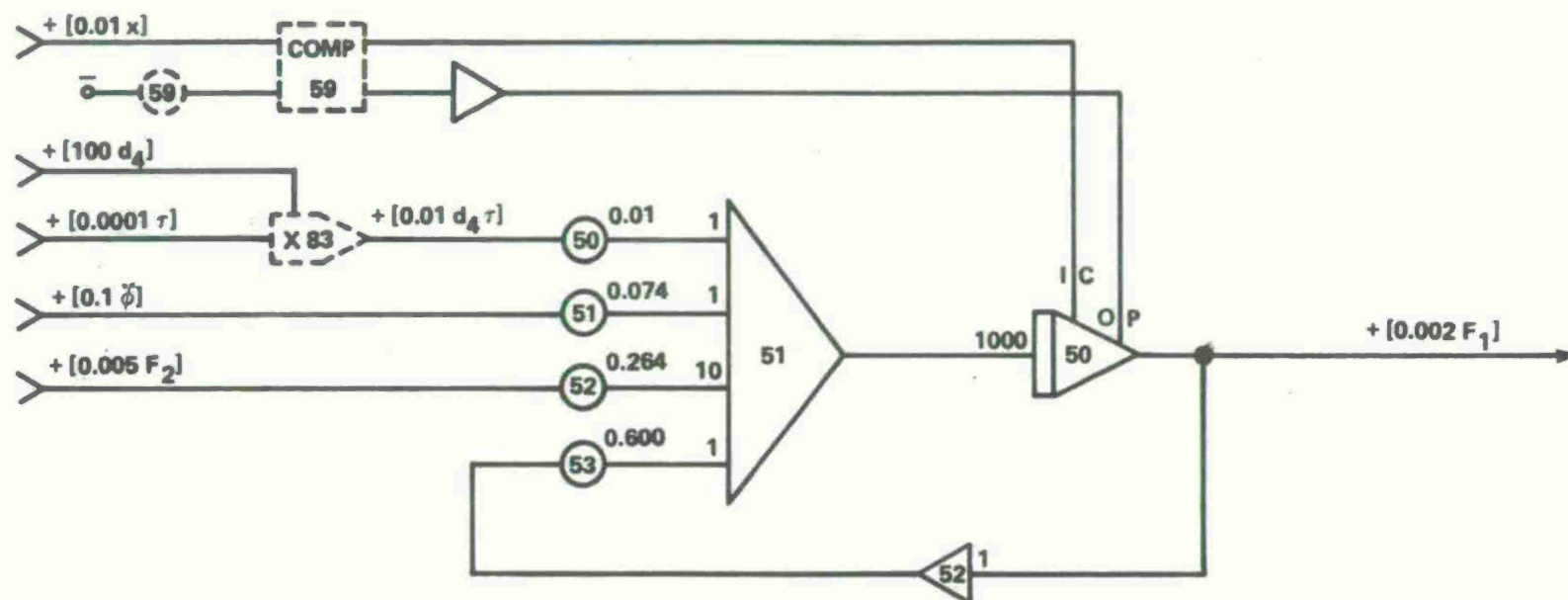


Figure A-9. Rocket pitch motion.



EQUATION:  
(CASE I)  $d_1 F_1 - I_{m_z} \ddot{\phi} - d_2 F_2 - \tau d_4 = 0$

$$6 [0.002 F_1] - 37 [0.1 \ddot{\phi}] - 66 [0.005 F_2] - [0.01 d_4 \tau] = 0$$

$$\frac{0.0002}{0.002} (6) [0.002 F_1] - \frac{0.0002}{0.1} (37) [0.1 \ddot{\phi}] - \frac{0.0002}{0.005} (66) [0.005 F_2] - \frac{0.0002}{0.01} [0.01 d_4 \tau] = 0$$

$$(0.0000) [0.002 F_1] - (0.0740) [0.1 \ddot{\phi}] - (0.2640) 10 [0.005 F_2] - (0.0200) [0.01 d_4 \tau] = 0$$

Figure A-10. Forward vertical missile - tube reaction force ( $F_1$ ).

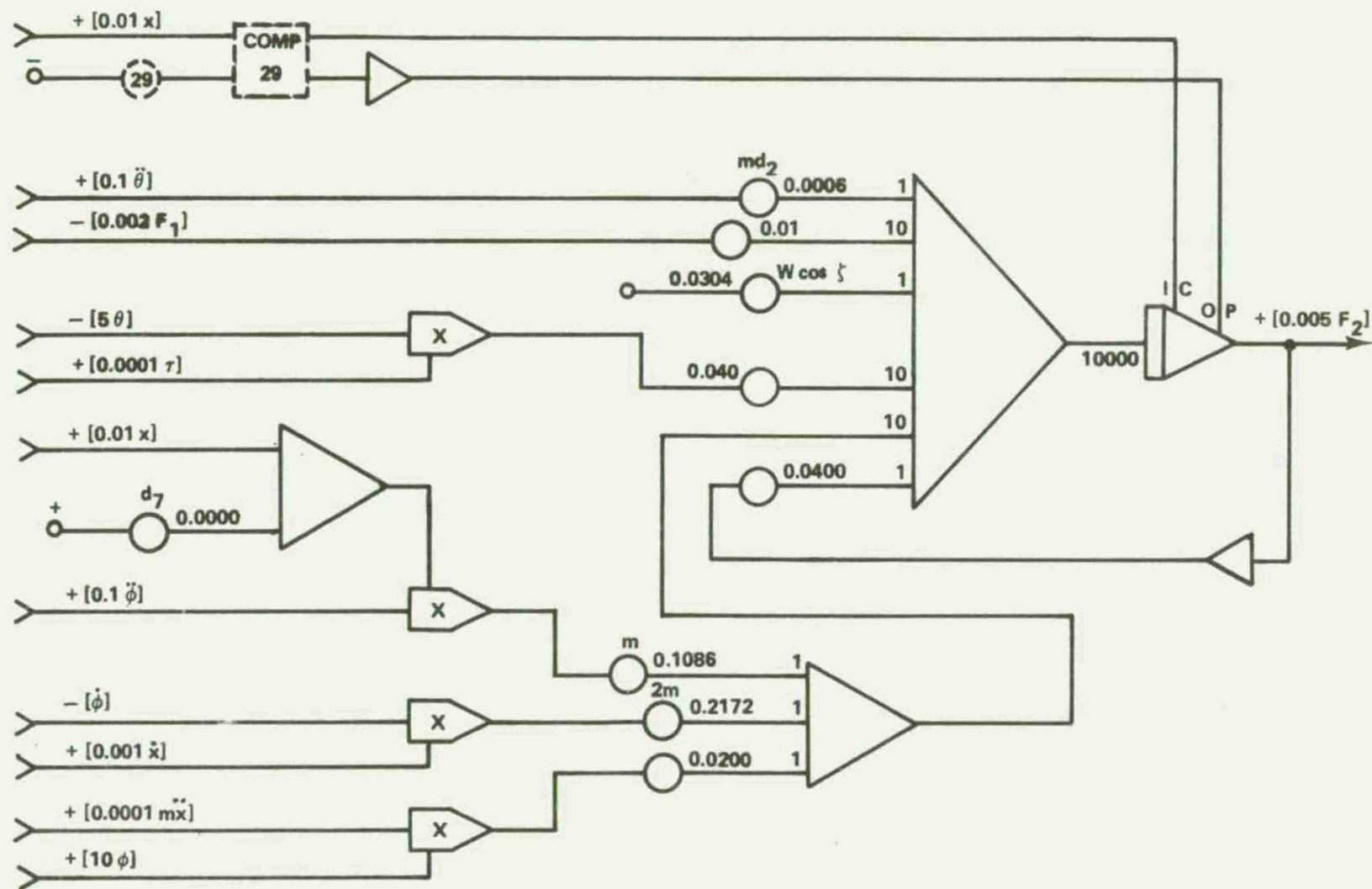


Figure A-11. Aft vertical missile - tube reaction force ( $F_2$ ).

**Appendix B**  
**EQUATIONS OF PITCH MOTION**

## I. PITCH PLANE EQUATIONS OF MOTION

### A. Case I: Rocket Constrained on the Launcher ( $\theta = \phi$ )

$$I_{\ell_z} \ddot{\phi} + (d_1 + d_2 + d_7 + x) F_1 + (d_7 + x) F_2 + K\phi + C\dot{\phi} - M_E + M_W - d_6 F_7 = 0 \quad (B-1)$$

$$I_{m_z} \ddot{\theta} - d_1 F_1 + d_2 F_2 + r_2 \tau - d_3 F_7 = 0 \quad (B-2)$$

$$m \ddot{x} - \tau + W \sin \xi - F_7 = 0 \quad (B-3)$$

$$m (d_2 + d_7 + x) \ddot{\phi} - F_1 - F_2 + m \phi \ddot{x} + 2 m \dot{x} \dot{\phi} + W \cos \xi - \tau \theta = 0 \quad (B-4)$$

### B. Case II: Rocket Tip-Off Phase ( $F_1 = 0$ )

$$I_{\ell_z} \ddot{\phi} + (x + d_7) F_2 + K\phi + C\dot{\phi} - M_E + M_W = 0 \quad (B-5)$$

$$I_{m_z} \ddot{\theta} + d_2 F_2 + r_2 \tau = 0 \quad (B-6)$$

$$m \ddot{x} - \tau + W \sin \xi = 0 \quad (B-7)$$

$$m (d_7 + x) \ddot{\phi} + m d_2 \ddot{\theta} - F_2 + m \phi \ddot{x} + 2 m \dot{x} \dot{\phi} + W \cos \xi - \tau \theta = 0 \quad (B-8)$$

### C. Case III: Rocket in Free Flight ( $F_1 = 0$ ; $F_2 = 0$ )

$$I_{\ell_z} \ddot{\phi} + K\phi + C\dot{\phi} - M_E + M_W = 0 \quad (B-9)$$

$$I_m \ddot{\theta} + r_2 \tau = 0 \quad (B-10)$$

$$m \ddot{x} - \tau + W \sin \xi = 0 \quad (B-11)$$

$$m \ddot{y} + W \cos \xi - \tau \theta = 0 \quad (B-12)$$

## II. SYMBOLS

|            |                                          |
|------------|------------------------------------------|
| $x, y, z$  | Coordinates attached to the rocket       |
| $m$        | Subscript denoting the rocket or missile |
| $l$        | Subscript denoting the launcher          |
| $I$        | Mass moment of inertia                   |
| $M$        | Moment                                   |
| $E$        | Subscript denoting rocket exhaust        |
| $W$        | Weight of the rocket                     |
| $T$        | Torque                                   |
| $F$        | Force                                    |
| $K$        | Torsional stiffness parameter            |
| $C$        | Torsional damping coefficient            |
| $r_1$      | Static mass unbalance (radial)           |
| $r_2$      | Radial thrust misalignment               |
| $d$        | Dimensions                               |
| $t$        | Time                                     |
| $t_i$      | Firing interval                          |
| $n$        | Number of rockets                        |
| $m$        | Mass                                     |
| $F_7$      | Detent force                             |
| $\gamma_1$ | Initial position of $r_1$                |
| $\gamma_2$ | Initial position of $r_2$                |
| $\tau$     | rocket thrust                            |

|           |                               |
|-----------|-------------------------------|
| $\phi$    | Launcher pitch motion         |
| $\lambda$ | Launcher yaw motion           |
| $\theta$  | Rocket pitch motion           |
| $\psi$    | Rocket yaw motion             |
| $\gamma$  | Rocket roll or spin motion    |
| $\xi$     | Launcher firing attitude (QE) |



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