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

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER RL-76-11	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Multiple Rocket Launcher Characteristics and Simulation Technique		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER RL-76-11
7. AUTHOR(s) Dean E. Christensen		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander US Army Missile Command ATTN: DRSMI-RL Redstone Arsenal, Alabama 35809		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Commander US Army Missile Command ATTN: DRSMI-RPR Redstone Arsenal, Alabama 35809		12. REPORT DATE 5 February 1976
		13. NUMBER OF PAGES 36
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Mallaunch
Malaim
Multiple rocket launcher
Simulation technique

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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.

(Abstract continued)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

(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.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

CONTENTS

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 exsistance. 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 intergration 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.

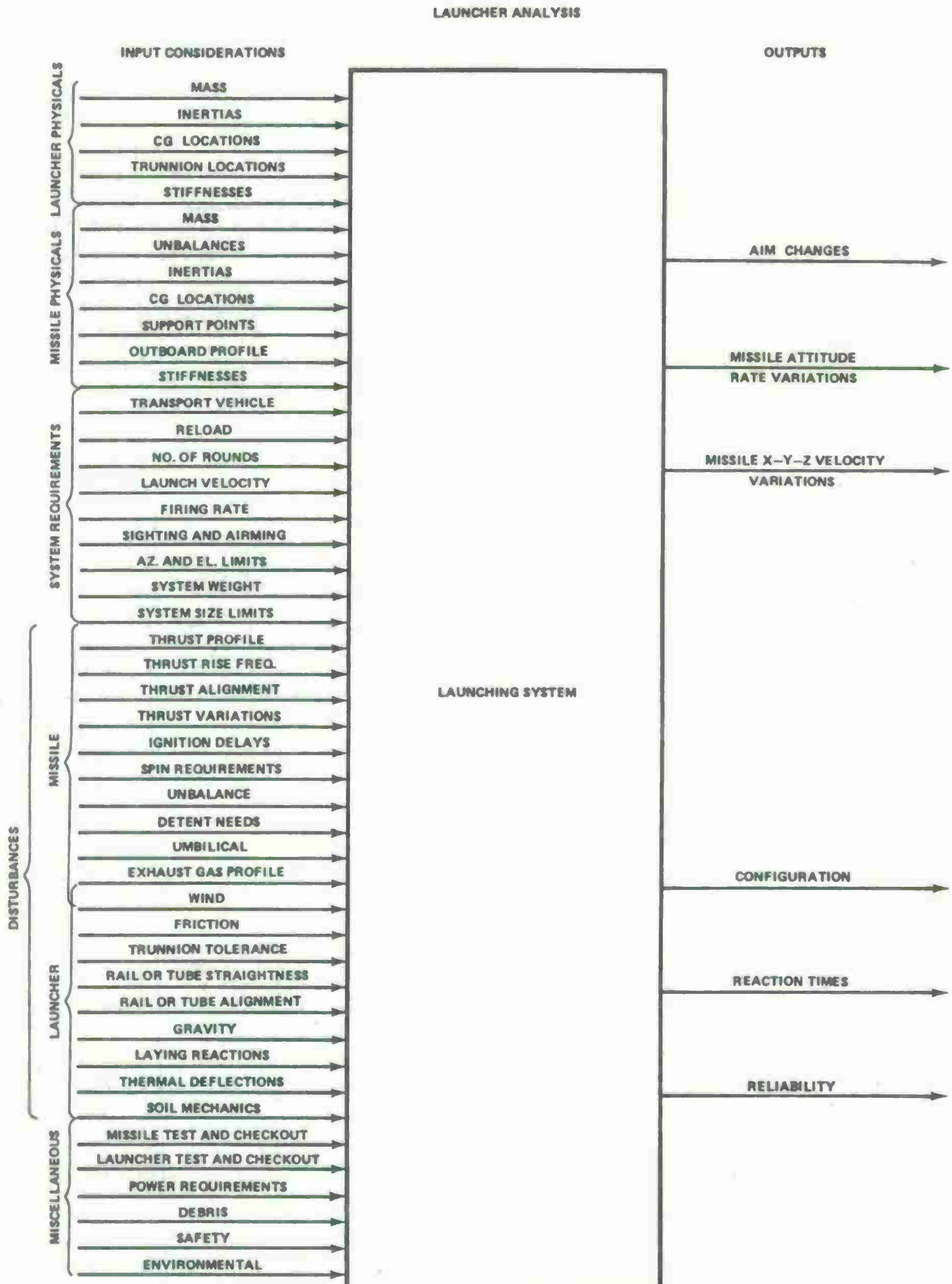


Figure 1. Launcher analysis.

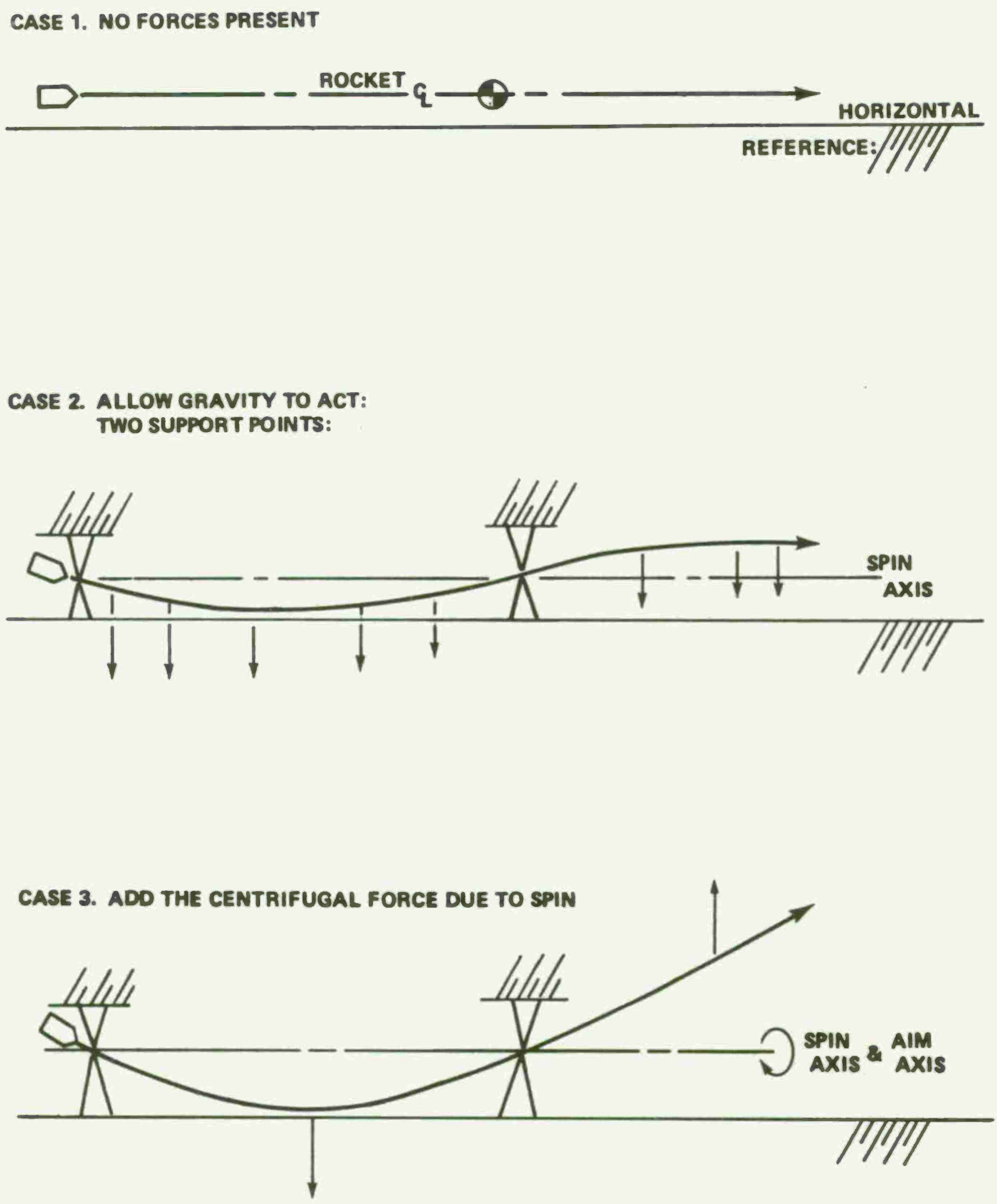


Figure 2. Deformed history of a spinning rocket.

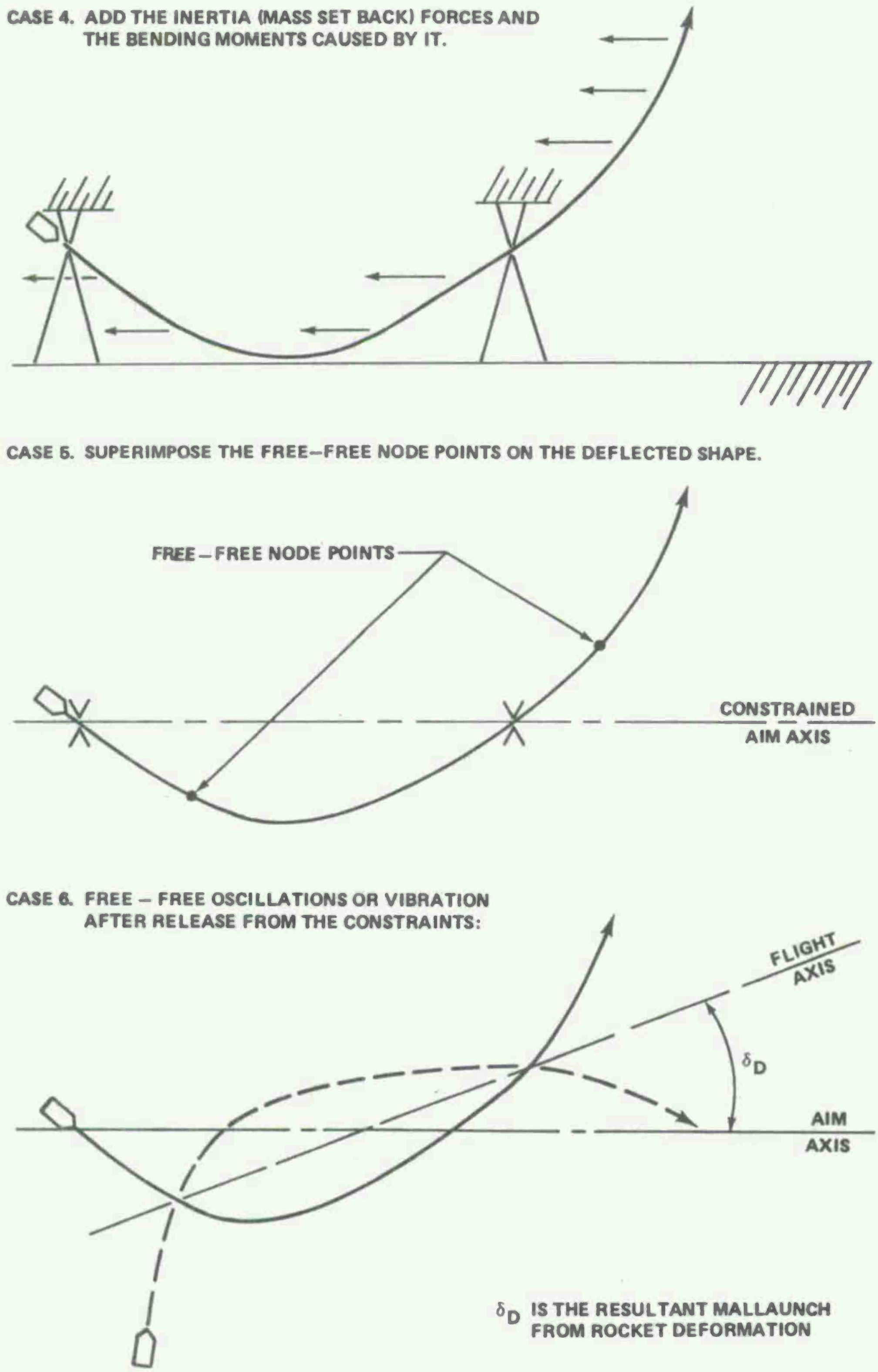


Figure 2. (Concluded).

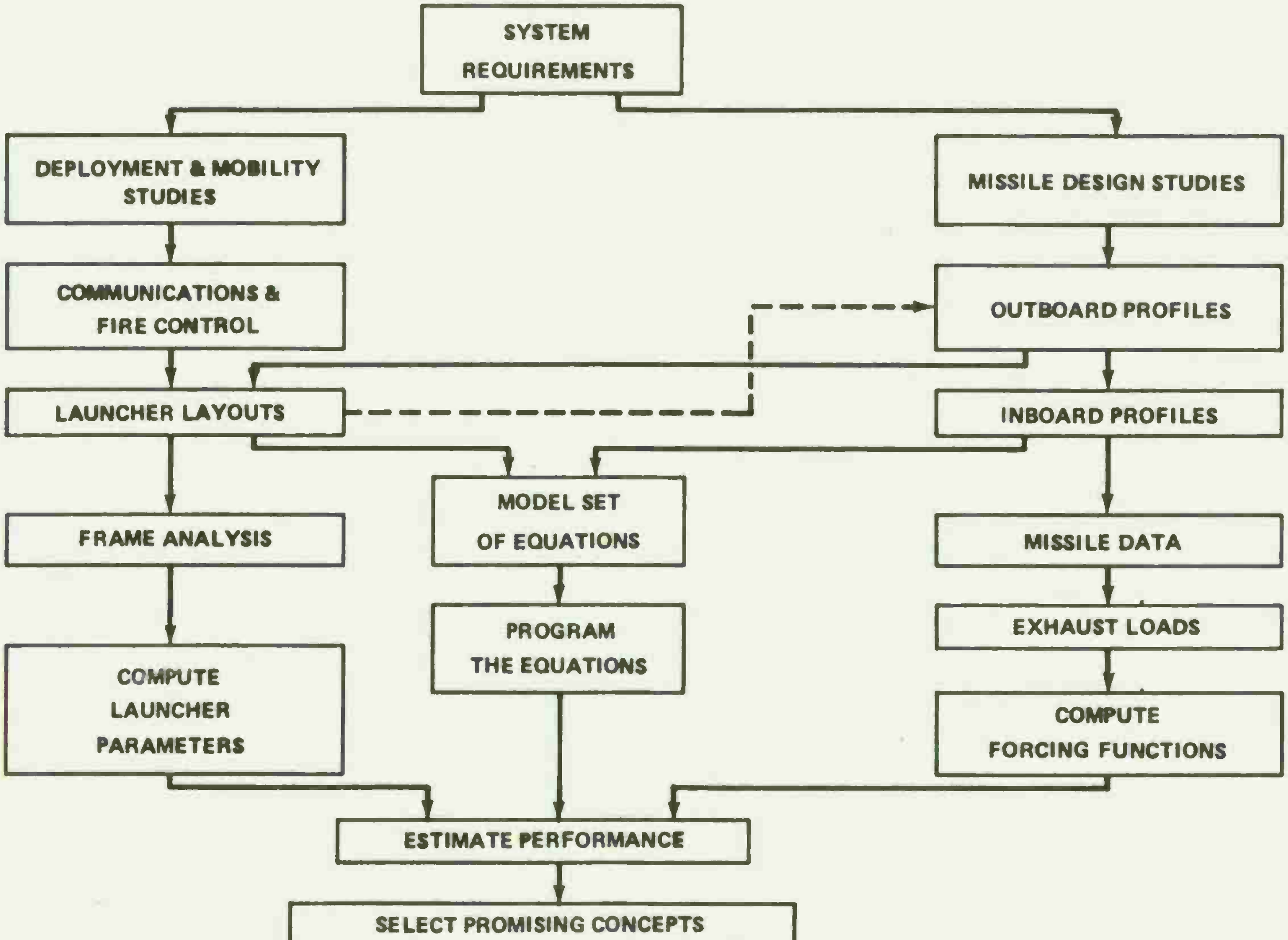


Figure 3. Missile — launcher interface (system's engineering).

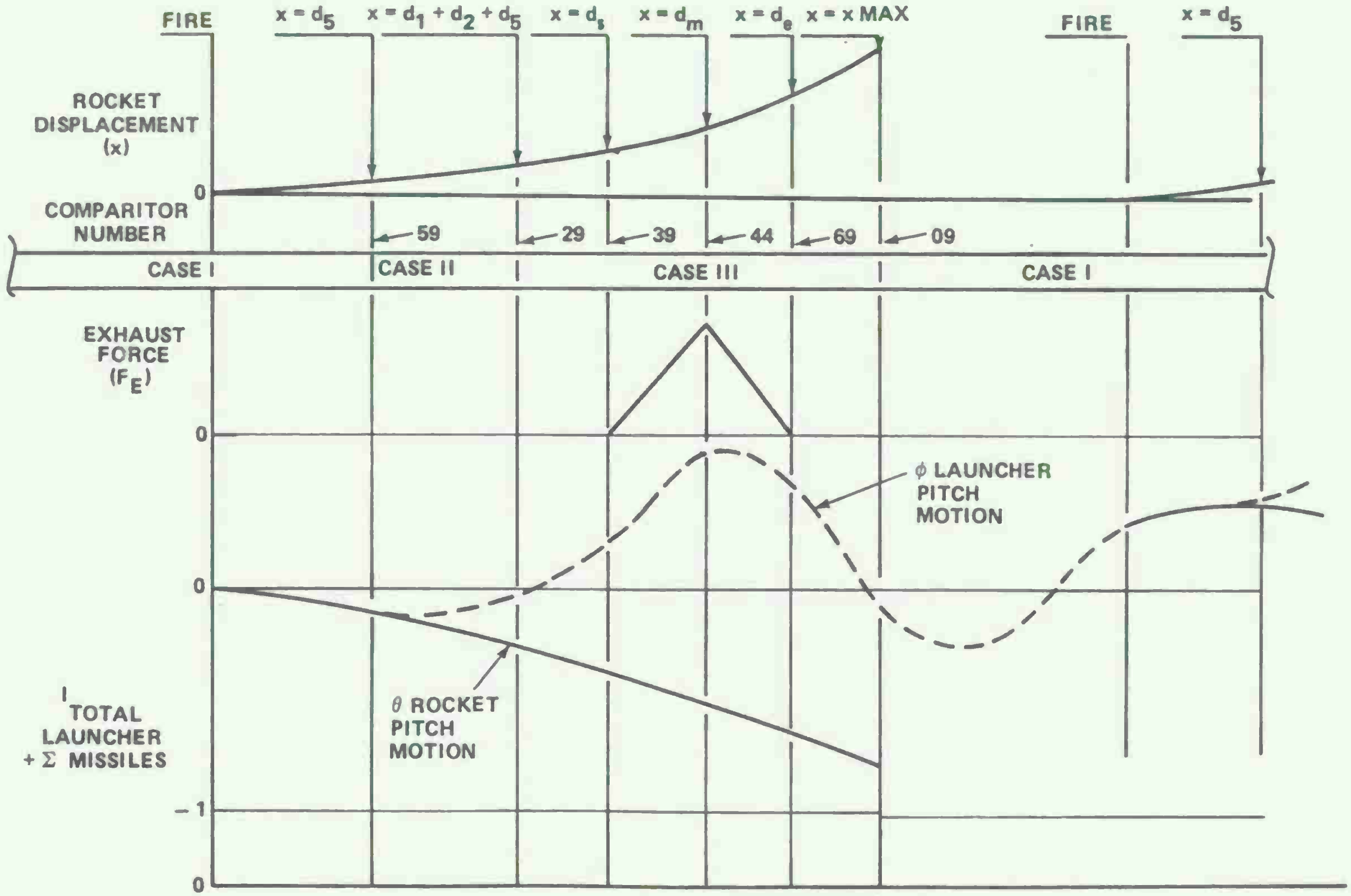


Figure 4. Timing and logic for one rocket fired in the sequence.

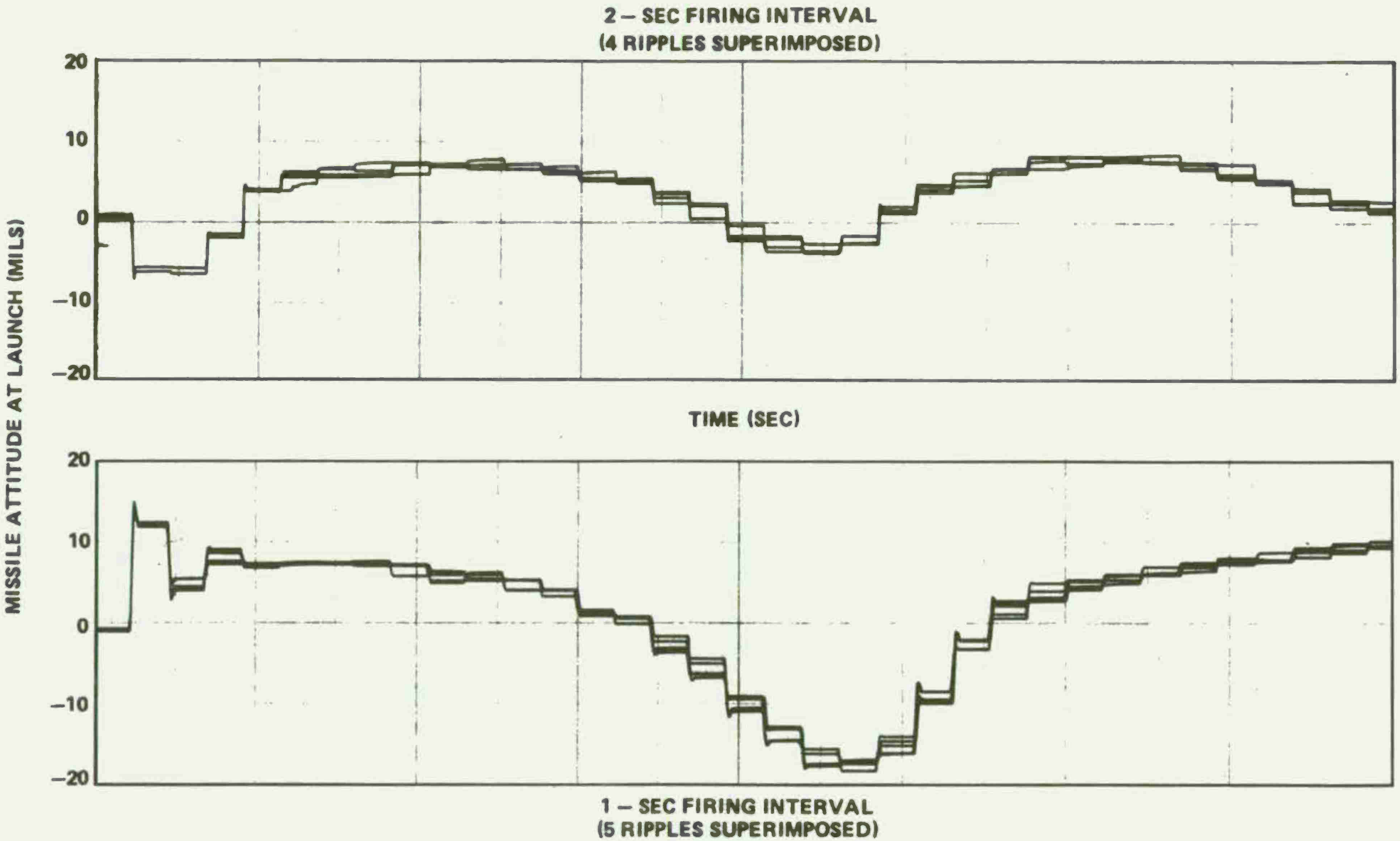


Figure 5. Missile pitch attitude at launch.

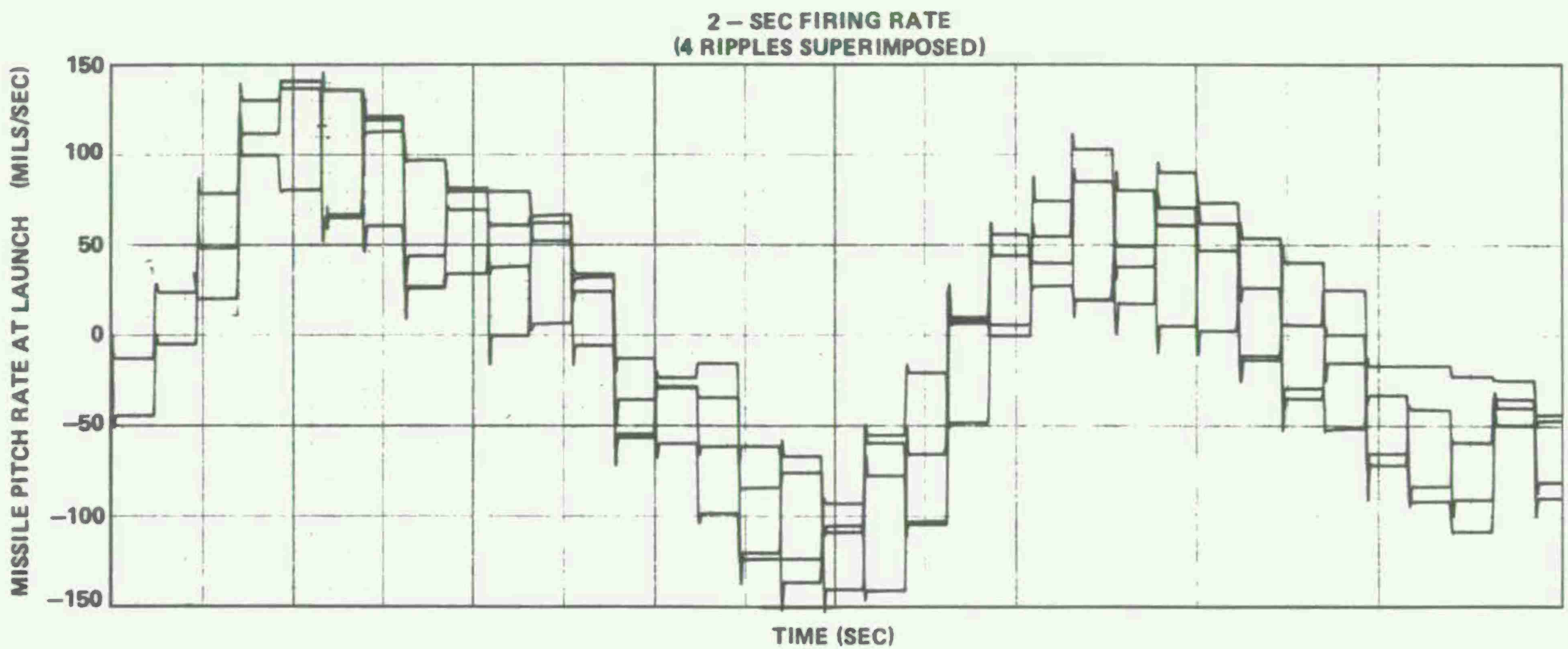


Figure 6. Missile pitch rate at launch — 2 second firing interval.

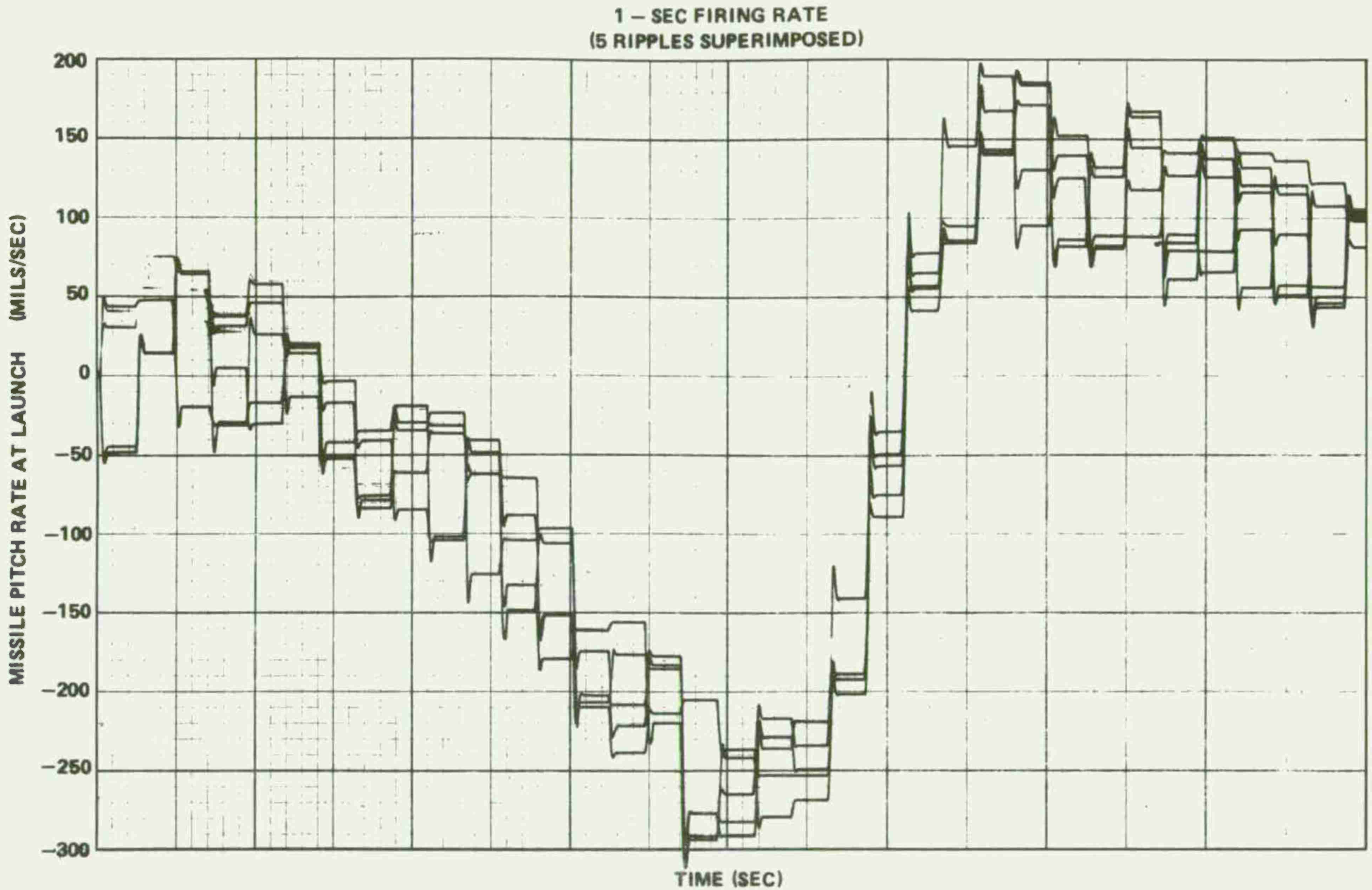


Figure 7. Missile pitch rate at launch — 1 second firing interval.

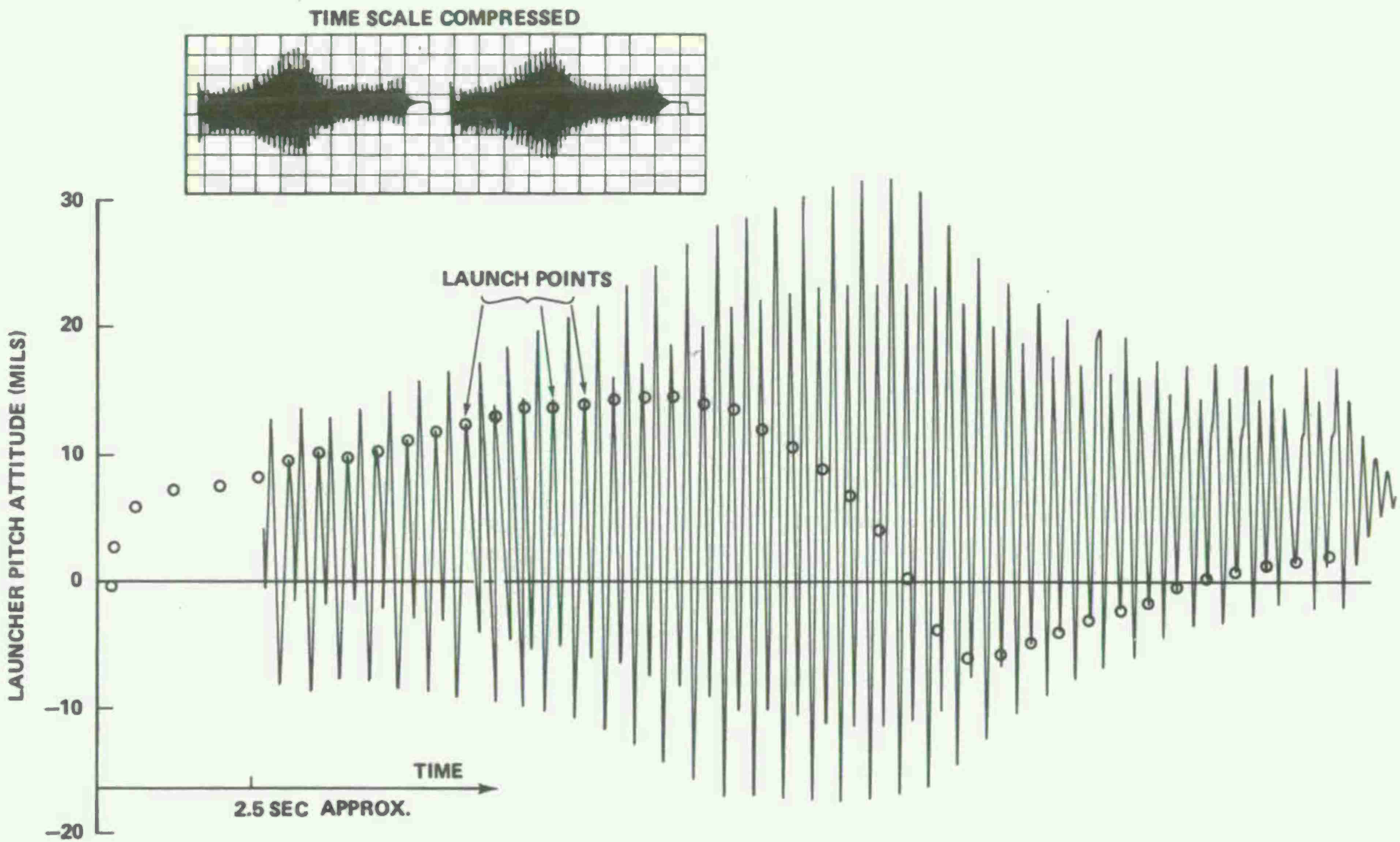
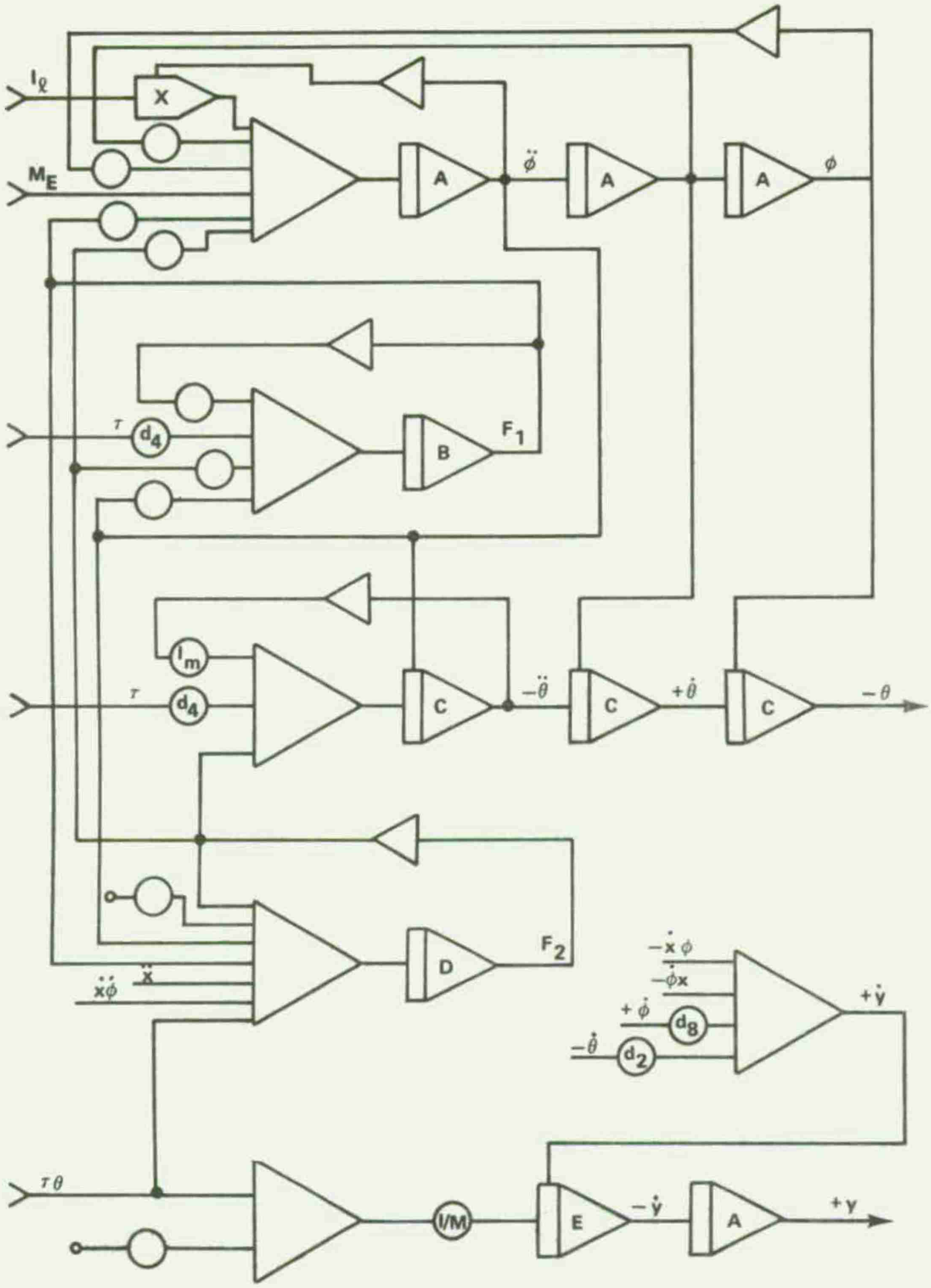


Figure 8. Launcher motion versus time.

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.

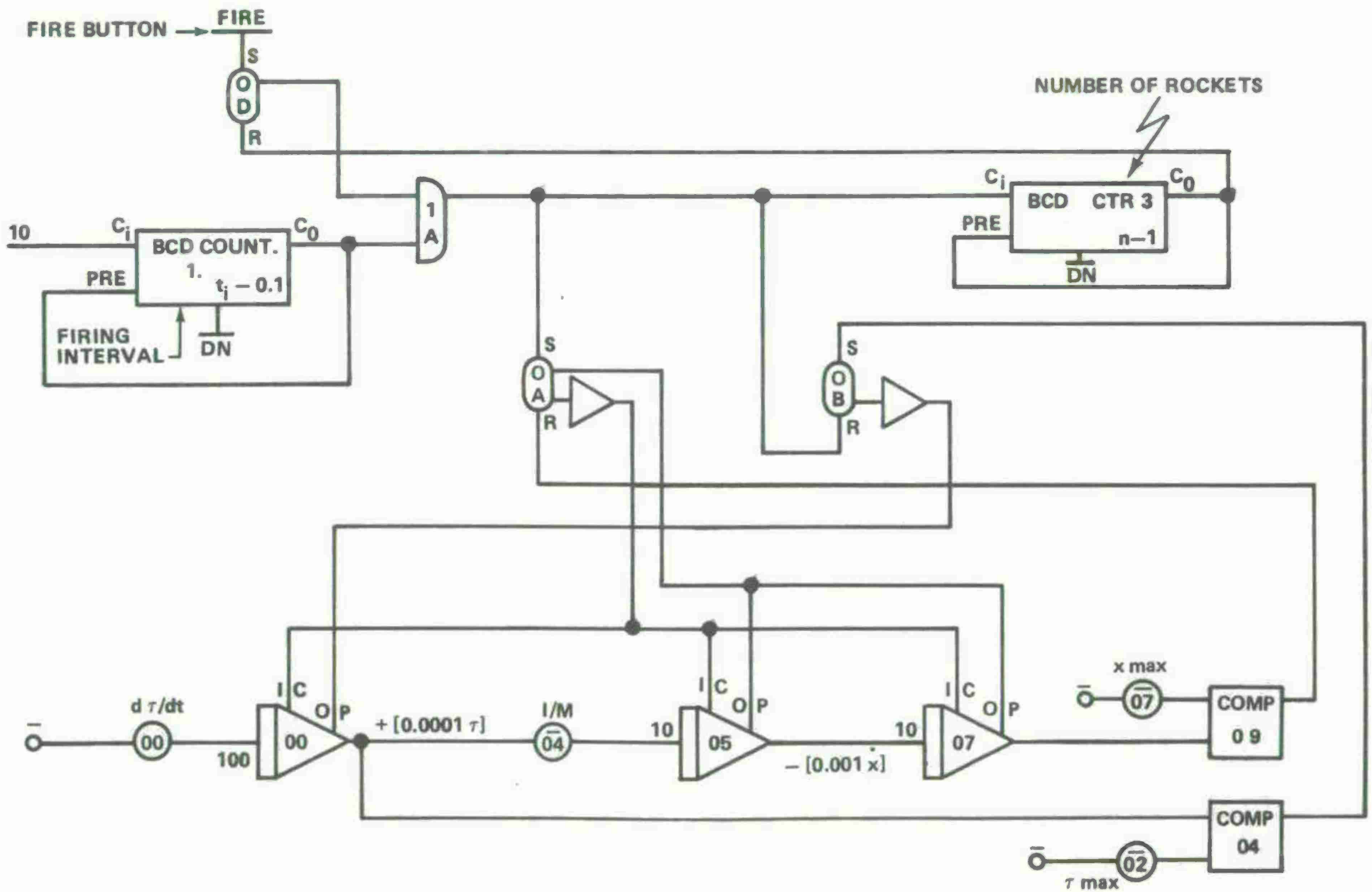


Figure A-2. Multiple rocket firing simulation (thrust and rocket translation).

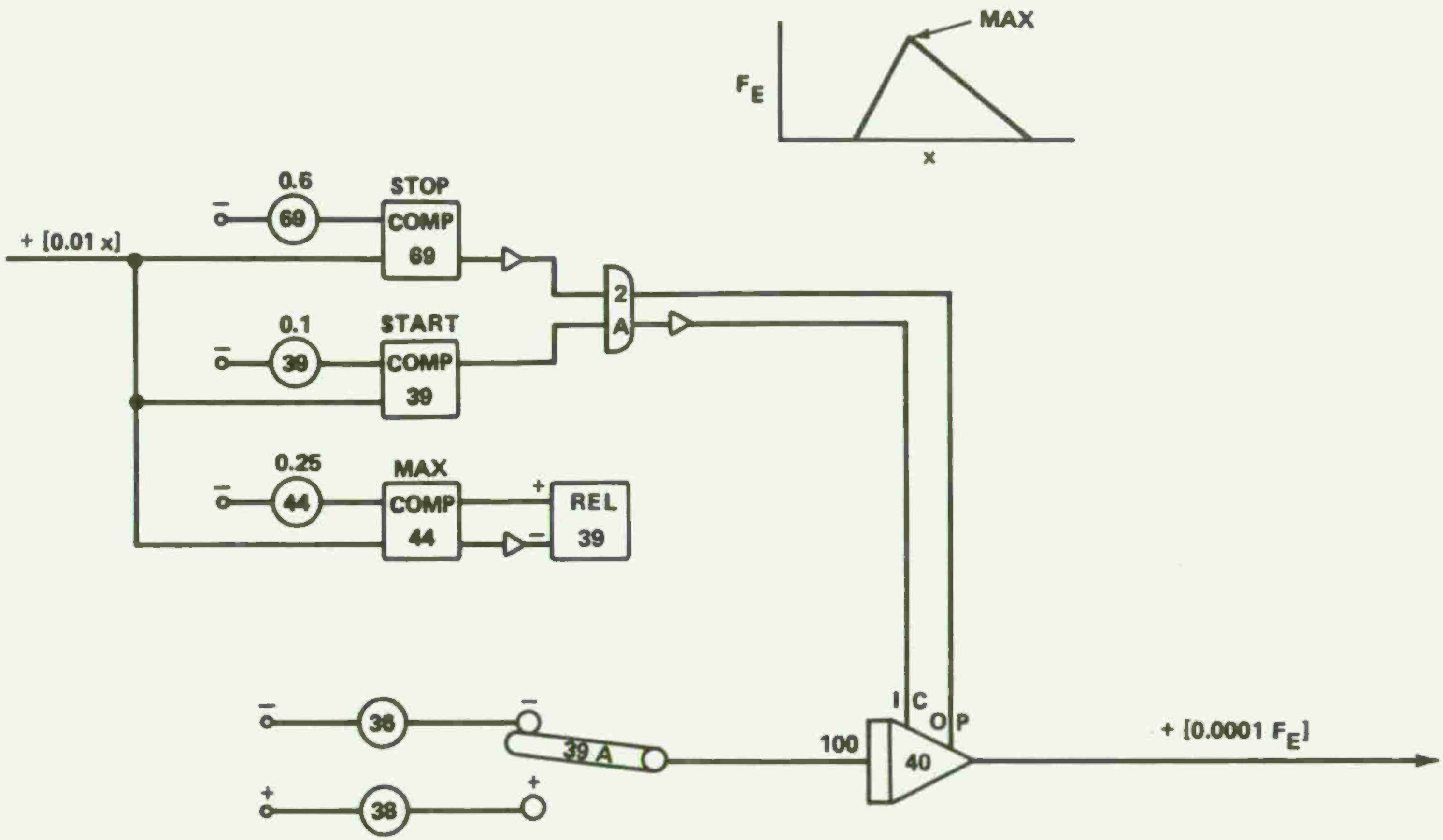


Figure A-3. Exhaust gas impingement force.

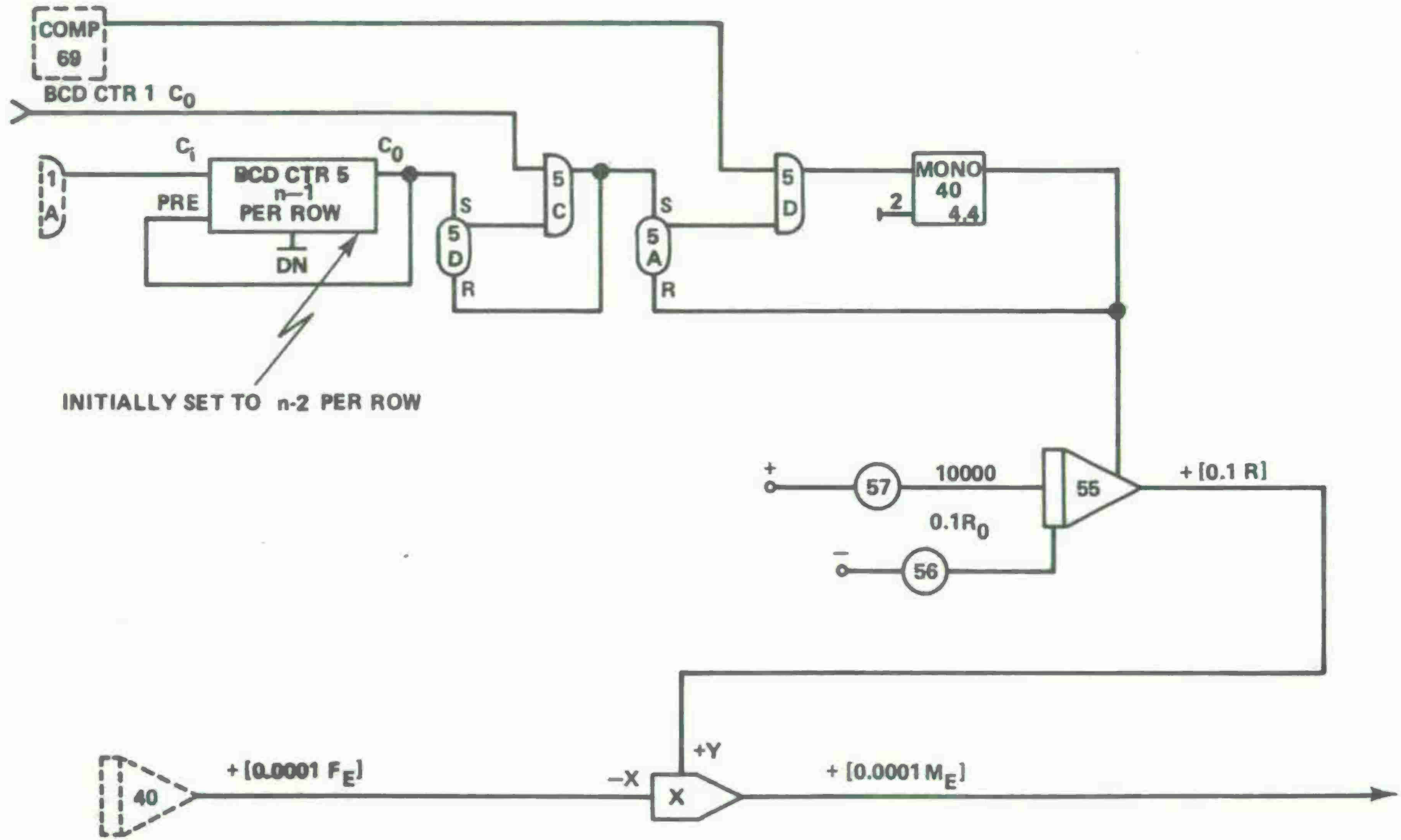


Figure A-4. Exhaust gas impingement moment arm and moment generation (pitch motion).

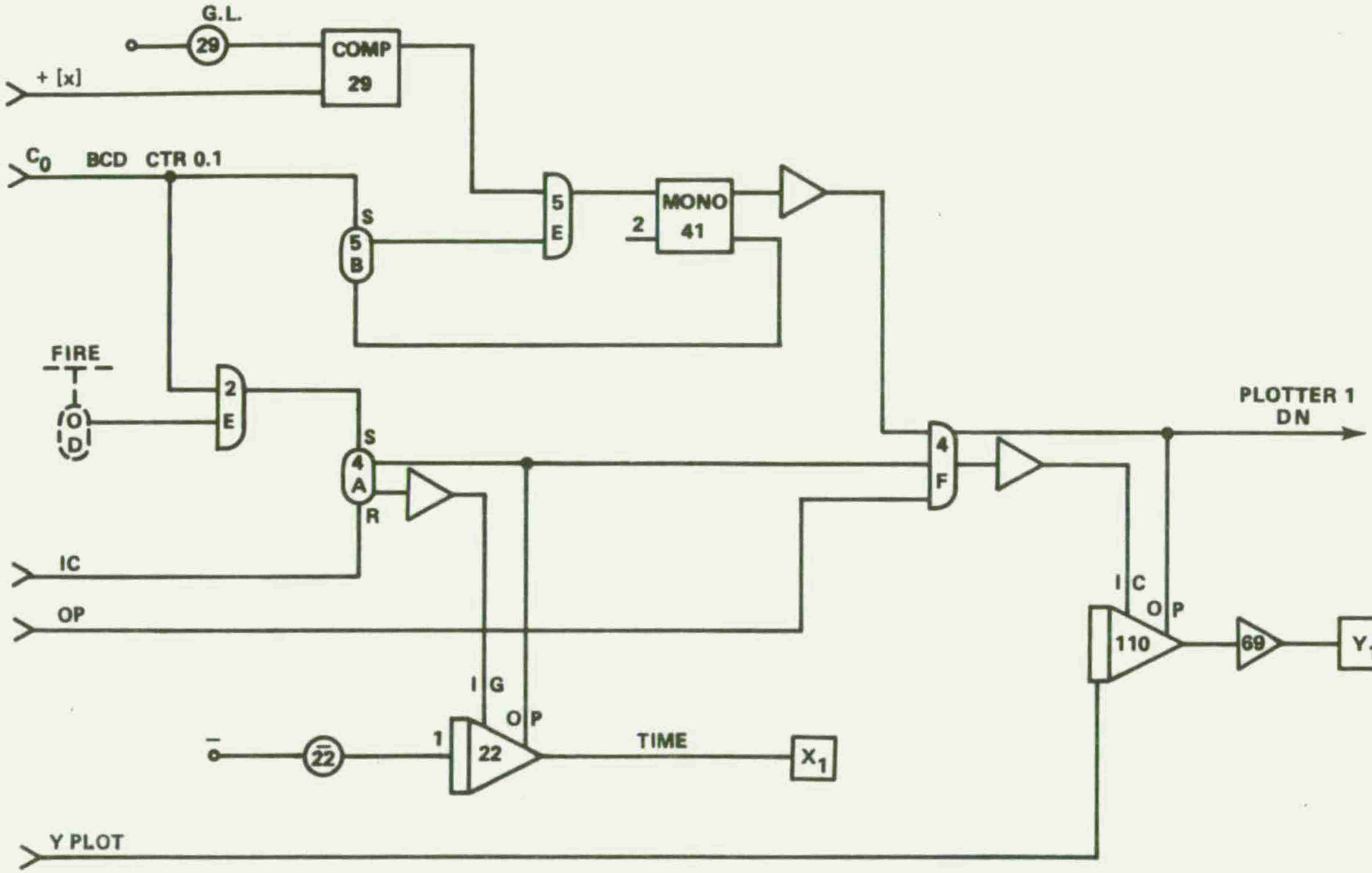


Figure A-5. Plotting values at end of guidance.

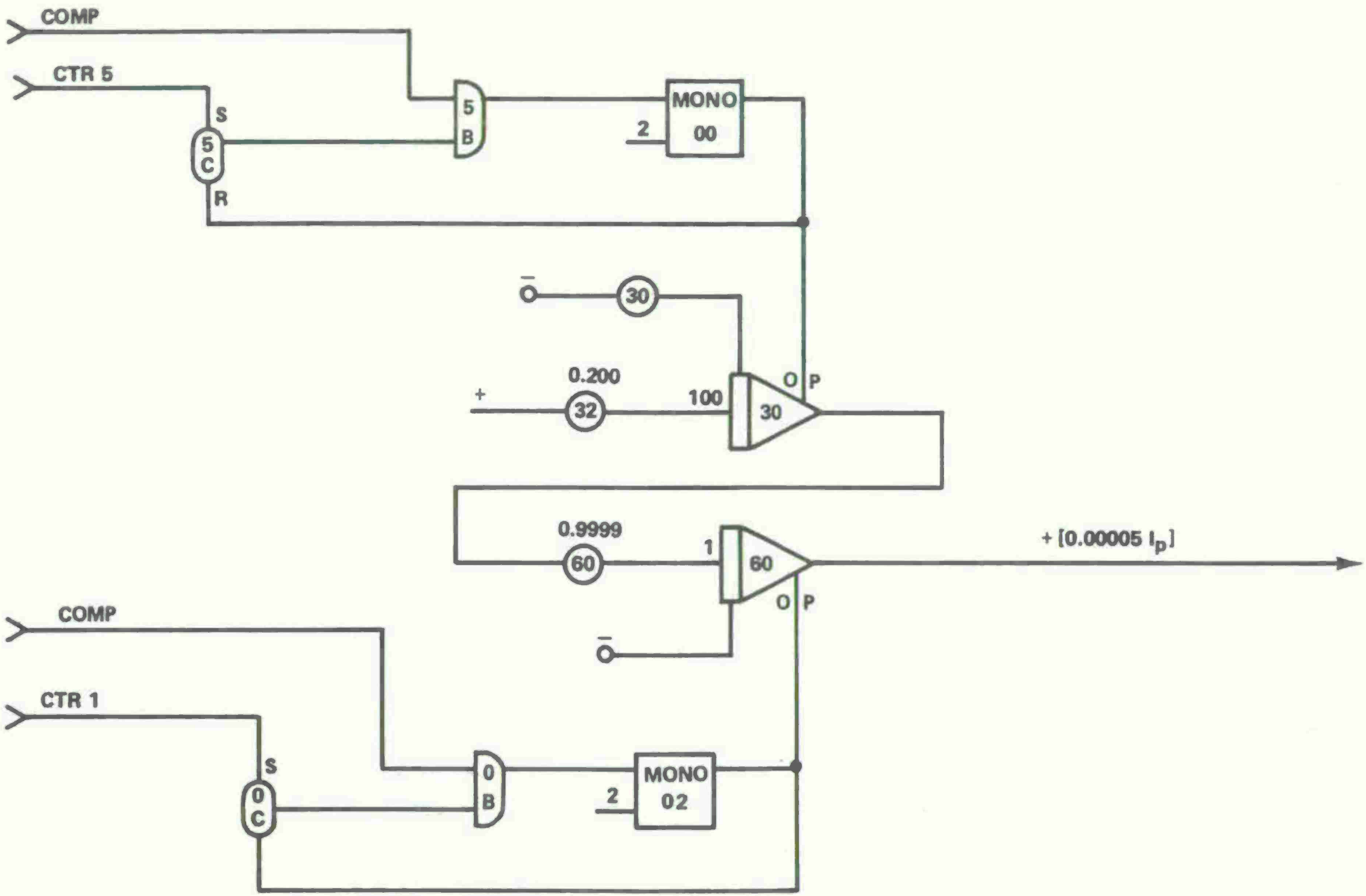


Figure A-6. Total pitch mass moment of inertia minus the missile to be launched.

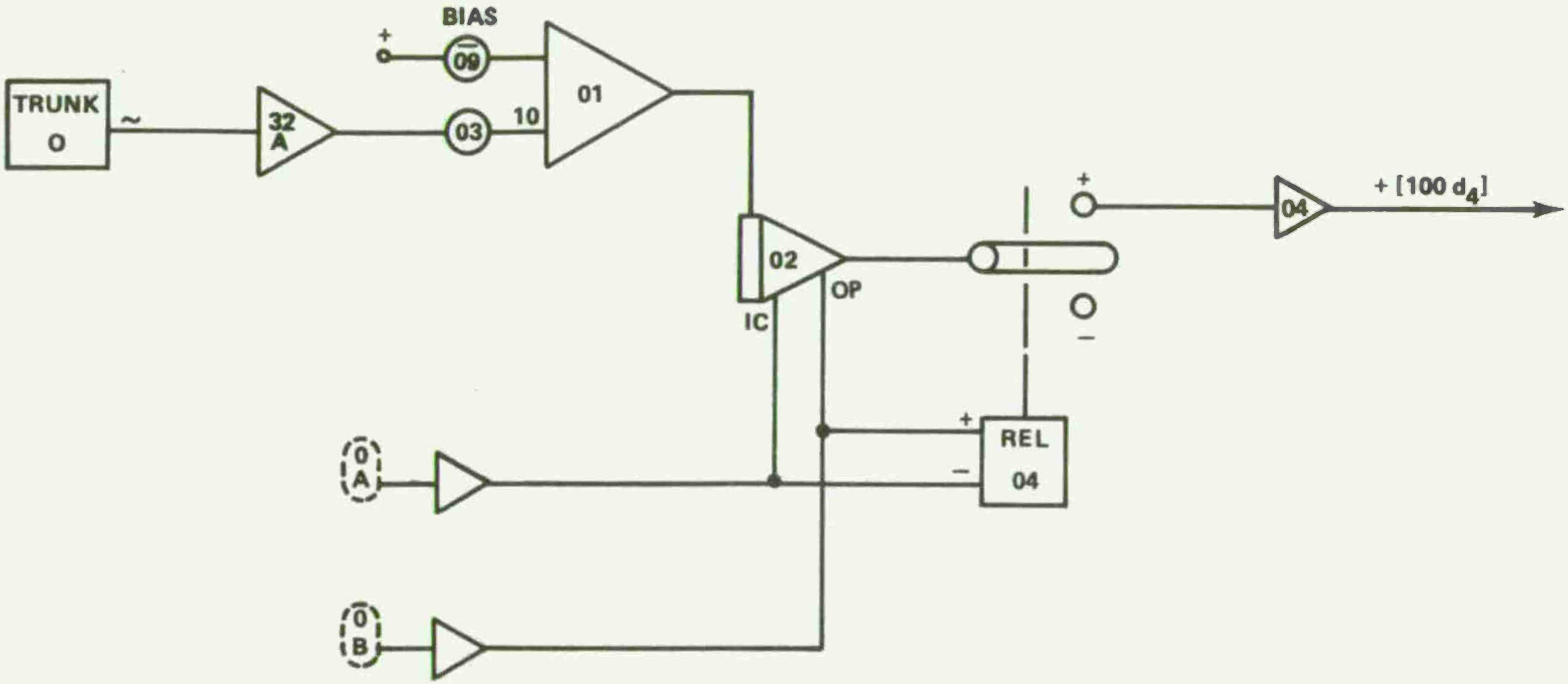


Figure A-7. Variable thrust misalignment (d_4) (random).

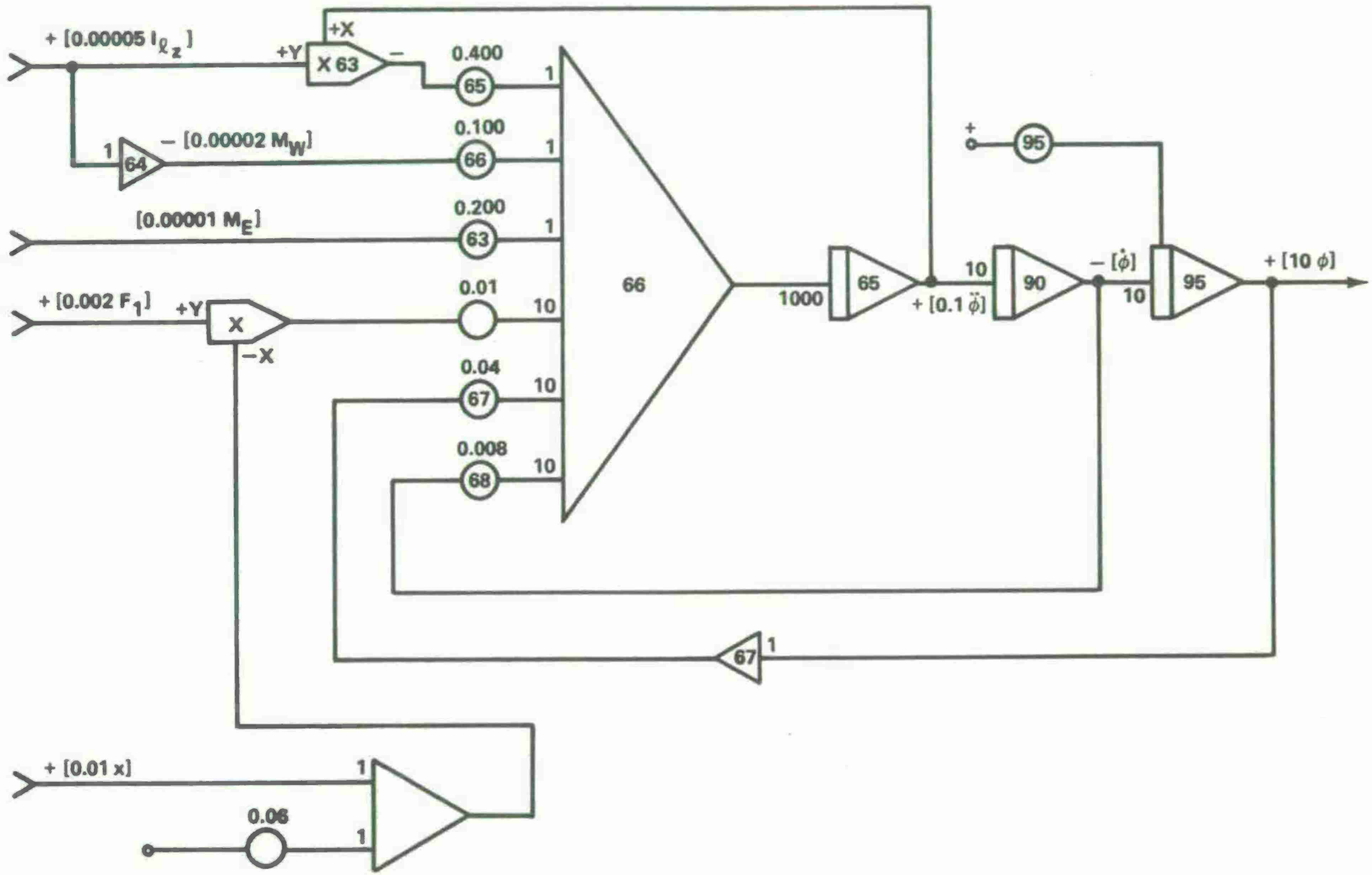


Figure A-8. Launcher pitch motion.

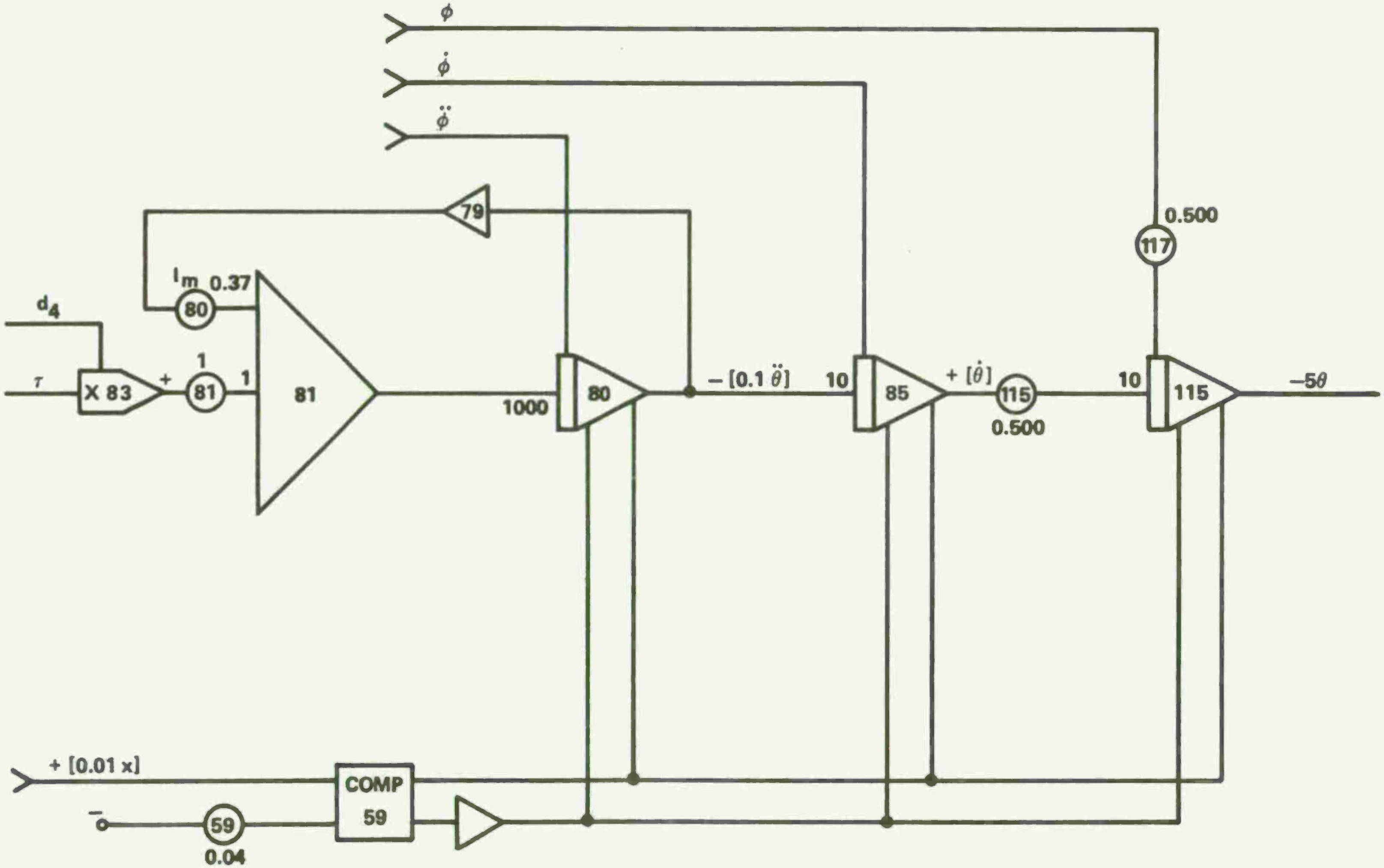
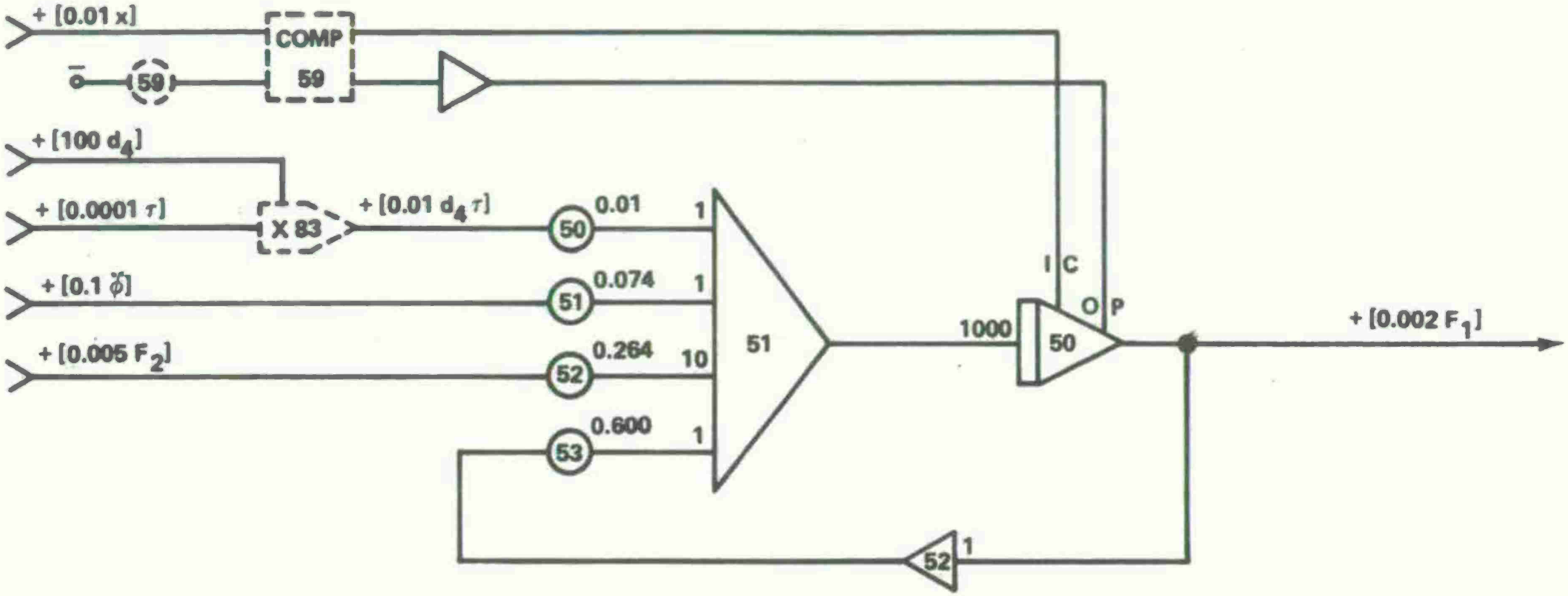


Figure A-9. Rocket pitch motion.



EQUATION:
(CASE I)

$$d_1 F_1 - I_{m_z} \ddot{\phi} - d_2 F_2 - \tau d_4 = 0$$

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

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

$$(0.6000)\,[0.002\,F_1] - (0.0740)\,[0.1\,\ddot{\phi}] - (0.2640)\,10\,[0.005\,F_2] - (0.0200)\,[0.01\,d_4\,\tau] = 0$$

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

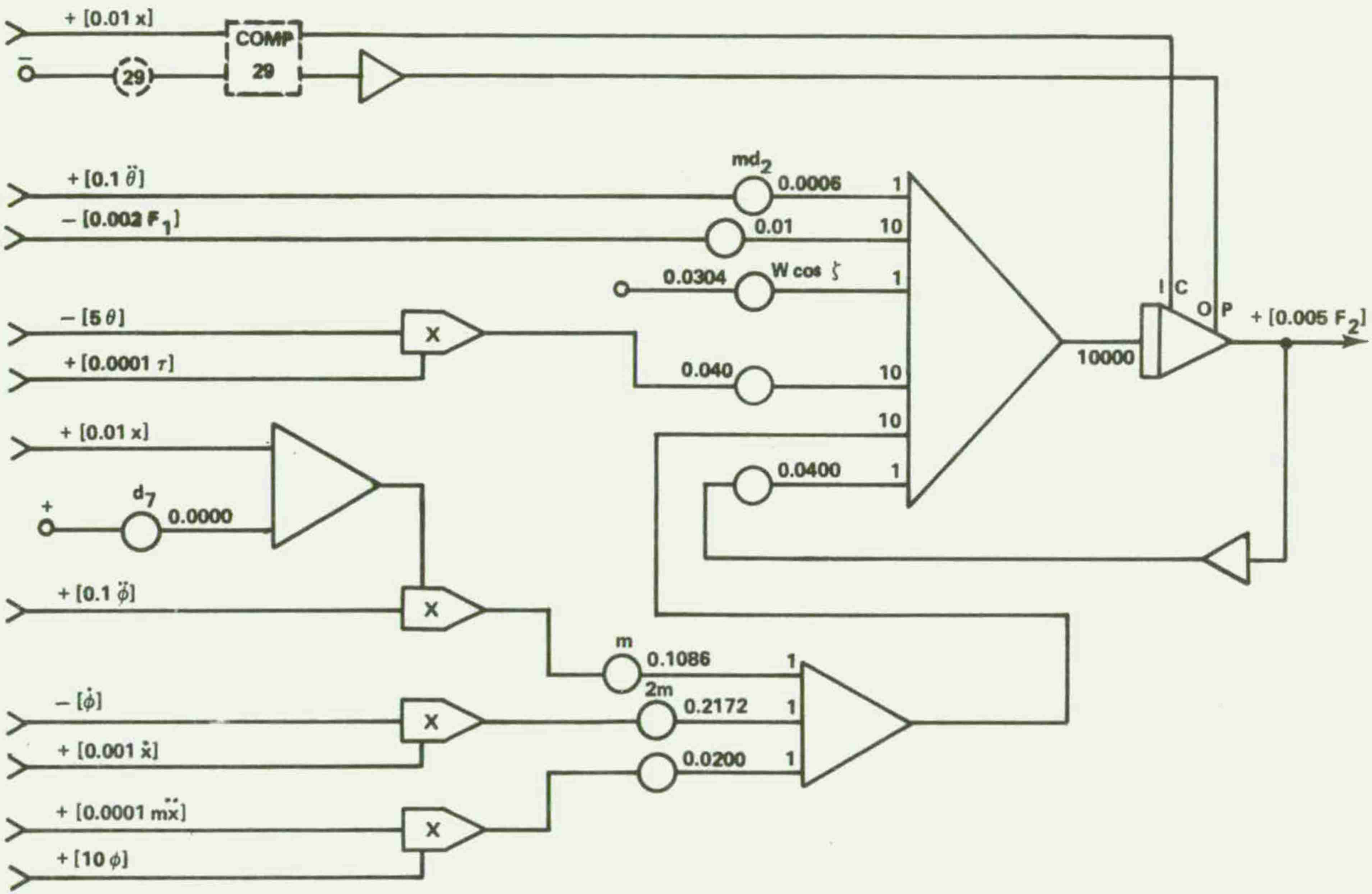


Figure A-11. Aft vertical missile – tube reaction force (F_2).

Appendix B

EQUATIONS OF PITCH MOTION

I. PITCH PLANE EQUATIONS OF MOTION

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

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

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

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

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

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

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

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

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

$$m (d_7 + x) \ddot{\phi} + md_2 \ddot{\theta} - F_2 + m\phi \ddot{x} + 2 m \dot{x} \dot{\phi} + W \cos \xi - \tau \theta = 0 \quad . \quad \text{(B-8)}$$

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

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

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

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

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

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
γ_1	Initial position of r_1
γ_2	Initial position of r_2
τ	rocket thrust

ϕ	Launcher pitch motion
λ	Launcher yaw motion
θ	Rocket pitch motion
ψ	Rocket yaw motion
γ	Rocket roll or spin motion
ξ	Launcher firing attitude (QE)

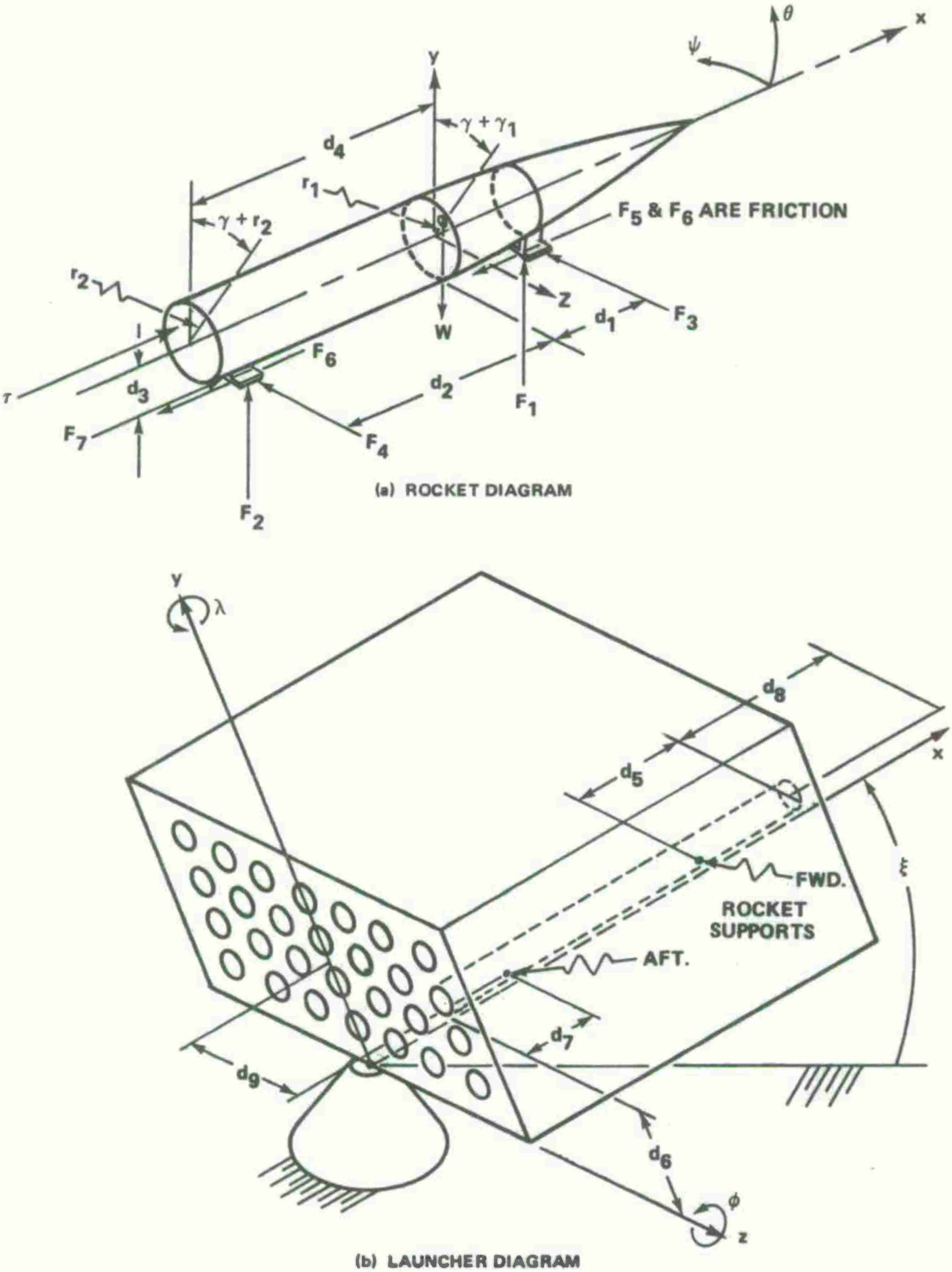


Figure B-1. Free body diagrams.

DISTRIBUTION

	No. of Copies
Defense Documentation Center Cameron Station Alexandria, Virginia 22314	12
Commander US Army Materiel Development and Readiness Command Attn: DRCRD DRCDL 5001 Eisenhower Avenue Alexandria, Virginia 22333	 1 1
Commander US Army Infantry School Attn: ATSH-CD Fort Benning, Georgia 31905	1
Commander US Army Ballistic Research Laboratories Attn: AMXBR-EB Aberdeen Proving Ground, Maryland 21005	1
Headquarters Rome Air Development Center (AFSC) Attn: TLLD Griffiss Air Force Base, New York 13440	1
Commander White Sands Missile Range Attn: STEWS-AD-L White Sands Missile Range, New Mexico 88002	1
Assistant Commander US Army Armor School Attn: ATSB-CD-M Fort Knox, Kentucky 40121	1
Library US Army War College Carlisle Barracks, Pennsylvania 17103	1
Commander Edgewood Arsenal Attn: SAREA-TS-L Aberdeen Proving Ground, Maryland 21010	1

	No. of Copies
Jet Propulsion Laboratory California Institute of Technology Attn: Library/Acquisitions 111-113 4800 Oak Grove Drive Pasadena, California 91103	1
Commander US Naval Missile Center Attn: Code 5632.2 Point Mugu, California 93042	1
Commander US Army Air Defense School Attn: ATSA-CTD-MO Fort Bliss, Texas 79916	1
Technical Library Naval Ordnance Station Indian Head, Maryland 20640	1
Commander US Naval Weapons Laboratory Attn: Technical Library Dahlgren, Virginia 22448	1
Commander Rock Island Arsenal Attn: SARRI-LP-L/Technical Library Rock Island, Illinois 61201	1
Commander (Code 533) Naval Weapons Center Technical Library China Lake, California 93555	1
Commander USACACDA Fort Leavenworth, Kansas 66027	1
US Army Research Office Attn: Information Processing Office Box CM, Duke Station Durham, North Carolina 27706	1
Commander US Army Air Defense School Attn: ATSA-TE-CSM Fort Bliss, Texas 79916	1

	No. of Copies
Commander US Army Air Defense School Attn: ATSA-CTD-TLW Fort Bliss, Texas 79916	1
US Army Command and General Staff College Attn: ATSW-SE-L Fort Leavenworth, Kansas 66027	1
Commander US Army Aberdeen Proving Ground Attn: STEAP-TL Aberdeen Proving Ground, Maryland 21005	1
Department of the Navy Commander, Operational Test and Evaluation Force Attn: Technical Library Norfolk, Virginia 23511	1
DRSMI-R, Dr. McDaniel	1
Dr. Kobler	1
-FR, Mr. Strickland	1
-LP, Mr. Voigt	1
-RBD	3
-RL	1
-RLH	20
-RFA	1
-RFG	1
-RD	1
-RK	1
-RT	1
-RPR (Record Copy)	1
(Reference Copy)	1