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INTEGRATED MANEUVERING AND LIFE SUPPORT SYSTEM SIMULATION FINAL REPORT

APRIL 1969

A. E. Wudell
L. M. Hunt
D. M. Adams

Prepared Under Contract No. NAS9-9109

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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FOREWORD

The research described in this report (Integrated Maneuvering and Life Support System Simulation, National Aeronautics and Space Administration Contract NAS9-9109) was performed by Martin Marietta Corporation, Denver Division, P. O. Box 179, Denver, Colorado, for the NASA Manned Spacecraft Center, Houston, Texas. Major C. E. Whitsett, Jr. (Principal Investigator for Experiment M-509 "Astronaut Maneuvering Equipment") was the NASA Program Manager and the test subject.

Allwin E. Wudell, Larry M. Hunt, and Dennis M. Adams performed the program planning, derivation of the equations, performed the simulation, and wrote the body of this report. John W. Sabo and Donald L. Rittenhouse aided in performing the simulation and writing the report. Arlen W. Schlaht and Walter F. Thiemet aided in setting up and performing the simulation. Mr. Allwin E. Wudell was Martin Marietta's Program Manager. This report was submitted by the authors April, 1969

ABSTRACT

This report describes a study effort on the comparison, through simulation, of the performance of four configurations of an Integrated Maneuvering and Life Support System (IMLSS). Variations in angular and rotational acceleration levels comprised the differences between configurations. Direct control in both attitude and translation was used. Data was collected on the performance of each configuration for one test subject flying a sequence of four space tasks. The tasks included: moving inspection, translating around corner, workshop excursion and LM-CSM transfer. C.G. shifts and inertia dyadic changes were also investigated.

Martin Marietta Corporation's Space Operations Simulation facility was used for the study. The test subject was suspended in the gimbaled head of the six-degree-of-freedom servo-driven moving base simulator. The simulation technique involves computation of the problem dynamics on a hybrid computer which then determines the commands for the moving base. Instrumented maneuvering unit hand controller mockups are used by the test subject. Signals from the hand controller mockups are used in the hybrid program to introduce the thrust histories.

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LIST OF ABBREVIATIONS AND SYMBOLS

IMLSS	-	Integrated Maneuvering and Life Support System
BP	-	Backpack maneuvering unit
X	-	Lateral position of system c.g. in inertial frame
Y	-	Longitudinal position of system c.g. in inertial frame
Z	-	Vertical position of system c.g. in inertial frame
$\dot{X}$	-	Lateral velocity of system c.g. in inertial frame
$\dot{Y}$	-	Longitudinal velocity of system c.g. in inertial frame
$\dot{Z}$	-	Vertical velocity of system c.g. in inertial frame
ϕ_c	-	Roll gimbal angle
$\dot{\phi}_1$	-	Time derivative of ϕ_c
θ_c	-	Pitch gimbal angle
$\dot{\theta}_1$	-	Time derivative of θ_c
ψ_c	-	Yaw gimbal angle
$\dot{\psi}_1$	-	Time derivative of ψ_c
$\bar{\xi}$	-	A 1 x 3 matrix defined to be $\begin{bmatrix} \phi \\ \theta_c \\ \psi_c \end{bmatrix}$
$\dot{\bar{\xi}}$	-	Time derivative of $\bar{\xi}$
p	-	Angular rate about body fixed x axis
q	-	Angular rate about body fixed y axis
r	-	Angular rate about body fixed z axis

LIST OF ABBREVIATIONS AND SYMBOLS Cont'd.

$\overline{F}_m$ - Total external forces acting on human system

$\overline{F}_j$ - Force due to jet thrusters

$_1F_x$ - Thruster force along x direction in body fixed coordinates

$_1F_y$ - Thruster force along y direction in body fixed coordinates

$_1F_z$ - Thruster force along z direction in body fixed coordinates

$\overline{F}_B$ - Forces acting upon human system due to BP thrusters

$_SF_{BX}$ - Lateral force acting on human system from BP thrusters expressed in inertial coordinates

$_SF_{BY}$ - Longitudinal force acting on human system from BP thrusters expressed in inertial coordinates

$_SF_{BZ}$ - Vertical force acting on human system from BP thrusters expressed in inertial coordinates

$\overline{F}_L$ - Forces acting upon the load cell array

$\overline{M}_M$ - Total external moments applied to the human system about the system c.g.

$\overline{M}_J = \overline{M}_{JT}$ - External moments applied to the human system about the system c.g. due to jet thrusters

$\overline{M}_B$ - External moments applied to the human system by the BP about the BP c.g.

$_1M_{MBX}$ - The x component of total external moments applied to the human system about the system c.g. due to BP thrusters expressed in body fixed coordinates

$_1M_{MBY}$ - The y component of total external moments applied to the human system about the system c.g. due to BP thrusters expressed in body fixed coordinates

LIST OF ABBREVIATIONS AND SYMBOLS Cont'd.

${}_1M_{MBZ}$ - The z component of total external moments applied to the human system about the system c.g. due to BP thrusters expressed in body fixed coordinates

M_{BX} - The x component of the external moments applied to the human system due to BP thrusters about the BP thruster geometric center expressed in coordinates fixed in the BP

M_{BY} - The y component of the external moments applied to the human system due to BP thrusters about the BP thruster geometric center expressed in coordinates fixed in the BP

M_{BZ} - The z component of the external moments applied to the human system due to BP thrusters about the BP thruster geometric center expressed in coordinates fixed in the BP

$\overline{M}_L$ - Moments applied to the load cell array resolved about a point fixed in inertial space

$\overline{R}_m$ - Position vector from an inertially fixed point, Q, to the composite center of mass of the human system

$\ddot{\overline{R}}_m$ - Second time derivative of $\overline{R}_m$ differentiation carried out in an inertially fixed reference frame

$\overline{R}_1$ - Position vector from combined c.g. to the center of mass of segment 1

$\ddot{\overline{R}}_1$ - Second time derivative of $\overline{R}_1$ differentiation carried out in an inertially fixed reference frame

$\overline{r}_i$ - Position vector from the c.g. of the human system to the c.g. of the ith segment

${}_1\dot{\overline{r}}_i$ - Derivative of $\overline{r}_i$. Differentiation carried out in a reference frame fixed in the torso

$\overline{\omega}_{ij}$ - Angular velocity of body i relative to reference frame j

ϕ_i, θ_i, ψ_i - Three axes Euler angles which define the attitude of body i

$\overline{H}_i$ - Angular momentum of ith body about center of mass of human system relative to an inertially fixed reference frame

$\overline{H}_T$ - Angular momentum of human system about the center of mass of the human system relative to an inertially fixed reference frame

$\dot{\overline{H}}_T$ - Time derivative of $\overline{H}_T$. Differentiation performed in an inertially fixed reference frame

$\overline{\overline{D}}_{i,\,j}$ - Transformation matrix from segment i to segment j

$\overline{\overline{U}}$ - Unit dyadic

$\overline{\overline{A}}$ - Dyadic defined on page 28

$\overline{\overline{A}}^{-1}$ - The inverse of $\overline{\overline{A}}$

$\overline{\overline{T}}$ - Dyadic defined on page 28

$\overline{B}$ - Vector defined on page 28

m_i - Mass of segment i

m_m - Mass of human system

${}_1\overline{\overline{II}}_m$ - Inertia dyadic for the human system about the c.g. of the human system

I_{XX}, I_{YY}, I_{ZZ}, I_{XY}, I_{XZ}, I_{YZ} - Components of the inertia dyadic for the system comprized of man and the BP about the c.g. of this system for axes fixed in the torso.

ρ'_c - BP roll command

θ'_c - BP pitch command

ψ'_c - BP yaw command

X'_c - BP longitudinal command

LIST OF ABBREVIATIONS AND SYMBOLS Cont'd.

Y'_c - BP lateral command

Z'_c - BP vertical command

IT - Product of total impulse and time consumed during maneuver

I_x - Longitudinal impulse

I_y - Lateral impulse

I_z - Vertical impulse

I_T - Total translational impulse

I_ϕ - Roll impulse

I_θ - Pitch impulse

I_ψ - Yaw impulse

I_R - Total rotational impulse

I - Total impulse

SECTION I

INTRODUCTION

This document is the result of a NASA contract with the Denver Division of the Martin Marietta Corporation. The overall objective of this contract was to provide data on the performance of four configurations of an Integrated Maneuvering and Life Support System (IMLSS). The configurations differed in translational and rotational acceleration levels. Also the effects of c.g. shifts and inertia cross-product changes were investigated. One test subject, Major C.E. Whitsett, Jr., flew a series of four simulated space tasks for each configuration. Each of the space task runs was repeated five times. The data gathered will be used to support NASA Experiment M-509 "Astronaut Maneuvering Equipment" which is to be conducted inside a Saturn IVB Orbital Workshop (OWS) as part of the Apollo Applications Program. Several of the maneuvering tasks and part of the target configuration were representative of the M-509 requirements. The M-509 experiment is described in reference 1. The IMLSS is an advanced development program jointly sponsored by NASA MSC and the U. S. Air Force 6570th Aerospace Medical Research Laboratories. The data gathered supplements the IMLSS program by providing performance data for future applications of the IMLSS, as well as providing, a base for trade studies to optimize the IMLSS design.

Martin Marietta Corporation's Space Operations Simulation Facility was used for the study. The test subject was suspended in the gimbaled head of the six-degree-of-freedom servodriven moving base simulator. The simulation technique involves computation of the problem dynamics on a hybrid computer which then determines the commands for the moving base. Instrumented maneuvering unit hand controller mockups are used by the test subject. Signals from the hand controller mockups are used in the hybrid program to introduce the thrust histories.

The report discusses the major parts of the program in the following series: program plan, maneuvering unit, simulation, data, and conclusions.

SECTION II

PROGRAM PLAN

During the study one test subject performed four designated maneuvers (tasks) using each of three configurations of the Integrated Maneuvering and Life Support System (IMLSS). Also, the effects due to c.g. shifts and large inertia cross-product terms were investigated. Finally a fourth IMLSS configuration was studied.

Prior to collecting data the test subject was familiarized with the simulator and the IMLSS. At the start the subject was allowed to fly IMLSS Configuration 1 for about thirty minutes to gain a feel for the handling characteristics. During this time he sequentially practiced the four maneuvers to be flown for data. The subject was given about ten minutes of practice time for each new configuration prior to collecting data on the maneuvers.

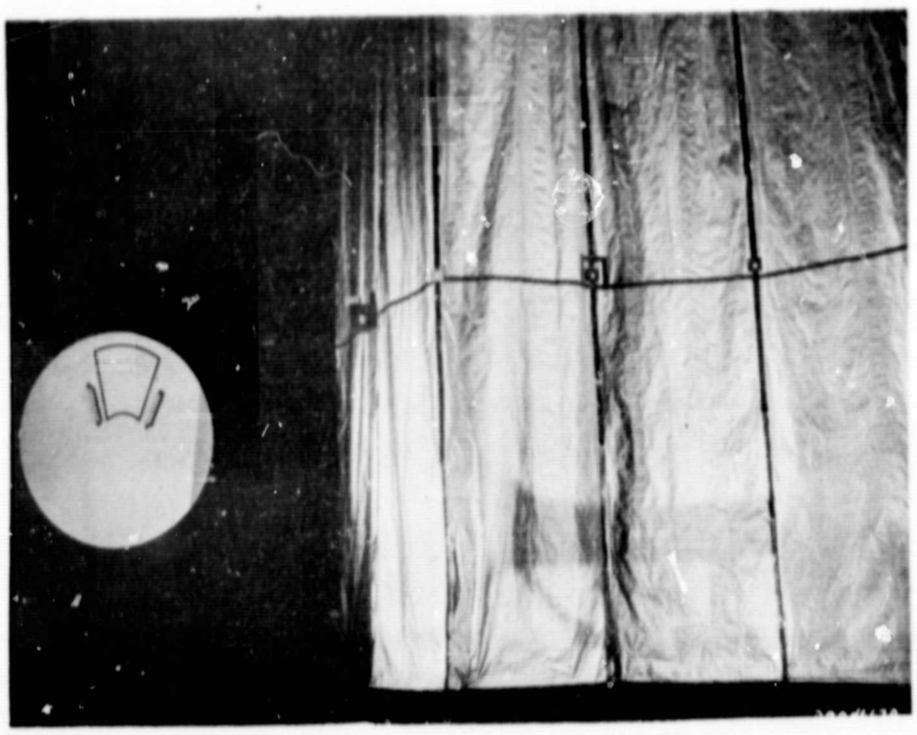
Data was collected for each maneuver for three practice runs and five flight runs. The subject was briefed on the results of his practice runs after completing them. The purpose was to aid the subject in trying to fly the maneuver the same for each IMLSS configuration.

This section discusses the maneuvers, the recorded data format, and the task peculiar data.

1. MANEUVERS

The tasks were flown using the space structure mockup shown in the photos of Figure 1. An S-shaped curtain hung from the ceiling of the simulator room was used for the mockup. It was approximately 20 ft. in height and 40 ft. in length. Top and side projections of the mockup are shown in the drawing of Figure 2. The shape of the curtain was chosen so as to permit most of the tasks to be performed relative to one mockup. The S-shape of the curtain represents a portion of the inside of the 22 ft. diameter S-IVB workshop and an outside portion of a 10 ft. diameter cylindrical space station. In the workshop section of the mockup a horizontal strip of red tape was used to mask the transition from the cylindrical portion of the workshop (lower half on mockup) to the dome. Four foot wide panels were used in the workshop mockup to simulate the panels that will be used in the S-IVB workshop. The vertical seams between the panels were marked

End view



Side view

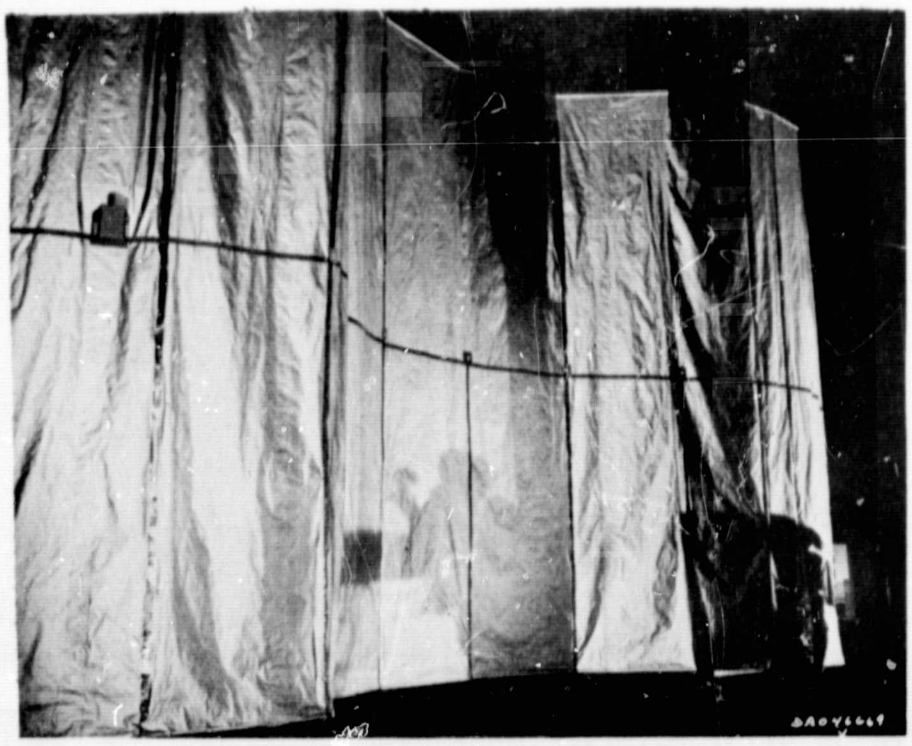
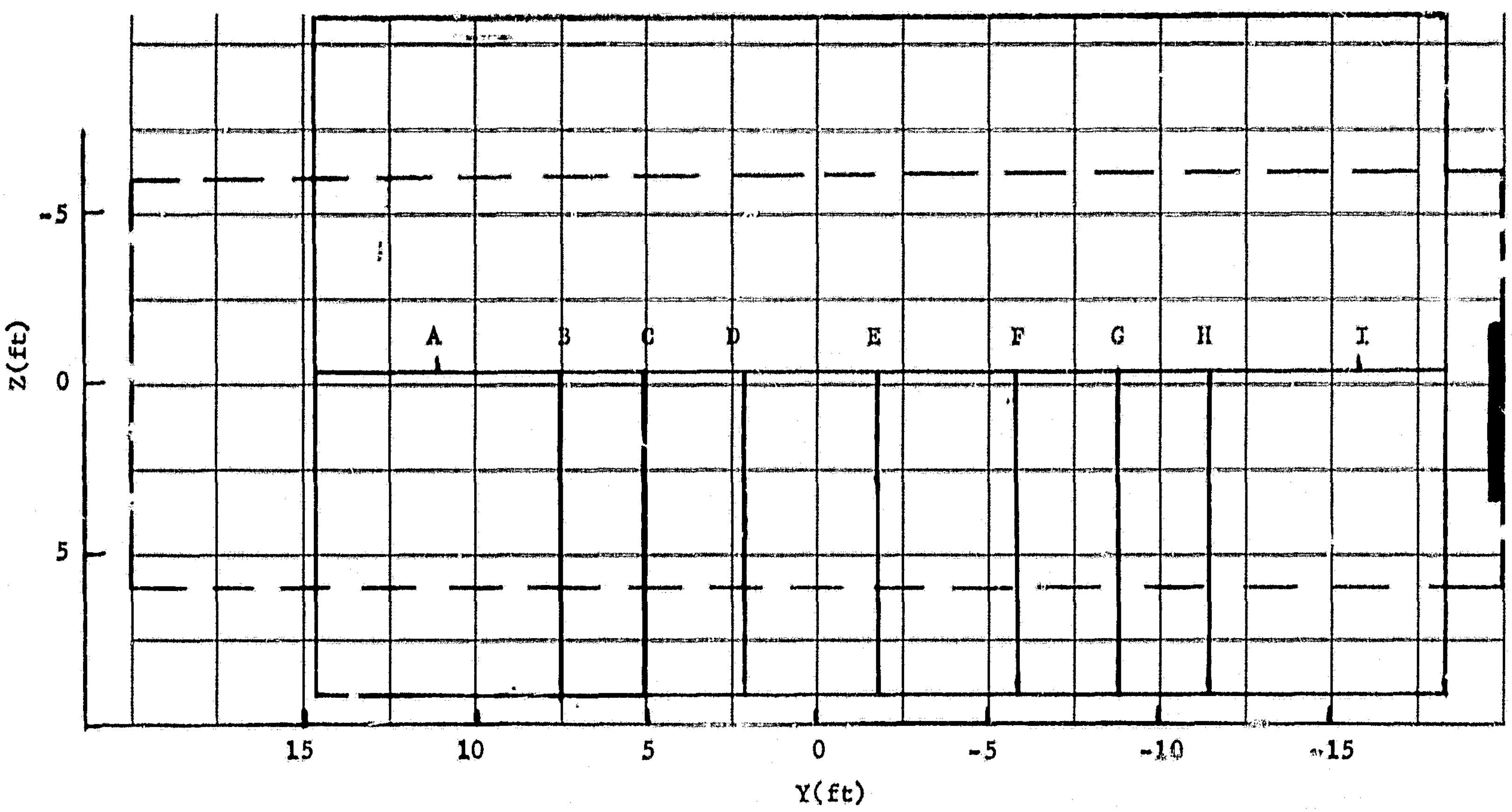


Figure 1 Space Structure Mockup in Simulator Room

Side view



Top view

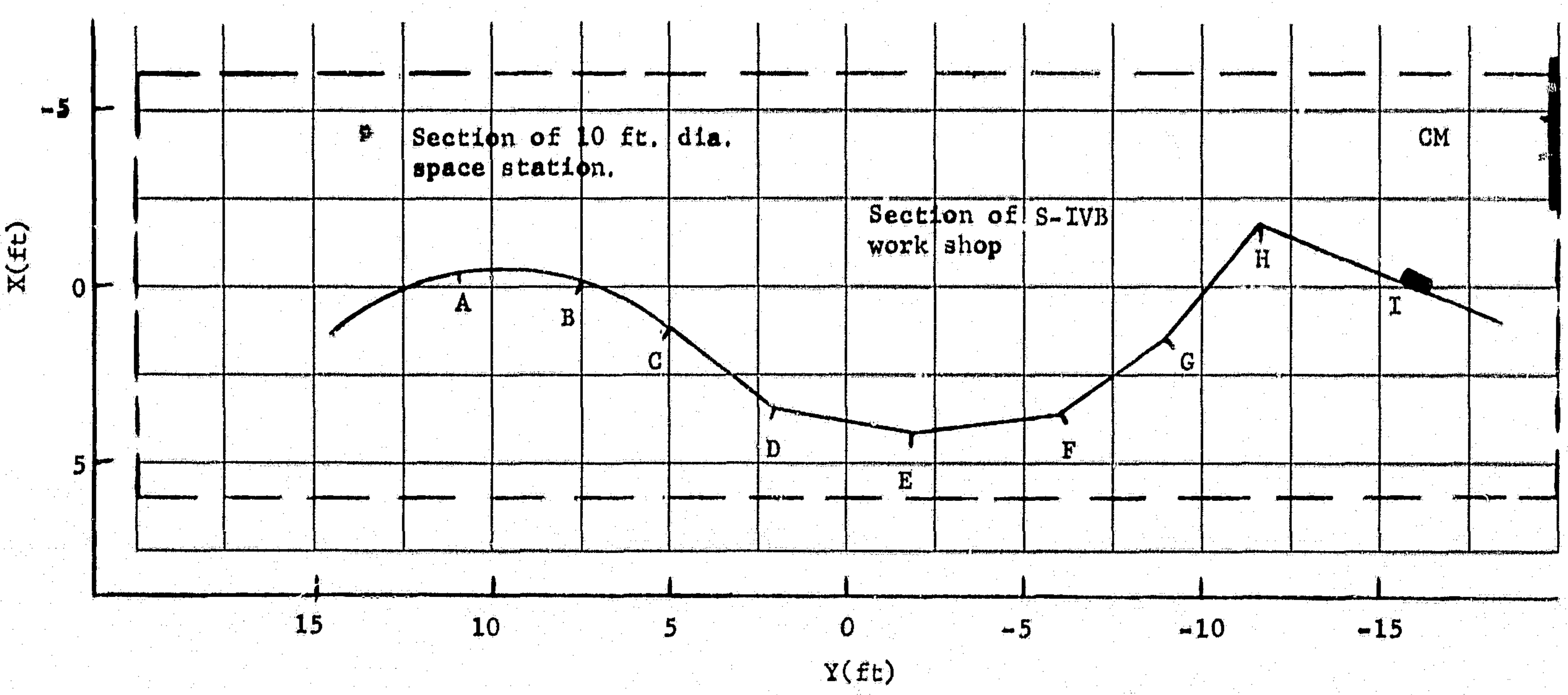


Figure 2 Layout of Space Structures Mockup

with strips of red tape. The tape gave the subject visual cues comparable to those he would have in the space workshop.

The initial conditions used for each of the eight tasks are listed in Table I. The task numbers used in the table correspond to the numbers used in the following description of the tasks.

Table I Task Initial Conditions

Task	X ft	Y ft	Z ft	ϕ_c deg	θ_c deg	ψ_c deg
1	-2.0	15.0	0	0	0	- 90
2	0.3	-8.0	0	0	0	-141
3	-2.5	4.0	4.8	0	0	- 76
4	-1.5	12.0	-2.5	-20	20	90
Both linear and angular rate initial conditions were zero.						

a. Moving Inspection (Task 1) - Starting from a stationary position (Table I) the subject moved horizontally along, without contacting, the S-curved surface of the mockup. He followed the red horizontal transition stripe for his vertical reference. A series of eight cards were hung on the mockup along the horizontal stripe at approximately every four feet. The locations of these cards are marked with letters A thru H on the mockup layout in Figure 2. Each card had five words on it as shown in Table II. These words were readable from 3 ft. or less. The print size used was the same as shown in Table II. The subject was directed to move along the S-curved surface and read the top word on each card aloud for the first run in the series. For the second run he read the second word and so on for the other three runs. The subject practiced the maneuver with different cards having comparable words printed on them. The run was terminated when the subject read the word on the final card. Any subject contacts with the mockup were noted. The objective of the task was to determine how well the subject could perform an inspection of the outside of a 10 ft. diameter space station and the inside of the 22 ft. diameter S-IVB workshop.

Table II Visual Task Cards for Task 1

H	G	F	E	D	C	B	A
coarse	severs	verses	acorns	curses	censor	covers	soccer
insure	corner	nerves	nurses	cornea	movers	waiver	crease
scours	mirror	mosaic	review	soarer	rumors	issues	nearer
rescue	murmur	across	server	scorns	cranes	remiss	arrive
cruise	oceans	scorer	comics	narrow	rivers	simmer	onions

b. Translate Around Corner (Task 2) - This task was performed around the right angle corner of the mockup (point H in Figure 2). The subject started out from a stationary position (Table I) approximately 10 ft. back from the corner along the surface of the workshop section. He was directed to proceed at his initial elevation parallel to the surface of the workshop to the corner. Then he was directed to change his translational velocity so as to move along the straight section of the mockup to a target box (point I in Figure 2). The target box can also be seen in the photos of Figure 1. Upon reaching the target box, the subject had to arrest his velocity conditions enough to permit him to perform two visual tasks and then pick up a small object off the top of the box. The visual task consisted of reading a designated word (like number two) from a listing of eight words on a card. There were two cards. One card was located on the left side of the box and the other card on the right side. The words used on the cards are shown in Table III. After reading the required word on each card, the subject picked up a small

Table III Visual Task Cards for Task 2

1. control	1. target
2. investigator	2. experiment
3. simulation	3. stabilize
4. alignment	4. translate
5. visual	5. facility
6. backpack	6. rotation
7. maneuver	7. mockup
8. technology	8. handgun

object off the top of the box. Once the object was picked up the task was ended. For each of the five runs the subject was informed just prior to the run to read a word next to one of the numbers. Different cards with comparable words were used during the practice runs. The objectives of this task were to determine how well the test subject could make a 90 deg velocity change, perform an inspection involving close in maneuvering, and pick up an object.

c. Workshop Excursion (Task 3) - Starting in a stationary position (Table I) near the right side and bottom of the workshop section of the mockup, the subject was directed to translate across and up the mockup to a point marked by card H (Figure 2). At this point he was instructed to stationkeep briefly. Then he translated horizontally to another point marked by card B (Figure 2). After reaching the second point he was instructed to arrest his velocities and that would complete the task. The objective of this task was to determine how well the subject could perform a typical M-509 workshop excursion task. The task involved many of the basic tasks such as: transfer initiate, braking, attitude changes, velocity changes and stationkeeping.

d. LM-CM Transfer (Task 4) - In this task the subject had initial conditions which simulated leaving a LM. He was facing away from the CM mockup (Figure 2). The subject started 3 ft. left of, 5 ft. above, and 35 ft. away from the target. He started from a stationary position with a yaw of 90 deg, pitch of 20 deg, and roll of 20 deg. The subject was directed to rotate in yaw until he saw the CM mockup, and then right his attitude. Next he set up a transfer velocity toward the CM mockup. Upon approaching the CM mockup, he was instructed to perform a braking maneuver and make a soft contact with the hand-holds on the mockup.

2. RECORDED DATA FORMAT

During the simulation the following parameters were monitored in the format indicated.

a. Parameters Printed Out at End of Run

(1) Test Conditions

Date
Maneuver number (1-4)
Maneuvering Unit (IMLSS)

(2) Body rates (p, q, r)
Body attitude $(\phi_c, \theta_c, \psi_c)$
Velocity of combined c.g. $(\dot{X}, \dot{Y}, \dot{Z})$
Position of combined c.g. (X, Y, Z)

(3) End Conditions

(a) Rotation

Body rate (p, q, r)
Body attitude $(\phi_c, \theta_c, \psi_c)$

(b) Translation

Velocity of combined c.g. $(\dot{X}, \dot{Y}, \dot{Z})$
Position of combined c.g. (X, Y, Z)

(4) Maneuver Characteristics

(a) Flight time

(b) Fuel

Total rotational thruster impulse (I_R)
Total translational thruster impulse (I_T)
Total thruster impulse (I)
Total roll thruster impulse (I_ϕ)
Total pich thruster impulse (I_θ)
Total yaw thruster impulse (I_ψ)
Total longitudinal thruster impulse (I_X)
Total lateral thruster impulse (I_Y)
Total vertical thruster impulse (I_Z)

b. Parameters Recorded on Strip Charts Continuously

(1) Rotation

IMLSS moments $({}_1M_{MBX}, {}_1M_{MBY}, {}_1M_{MBZ})$
Body rates (p, q, r)
Body attitude $(\phi_c, \theta_c, \psi_c)$

(2) Translation

IMLSS forces ($_SF_{BX}$, $_SF_{BY}$, $_SF_{BZ}$)
Velocity of combined c.g. (X, Y, Z)
Position of combined c.g. (X, Y, Z)

(3) Maneuver Characteristics

Rotational thruster impulse (I_R)

Translational thruster impulse (I_T)

Thruster forces ($_1F_X$, $_1F_Y$, $_1F_Z$ -- in torso coordinates)

c. Parameters Recorded on Cartesian Plots

Position of combined c.g.

X versus Y
Z versus Y

3. TASK PECULIAR DATA

a. Number of subject contacts with mockup

b. Visual tasks performed successfully

c. Product of fuel and time

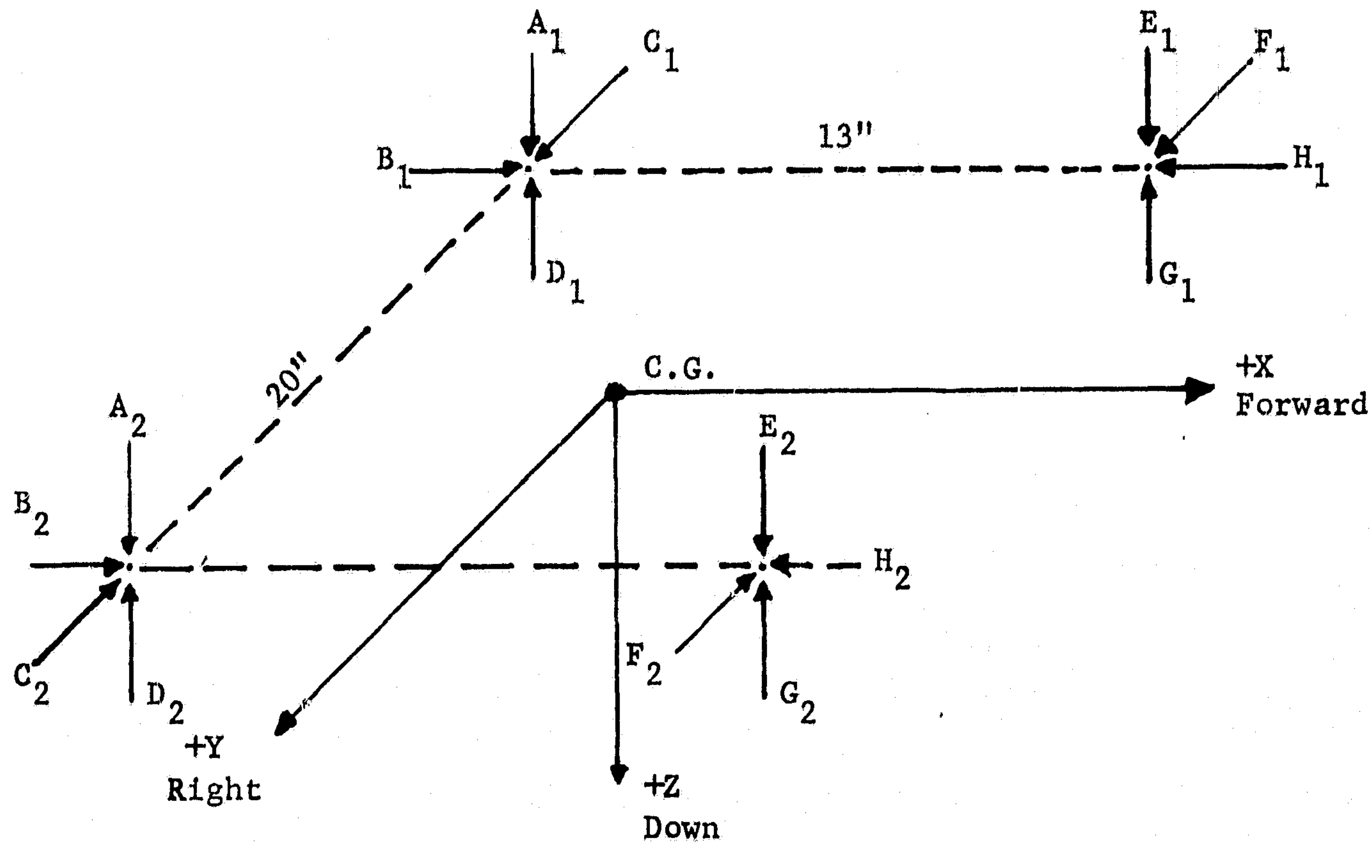
d. Object picked up successfully (Task 2 only)

SECTION III

MANEUVERING UNIT - IMLSS

The Integrated Maneuvering and Life Support System (IMLSS) simulated for the program is discussed in this section. Four configurations of the IMLSS were studied. The first three configurations were decided upon before the study. The fourth was determined during the study. Figure 3, 4, 5, and 6 show the thruster location and logic for Configurations 1, 2, 3, and 4 respectively. The performance characteristics are shown in Tables IV and V. The geometric center of the thrust array and combined system's c.g. were considered to be coincident. Also, they were positioned at the man's c.g. (without maneuvering unit).

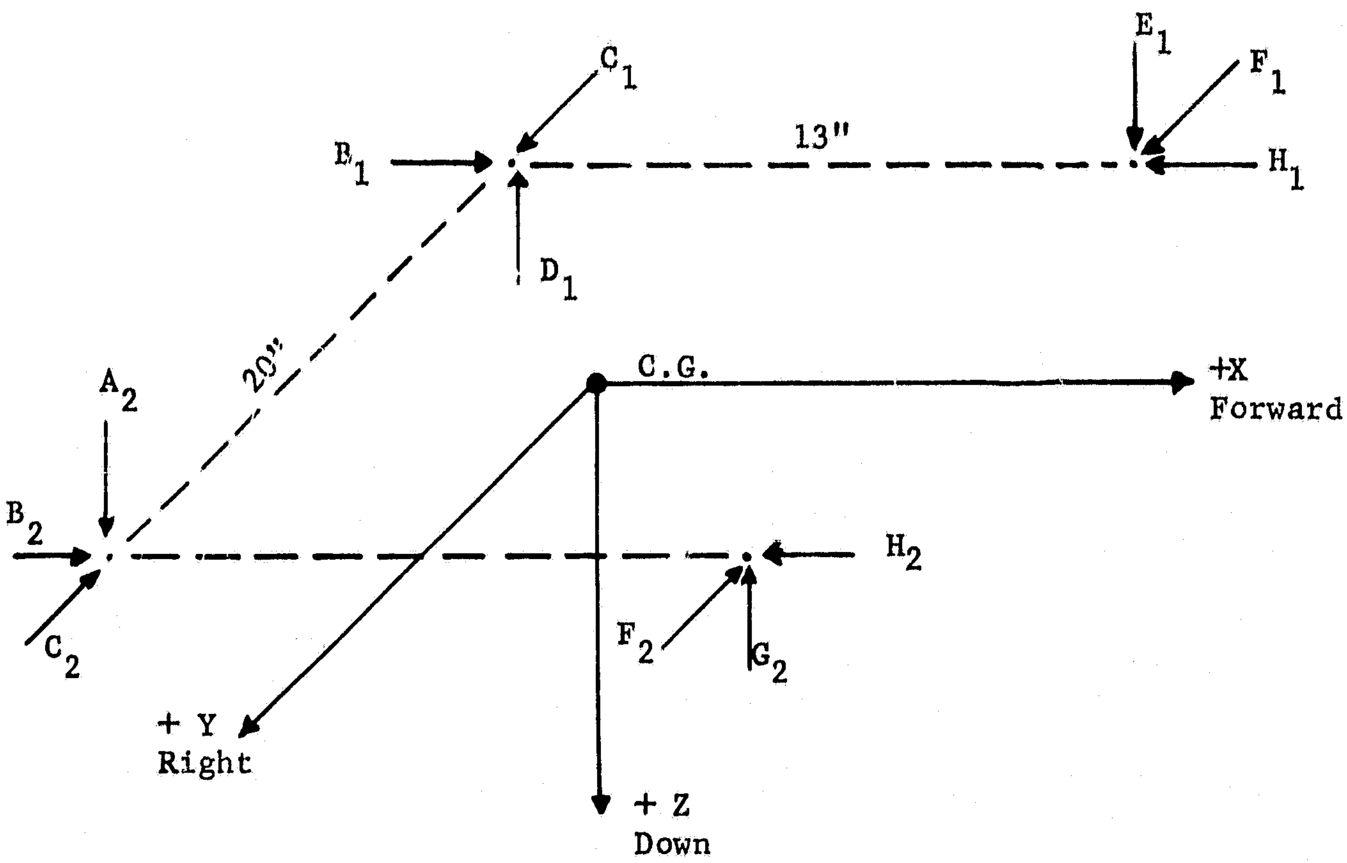
For the simulation the IMLSS controllers mockup shown in Figure 7 was used. The rest of the IMLSS was synthesized by a math model in the computer program. The controllers used were finger type controllers that were available from another in-house study. When the program was defined; it was felt that there was no need to duplicate the flight model controllers for this type of study. The translational controller is the left one. It has the standard three degrees of freedom. The subject merely had to push or pull the handle in the direction he desired to move. The rotational controller has the standard three degree motion. Again, the handle was used by moving it in the direction of desired rotation.



Translation		Rotation	
Direction	Firing Thruster	Direction	Firing Thruster
Forward	B_1 B_2	Pitch Down	E_1E_2 D_1D_2
Aft	H_1 H_2	Pitch Up	A_1A_2 G_1G_2
Up	D_1 G_2	Roll Left	A_1E_1 D_2G_2
Down	A_2 E_1	Roll Right	A_2E_2 D_1G_1
Left	C_2 F_2	Yaw Left	C_1F_2
Right	C_1 F_1	Yaw Right	C_2F_1

Note: All thrusters are 1.55 lbs.

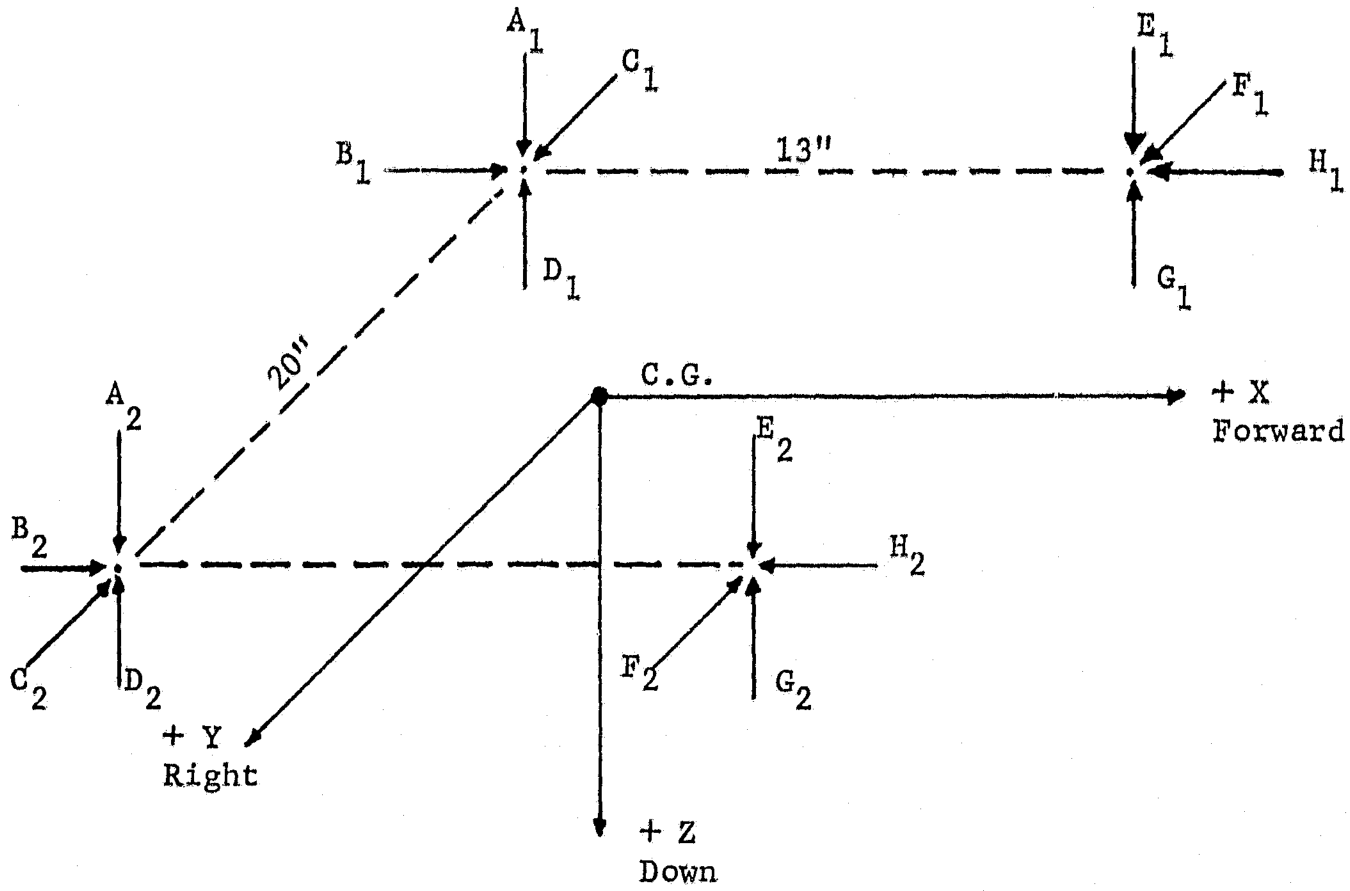
Figure 3 IMLSS Config. 1 Thruster Location and Logic



Translation		Rotation	
Direction	Firing Thruster	Direction	Firing Thruster
Forward	B_1 B_2	Pitch Down	D_1E_1
Aft	H_1 H_2	Pitch Up	A_2G_2
Up	D_1 G_2	Roll Left	E_1G_2
Down	A_2 E_1	Roll Right	A_2D_1
Left	C_2 F_2	Yaw Left	C_1F_2
Right	C_1 F_1	Yaw Right	C_2F_1

Note: All Thrusters are 1.55 lbs.

Figure 4 IMLSS Config. 2 Thruster Location and Logic

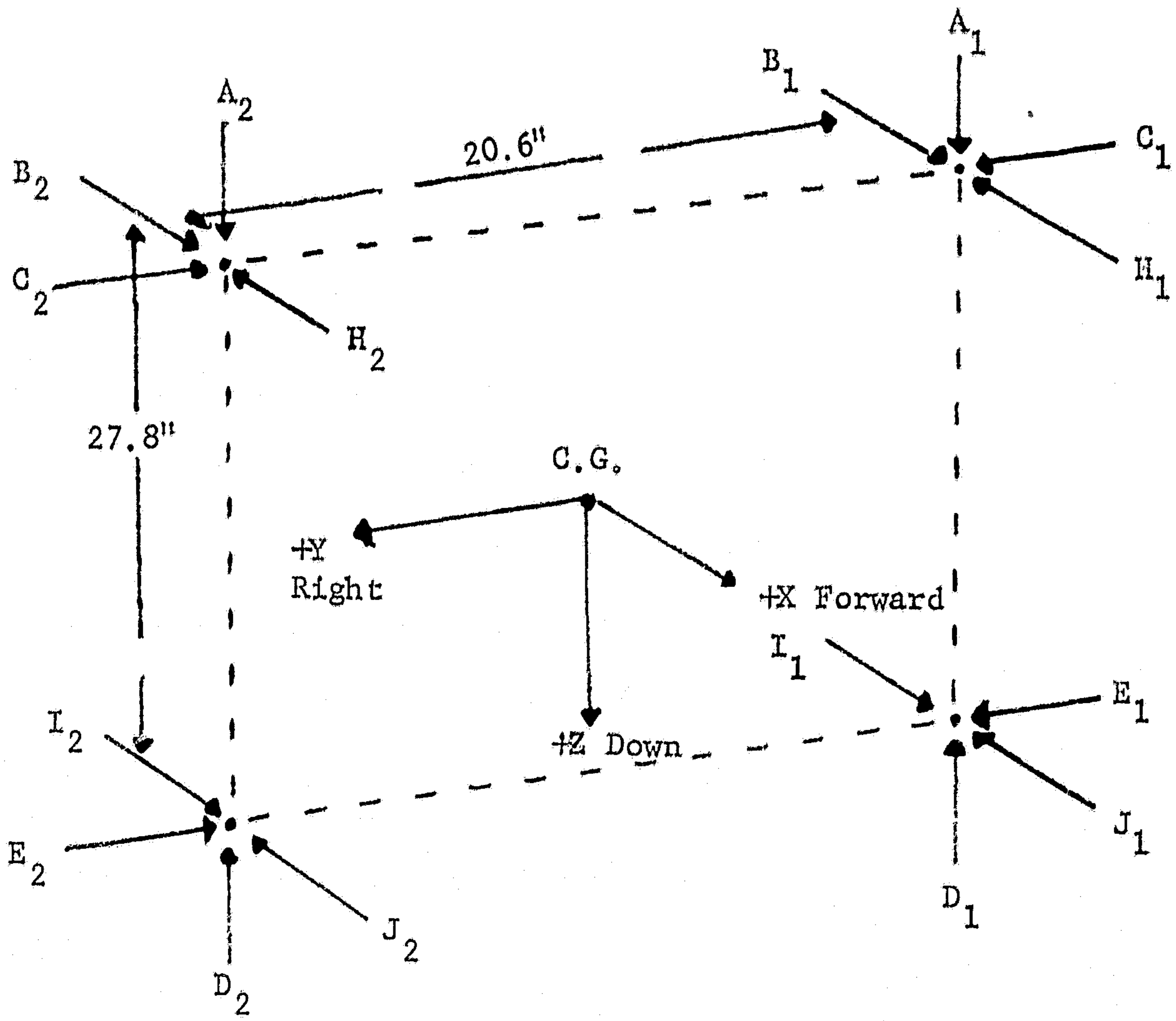


Translation		Rotation	
Direction	Firing Thruster	Direction	Firing Thruster
Forward	B_1 B_2	Pitch Down	E_1 E_2 D_1 D_2
Aft	H_1 H_2	Pitch Up	A_1 A_2 G_1 G_2
Up	D_1 G_2	Roll Left	A_1 E_1 D_2 G_2
Down	A_2 E_1	Roll Right	A_2 E_2 D_1 G_1
Left	C_2 F_2	Yaw Left	C_1 F_2
Right	C_1 F_1	Yaw Right	C_2 F_1

Note: Thrusters $A_1, A_2, C_1, C_2, D_1, D_2, E_1, E_2, F_1, F_2, G_1, G_2$ are 1.03 lbs.

Thrusters B_1, B_2, H_1, H_2, are 1.55 lbs.

Figure 5 IMLSS Config. 3 Thruster Location and Logic



Translation		Rotation		
Direction	Firing Thrusters	Direction		Firing Thrusters
Forward	B_1B_2 I_1I_2	Pitch	Down	B_1B_2 J_1J_2
Aft	H_1H_2 J_1J_2	Pitch	Up	H_1H_2 I_1I_2
Up	D_1D_2	Roll	Left	C_2E_1
Down	A_2A_1	Roll	Right	C_1E_2
Left	C_2E_2	Yaw	Left	I_2J_1
Right	C_1E_1	Yaw	Right	B_1H_2

Note: Thrusters A_1A_2, C_1, C_2, D_1D_2, E_1E_2, at 1.55 lbs.

Thrusters B_1,B_2,H_1,H_2,I_1,I_2,J_1,J_2 at 0.77 lbs.

Figure 6 IMLSS Config. 4 Thruster Location and Logic

Table IV IMLSS Config. 1, 2, and 3 Performance Characteristics

			Inertia (slug-ft^2)	Thrust level	Moments (ft-lbs)	Rotation (deg/sec^2)
Configuration #1	ψ	Yaw	I_{ZZ} = 4.78	2 at 1.55 lbs	$_1M_{MBZ}$ = ± 1.71	± 20.5
	θ	Pitch	I_{YY} = 18.76	4 at 1.55 lbs	$_1M_{MBY}$ = ± 3.38	± 10.3
	ϕ	Roll	I_{XX} = 18.76	4 at 1.55 lbs	$_1M_{MBX}$ = ± 5.18	± 15.8
			Mass (slugs)	Thrust level	Force (lbs)	Translation (ft/sec^2)
	X	Long.	Man = 165 lbs = 5.1 slugs	2 at 1.55 lbs	$_1F_{BX}$ = ± 3.09	± 0.3
			B.P. = 167 lbs = 5.2 slugs			
	Y	Lat.	Tot. = 332 lbs = 10.3 slugs	2 at 1.55 lbs	$_1F_{BY}$ = ± 3.09	± 0.3
	Z	Vert.		2 at 1.55 lbs	$_1F_{BZ}$ = ± 3.09	± 0.3
Configuration #2			Inertia (slug-ft^2)	Thrust level	Moments (ft-lbs)	Rotation (deg/sec^2)
	ψ	Yaw	Same as Config. #1	2 at 1.55 lbs	$_1M_{MBZ}$ = ± 1.71	± 20.5
	θ	Pitch		2 at 1.55 lbs	$_1M_{MBY}$ = ± 1.68	± 5.2
	ϕ	Roll		2 at 1.55 lbs	$_1M_{MBX}$ = ± 2.59	± 7.9
			Mass (slugs)	Thrust level	Force (lbs)	Translation (ft/sec^2)
	X	Long.	Same as Config. #1	2 at 1.55 lbs	$_1F_{BX}$ = ± 3.09	± 0.3
	Y	Lat.		2 at 1.55 lbs	$_1F_{BY}$ = ± 3.09	± 0.3
	Z	Vert.		2 at 1.55 lbs	$_1F_{BZ}$ = ± 3.09	± 0.3
Configuration #3			Inertia (slug-ft^2)	Thrust level	Moments (ft-lbs)	Rotation (deg/sec^2)
	ψ	Yaw	Same as Config. #1	2 at 1.03 lbs	$_1M_{MBZ}$ = ± 1.13	± 13.6
	θ	Pitch		4 at 1.03 lbs	$_1M_{MBY}$ = ± 2.23	± 6.8
	ϕ	Roll		4 at 1.03 lbs	$_1M_{MBX}$ = ± 3.45	± 10.5
			Mass (slugs)	Thrust level	Force (lbs)	Translation (ft/sec^2)
	X	Long.	Same as Config. #1	2 at 1.55 lbs	$_1F_{BX}$ = ± 3.09	± 0.3
	Y	Lat.		2 at 1.03 lbs	$_1F_{BY}$ = ± 2.06	± 0.2
	Z	Vert.		2 at 1.03 lbs	$_1F_{BZ}$ = ± 2.06	± 0.2

TABLE V IMLSS Config. 4 Performance Characteristics

			Inertia (slug-ft^2)	Thrust Level	Moments (ft-lbs)	Rotation (deg/sec^2)
Configuration #4	ψ	Yaw	Same as Config. #1	2 at .77 lbs	$1^{M}_{MBZ} = \pm 1.33$	$\pm$ 16.0
	θ	Pitch		4 at .77 lbs	$1^{M}_{MBY} = \pm 3.60$	$\pm$ 11.0
	ϕ	Roll		2 at 1.55 lbs	$1^{M}_{MBX} = \pm 3.60$	$\pm$ 11.0
			Mass (slugs)	Thrust level	Force (lbs)	Translation (ft/sec^2)
	X	Long		4 at .77 lbs	$1^{F}_{BX} = \pm 3.09$	$\pm$ 0.3
	Y	Lat	Same as Config #1	2 at 1.55 lbs	$1^{F}_{BY} = \pm 3.09$	$\pm$ 0.3
	Z	Vert		2 at 1.55 lbs	$1^{F}_{BZ} = \pm 3.09$	$\pm$ 0.3

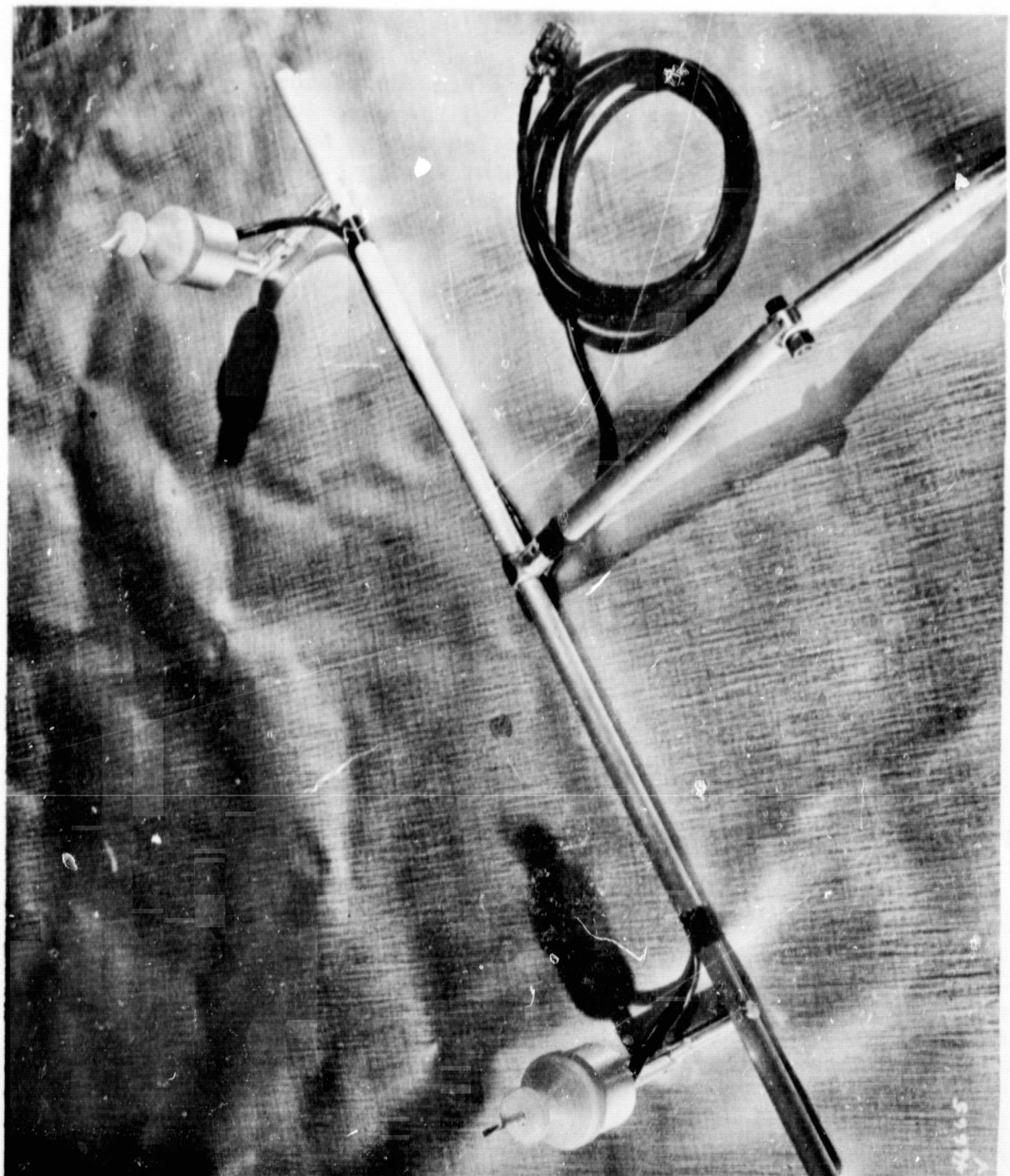


Figure 7 IMLSS Controller Mockup

SECTION IV

SIMULATION

1. SPACE OPERATIONS SIMULATION FACILITY

Simulation experience, gained from studies of space problems over the past several years, has provided the base for determining the present configuration of the Space Operations Simulator (SOS) facility used in this program. Simulator design and performance requirements have been considered and published (Ref. 3). The Space Operations Simulator facility, shown in Figure 8, consists of five interdependent parts -- the moving base carriage, the control capsule, simulation instrumentation, the test monitor station, and the hybrid computational equipment.

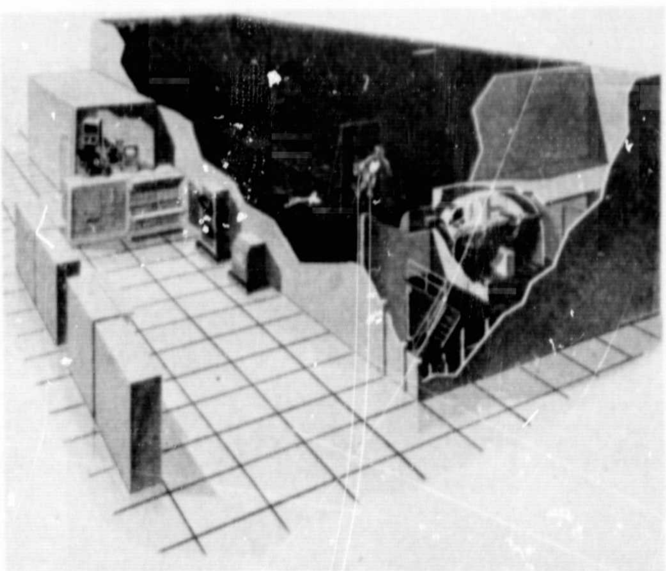


Figure 8 Simulator Facility

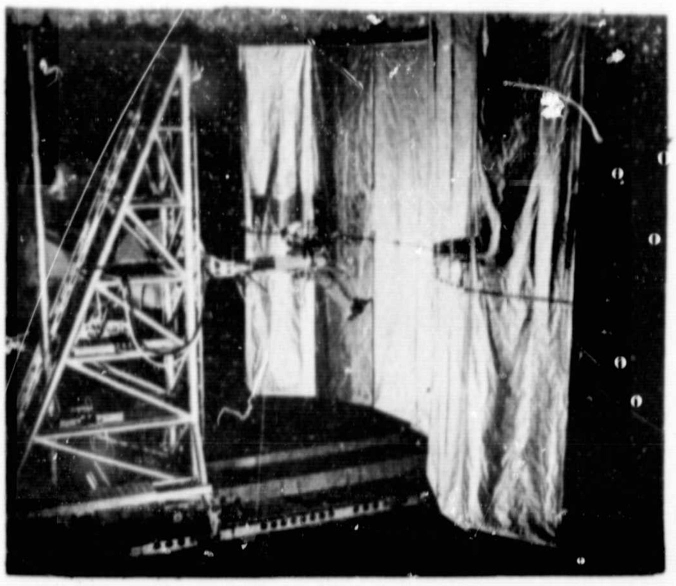


Figure 9 Moving Base

a. Moving Base Carriage - The Martin Marietta moving base carriage (Figure 9) utilizes the "powered" simulation approach rather than the "free-motion" approach. A 90 by 32 by 24 foot room, providing an 8640 cubic foot maneuvering volume, houses the moving base which is servodriven in three translational axes and three rotational axes. The base of the carriage translates the length of the room on three rails and is driven by four one horsepower AC motors which engage two gear racks mounted on the floor. The vertical pedestal translates on rollers and rails laterally on the base structure and is driven by two one horsepower AC servomotors. The gimbaled head located on the front of the pedestal is supported by a set of negator springs and a counterbalance weight. This system effectively counterbalances the weight of the gimbaled head and its payload. Two one-quarter horsepower DC motors, which engage two vertical gear racks on the front of the pedestal, provide the servo-

Figure 10 Gimbaled Head

power for the vertical translation. The gimbaled head (Figure 10) has been designed to provide maximum safety and freedom of motion for the test subject. Motors and gear drives are enclosed in the structure of the gimbals. The gimbal sequence of roll, pitch and yaw was selected because it allows all three drive axes to nominally pass through the c.g. of the test subject. Thus, counterbalance and overhanging moment problems on the gimbal axes are minimized. Each gimbal is driven by a one-quarter horsepower DC motor. The overall weight of the moving base carriage is 5000 lbs. Simulator performance is shown in Table VI.

Table VI Moving Base Performance

	Longitudinal	Lateral	Vertical
Travel (ft)	60.0	± 6.0	± 6.0
Velocity (fps)	3.0	3.0	3.0
Acceleration (fps^2)	6.0	3.0	3.0
	Roll	Pitch	Yaw
Travel (rad)	± 1.0	± 3.8	± 3.1
Velocity (rad/sec)	2.0	2.0	2.0
Acceleration (rad/sec^2)	8.0	8.0	8.0

b. Control Capsule - Several control capsules have been in operation in the SOS laboratory; however, the one that seems to provide desired flexibility is shown in Figure 11. This mockup has a two-man capacity and contains sufficient display and control instruments to allow several types of space mission tests to be run. These tests include both manual and automatic piloting and ground tracking as well as aerial tracking. Normally, a flight requires the use of both the out-the-window scene and several instruments. This part of the SOS was not used for this study.

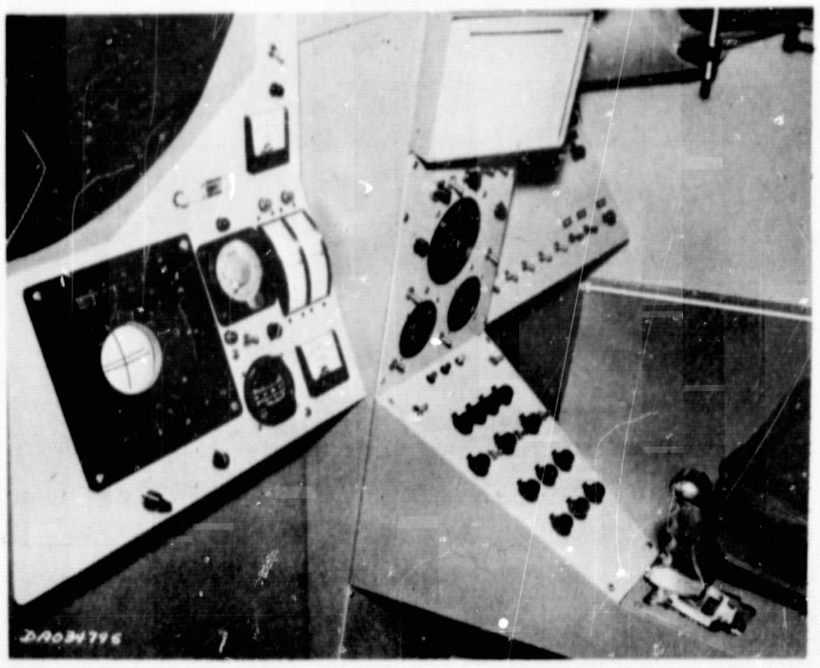


Figure 11 Control Capsule

c. Simulation Instrumentation

(1) Limb Motion Sensor (LIMS) - For many of the manned simulations (EVA, IVA, Maneuvering Units, etc.) it is necessary to compute c.g. shifts and inertia changes as a function of limb position. Also, the case of some maneuvering units (HHMU for example), the orientation of a thrust vector relative to the subject's torso must be known. The LIMS (Figure 12) was designed to fill this need. Figure 10 shows the test subject wearing the LIMS during the simulation. By monitoring the orientation of each of the body pivot points and knowing the length of the connecting links, the dynamic effects of c.g. shifts, inertia changes and self-induced rotations can be computed and introduced properly into the problem. Also, the orientation and location of thrust vectors for simulated handguns can be computed using LIMS extensions.

(2) Load Cell Array - For EVA/IVA simulations where the test subject is in contact with the simulated space station, the contact forces and moments must be measured in order to be able to

simulate the problem. In the SOS facility, an array of load cells is used to measure the contact conditions. The worksite or vehicle mockup is mounted on a load-sensing platform which is an equilateral triangle with two load cells at each apex. The load cells are mechanically attached to the platform with pairs of flexure joints. The total configuration is symmetrical about any axis that contains the centroid and any apex of the triangle. This part of the instrumentation was not used for this study.

d. Test Monitor Station - Simulator operation is controlled by an engineer at a test monitor station. From the monitor panel he can observe the test subject on a TV monitor. In addition he has control of the servopower to the moving base and the computer control signals. Also, a wide range of test points can be monitored. The monitor station provides another safety check on the proper functioning of the simulator. The engineer can override the computer and remove power from the moving base at any time.

e. Computational Equipment - The simulator is supported by two computer systems. One system contains four EAI 231R computers located as an integral part of the facility. The other consists of a hybrid computer (Figure 13) installation consisting of three EAI 8800 analog computers, one EAI digital computer, and one EAI 8930 linkage subsystem. The hybrid computer was used for this program. One of the EAI 8800 analog computers and the EAI digital computer were required.

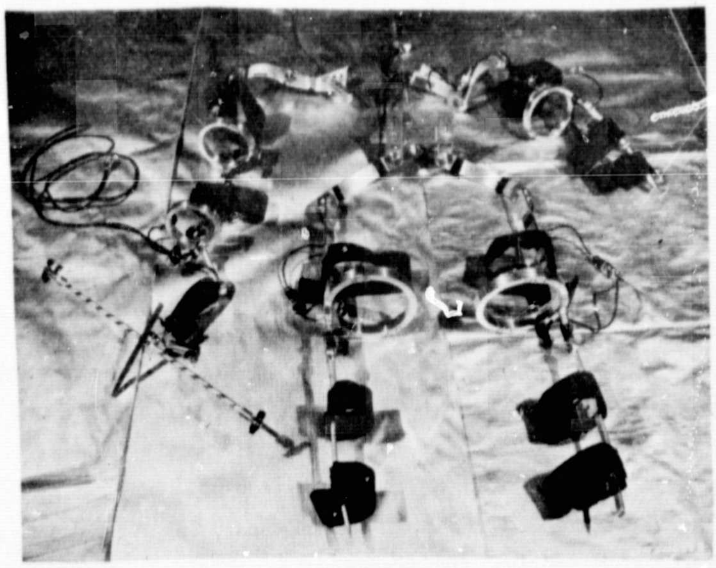


Figure 12 Limb Motion Sensor

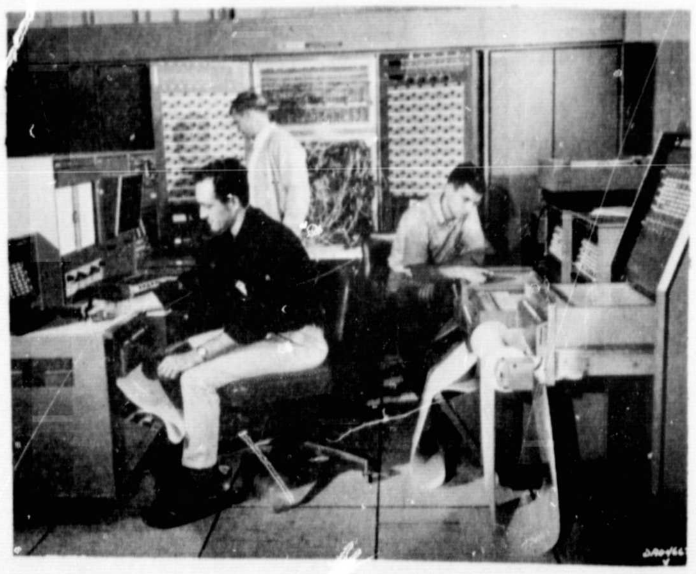


Figure 13 Hybrid Computer

2. SIMULATION TECHNIQUE

The information flow of the mobility aid simulation technique is shown in Figure 14. A test subject is suspended from the inner gimbal ring of the moving base simulator (Figure 10). The test subject can maneuver in the room using the controls of the simulated

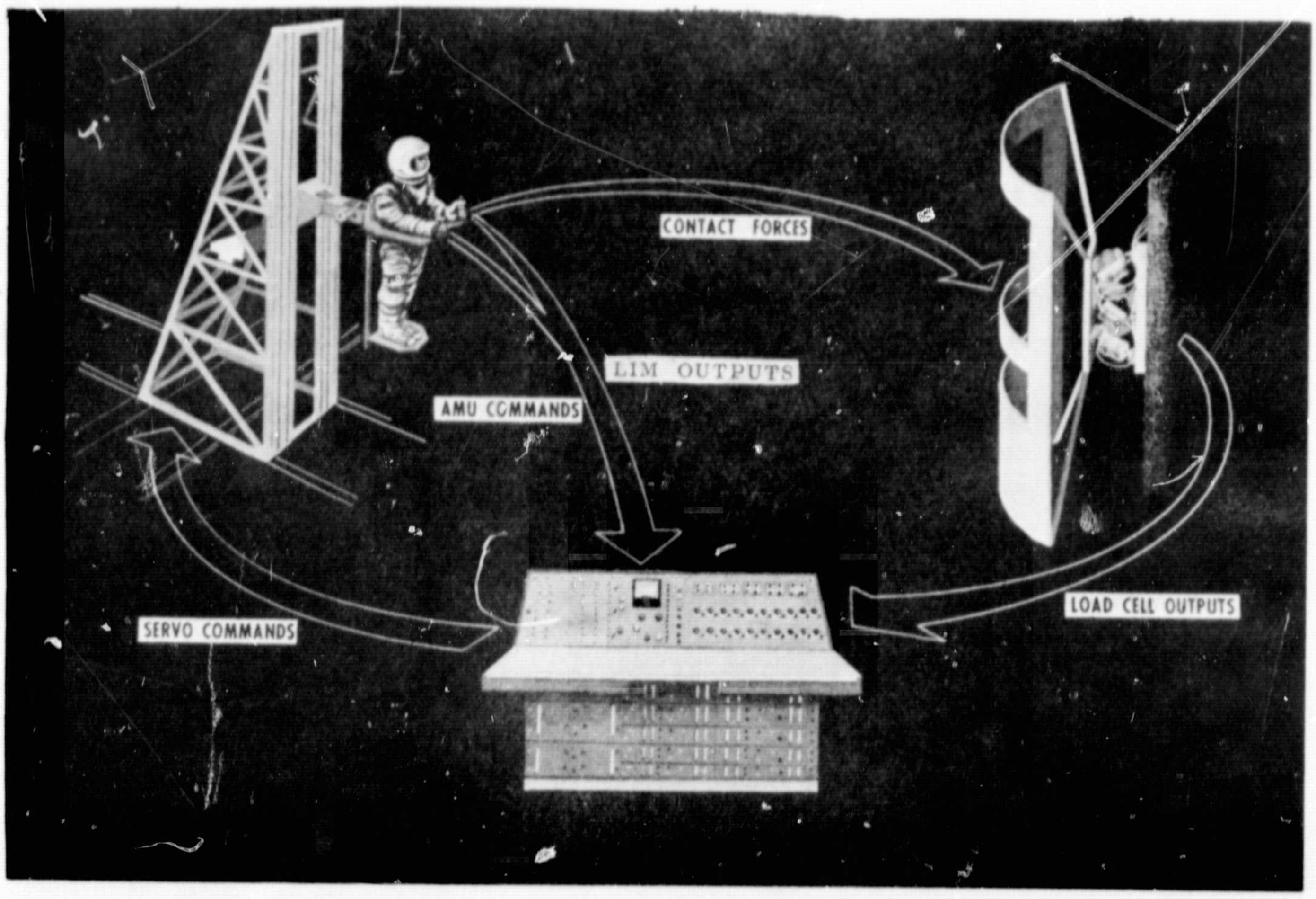


Figure 14   Simulation Information Flow

maneuvering unit. A math model of the maneuvering unit including switching logic is contained in the computer program. A Limb Motion Sensor (LIMS) attached to the test subject's body is used to monitor the position of the various body segments. Information from the LIMS, along with thrust initiate signals from the maneuvering unit controls, is used by the hybrid computer to determine continuously the positional servocommands for the moving base and gimbals. The computer program contains the equations of motion and approximates the test subject by a model man consisting of nine rigid body segments. When the subject comes in contact with the worksite, the contact forces and moments, as measured by a set of load cells, are sent to the computer. The effects of the contact forces and moments on the test subject's motion are computed by the hybrid program and the simulator positional commands are modified accordingly. Thus, the test subject moves dynamically about the room or worksite as if he was working in zero "g". For this study the worksite with a load cell array was not required.

3. ANALYTICAL SYSTEM

a. Model of Man - A mathematical model which approximates the complicated and variable mass distribution of the human body must be defined before an analytic investigation can begin. Hanavan (Ref. 4) developed a model of the human body comprised of fifteen rigid body segments. A modification of this model to nine rigid body segments (Figure 15) was made by Wooley (Ref. 5) who analyzed the biomechanical

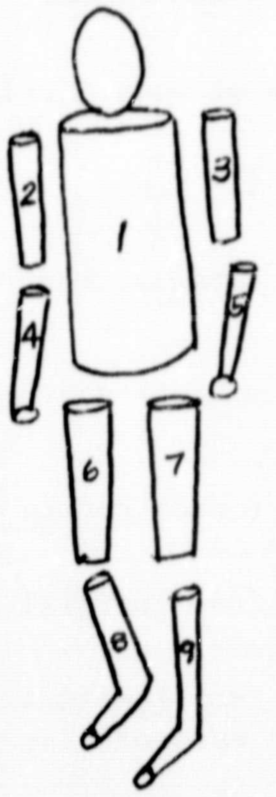


Figure 15 Segmented Model of Man

properties of man and demonstrated that the segment masses, centers of gravity, pivot points, and moments of inertia can be expressed solely as a function of man's weight. Thus, using man's weight as the only program input, the inertia properties and geometric dimensions for each of the model segments can be determined. The formulas which describe this nine segment model man as a function of the subject's weight are contained in Appendix I.

b. Derivation of Dynamical Equations - Nomenclature used in deriving the equations of motion is defined as follows: A single bar above a quantity denotes a vector, two bars a dyadic; similarly a dot above a quantity denotes the first time derivative, two dots denote the second time derivative.

A subscript appearing to the left of a vector or dyadic indicates the reference frame in which the derivative is taken. If no subscript is present (or the subscript is 0) then the reference frame is inertially fixed. i refers to a typical rigid body in the system or the reference frame fixed in rigid body i. cg refers to the center of mass.

$\vec{r}_i$ = position vector from the cg of the system to the cg of the ith segment.

$\bar{\bar{I}}_i$ = inertia dyadic of ith segment about cg of ith segment.

$\vec{\omega}_{ij}$ = angular velocity of body i relative to reference frame j.

m_i = mass of segment i.

m_m = $\sum_i m_i$ = mass of total system.

$\bar{M}_m$ = sum of external moments acting on system m about the cg of system m.

$\bar{F}_m$ = sum of external forces acting on system m.

$\bar{R}_1$ = position vector from inertial frame to cg of segment 1.

$\vec{R}_m$ = position vector from inertial frame to cg of the composite center of mass of system m.

$\bar{H}_i$ = angular momentum of ith body about center of mass of man system.

$\bar{H}_T$ = angular momentum of man system about center of mass of man system.

$\bar{\bar{D}}_{i,j}$ = transformation matrix from segment i to segment j.

ϕ_i, θ_i, ψ_i = three axis Euler angles which define the attitude of body i.

Subscript J refers to segment #10, which is a jet thruster maneuvering unit such as a backpack, hand held gun, or jet shoes.

${}_{10}\bar{F}_J$ = force due to jet thrusters.

${}_{10}\bar{M}_J$ = moment about cg of body #10 due to jet thrusters.

$\bar{M}_{JT}$ = moment about cg of human system due to jet thrusters.

In essence, the dynamical problem consists of a system that is composed of a set of rigid bodies, with the only constraint being that the initial constitution of the system does not change. That is, if rigid body i is attached to rigid body j through a joint, then the relative orientation of i and j may vary, but the point of attachment must remain common to both rigid bodies.

Now the collection of rigid bodies that comprise the human system will be explained in more detail, leading to the determination of the motion of each rigid body. Since the orientation of one rigid body relative to another is a known output of LIMS, then knowing the orientation and translation of one rigid body in the system relative to an inertial frame allows one to determine the motion of all segments relative to the fixed reference. Thus the complete dynamical equations for this system can be determined, if the inertial motion of one segment is determined. This principle is used in the operation of the servodriven simulator where only one rigid body in a system is attached to the simulator, and thus the entire system is positioned. Since the object of the computer program is to supply commands to the simulator, so that the system can move in accordance with the dynamical equations of motion, and the simulator acts on the system by being rigidly attached to only one segment of the system, the desired end result of this analysis is to obtain the equation of motion of one segment in the system. Now the motion of a single segment will be obtained (we arbitrarily choose segment number one). The motion of this segment is completely described by the three axis Euler angles, ϕ_1, θ_1, ψ_1 and the position vector $\bar{R}_1$.

The rotational equations which describe the orientation of each body will be derived by finding the angular momentum of the system relative to the composite center of mass, and differentiating in an inertial frame. Figure 16 illustrates the system under consideration.

Using the fact that the angular momentum of rigid body i about point Q is equal to the angular momentum of i about the cg of i plus the angular momentum of i about Q, computed as though i was a single particle located at the cg of i with mass equal to the total mass of i,

$$\bar{H}_i = \bar{\bar{I}}_i \cdot \bar{\omega}_{10} + m_i(\bar{r}_i \times \dot{\bar{r}}_i) \qquad (9)$$

Since the angular momentum of a set of rigid bodies about point Q is equal to the sum of the angular momentum of each body in the set about Q,

$$\bar{H}_T = \sum_i \bar{H}_i \qquad (10)$$

Equating the sum of external moments acting about the composite

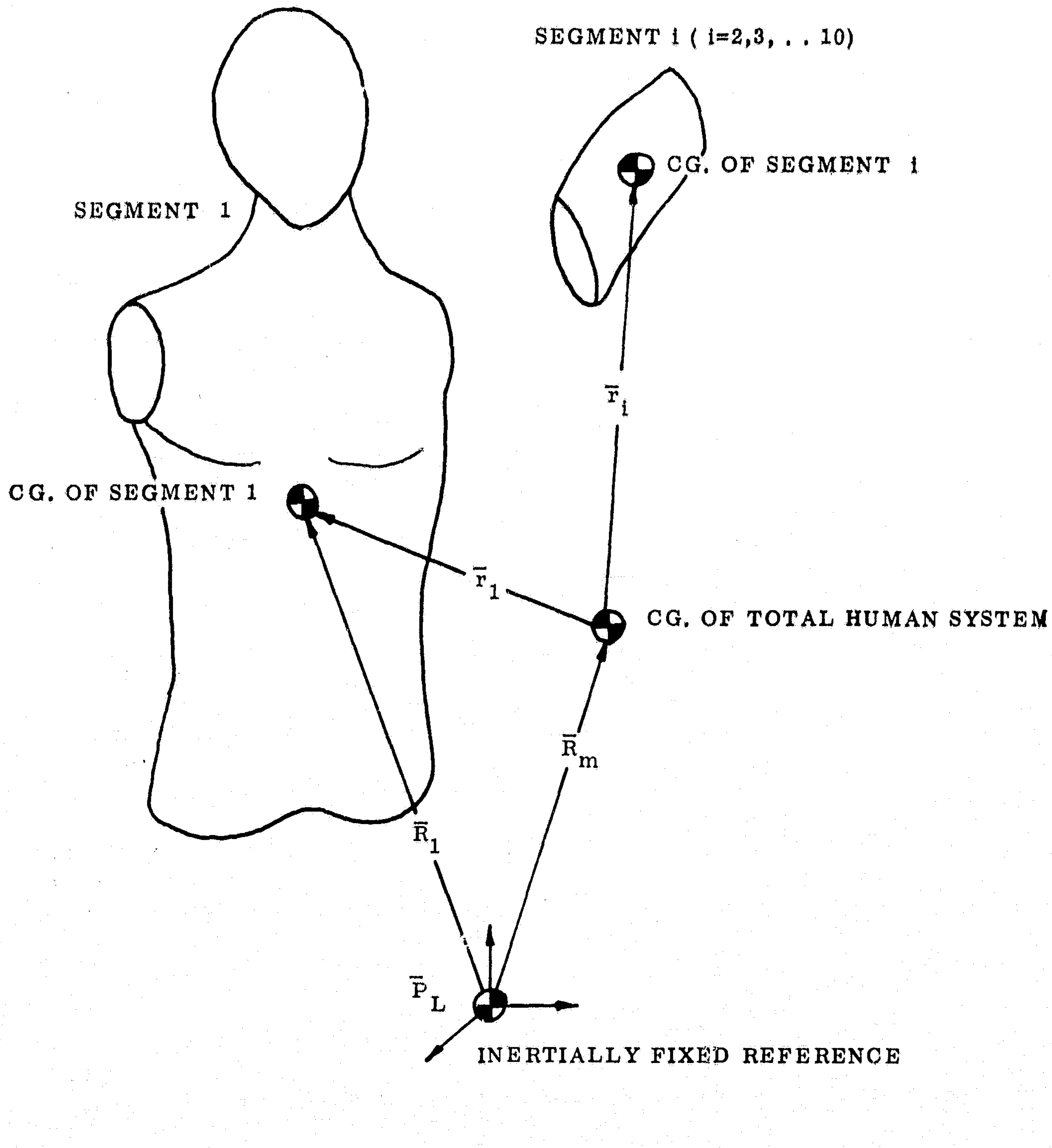


Figure 16 Model of Human System

cg of a system of rigid bodies to the inertial time derivative of the angular momentum of the system about the composite cg yields

$$\bar{M}_m = \dot{\bar{H}}_T \tag{11}$$

Because $\bar{H}_T$ is determined in a rotating frame, the inertial derivative of $\bar{H}_T$ will be expressed in terms of the derivative of $\bar{H}_T$, taken in the rotating reference frame, and the angular velocity of this reference frame with respect to an inertially fixed reference:

$$\dot{\bar{H}}_T = {}_1\dot{\bar{H}}_T + \bar{\omega}_{10} \times {}_1\bar{H}_T \tag{12}$$

$${}_1\bar{H}_T = \int (\bar{M}_m - \bar{\omega}_{10} \times {}_1\bar{H}_T)dt \tag{13}$$

(from eqns. 11, 12)

Now to extract $\bar{\omega}_{10}$ from the other terms that comprise $\bar{H}_T$ we use

$$\bar{\omega}_{i0} = \bar{\omega}_{10} + \bar{\omega}_{i1} \tag{14}$$

$$\dot{\bar{r}}_i = {}_1\dot{\bar{r}}_i + \bar{\omega}_{10} \times {}_1\bar{r}_i \tag{15}$$

Equation (9) can be expressed as

$$\bar{H}_i = \bar{\bar{I}}_i \cdot (\bar{\omega}_{10} + \bar{\omega}_{i1}) + m_{i1}\bar{r}_i \times ({}_1\dot{\bar{r}}_i + \bar{\omega}_{10} \times {}_1\bar{r}_i) \tag{16}$$

(9, 14, 15)

Using the identity

$${}_1\bar{r}_i \times (\bar{\omega}_{10} \times {}_1\bar{r}_i) \equiv \left[({}_1\bar{r}_i \cdot {}_1\bar{r}_i)\bar{\bar{U}} - {}_1\bar{r}_i\,{}_1\bar{r}_i\right] \cdot \bar{\omega}_{10}, \tag{17}$$

where $\bar{\bar{U}}$ is the unit dyadic, equation (16) can be written

$$\bar{H}_i = \left(\bar{\bar{I}}_i + m_i \left[({}_1\bar{r}_i \cdot {}_1\bar{r}_i)\bar{\bar{U}} - {}_1\bar{r}_i\,{}_1\bar{r}_i\right]\right) \cdot \bar{\omega}_{10}$$

(16, 17)

$$+ \bar{\bar{I}}_i \cdot \bar{\omega}_{i1} + m_i({}_1\bar{r}_i \times {}_1\dot{\bar{r}}_i) \tag{18}$$

The variables ${}_1\bar{r}_i$, m_i, $\bar{\bar{I}}_i$, $\bar{\omega}_{i1}$, ${}_1\dot{\bar{r}}_i$ and $\bar{M}_m$, are all known quantities, because we know the dimensions and inertia properties of the segments from the model of man, the angles between adjacent segments from LIMS, and external forces and moments acting on the system from the thruster logic. So $\bar{H}_T$ can be expressed as

$$\bar{H}_T = \bar{\bar{A}} \cdot \bar{\omega}_{10} + \bar{B} \qquad (19)$$

(10, 18)

where $\bar{\bar{A}}$ is the known matrix $\left(\bar{\bar{I}}_1 + m_1\left[({}_1\bar{r}_1 \cdot {}_1\bar{r}_1)\bar{U} - {}_1r_1\;{}_1r_1\right]\right)$

and $\bar{B}$ is the known vector $\left(I_1 \cdot \bar{\omega}_{11} + m_1({}_1\bar{r}_1 \times {}_1\dot{\bar{r}}_1)\right)$

Equation (13), which, expressed in terms of the known matrix A and vector $\bar{B}$, is

$$\bar{\bar{A}} \cdot \bar{\omega}_{10} + \bar{B} = \int \left[\bar{M}_m - \bar{\omega}_{10} \times (\bar{\bar{A}} \cdot \bar{\omega}_{10} + \bar{B})\right] dt \qquad (20)$$

(13, 19)

Since $\bar{\bar{A}}$ is non singular,

$$\bar{\omega}_{10} = \bar{\bar{A}}^{-1} \cdot \left(\int \left[\bar{M}_m - \bar{\omega}_{10} \times (\bar{\bar{A}} \cdot \bar{\omega}_{10} + \bar{B})\right] dt - \bar{B}\right) \qquad (21)$$

(20)

The time derivative of the Euler angles for body 1 is given by

$$\dot{\bar{\xi}} = \begin{bmatrix} \dot{\phi}_1 \\ \dot{\theta}_1 \\ \dot{\psi}_1 \end{bmatrix} = \begin{bmatrix} \cos\psi_1/\cos\theta_1 & -\sin\psi_1/\cos\theta_1 & 0 \\ \sin\psi_1 & \cos\psi_1 & 0 \\ -\cos\psi_1\sin\theta_1/\cos\theta_1 & \sin\psi_1\sin\theta_1/\cos\theta_1 & 1 \end{bmatrix} \cdot \bar{\omega}_{10} = \bar{\bar{T}} \cdot \bar{\omega}_{10} \qquad (22)$$

$$\bar{\xi} = \int \left\{ \bar{\bar{T}} \cdot \left[\bar{\bar{A}}^{-1} \cdot \left(\int \left[\bar{M}_m - \bar{\omega}_{10} \times (\bar{\bar{A}} \cdot \bar{\omega}_{10} + B)\right] dt - \bar{B}\right)\right]\right\} dt \qquad (23)$$

(21, 22)

$\bar{\xi}$, the only unknown in this equation, is one of the two desired variables needed to position the simulator.

The other required quantity, the translational command $\vec{R}_1$, can be obtained by applying Newton's second law.

$$\vec{F}_m = m_m \ddot{\vec{R}}_m \qquad (24)$$

where $\vec{F}_m$ is the sum of external forces which are due to the action of jet thrusters.

$$\vec{R}_m = \vec{R}_1 - \vec{r}_1 \qquad (25)$$

$$\vec{F}_m = m_m(\ddot{\vec{R}}_1 - \ddot{\vec{r}}_1) \qquad (26)$$

Thus the translational command is:

$$\vec{R}_1 = \iint \frac{\vec{F}_m}{m_m}\, dt + \vec{r}_1 \qquad (27)$$

c. Hybrid Program - The above equations were programmed on an EAI 8900 hybrid computing system. The organization of this computer program is explained in the logic flow diagram (Figure 17). This diagram illustrates how the output of physical mechanisms, such as LIMS and a load cell array (not required for this study) are combined in real time according to the developed dynamical equations for the human system to yield $\underline{\xi}$ and $\vec{R}_1$, the commands which position the servodriven simulator.

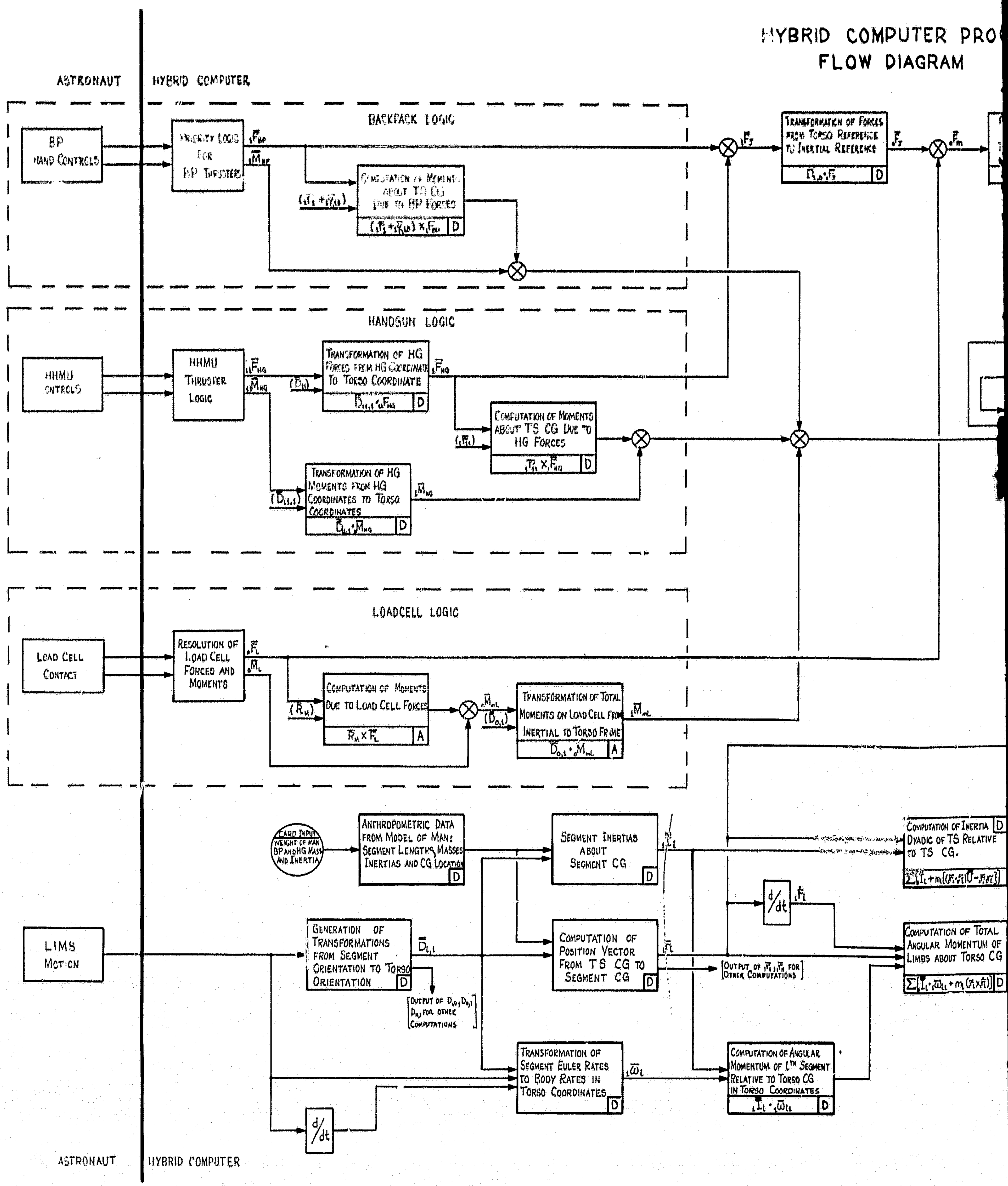


Figure 17 Hybrid Computer Program

...OMPUTER PROGRAM
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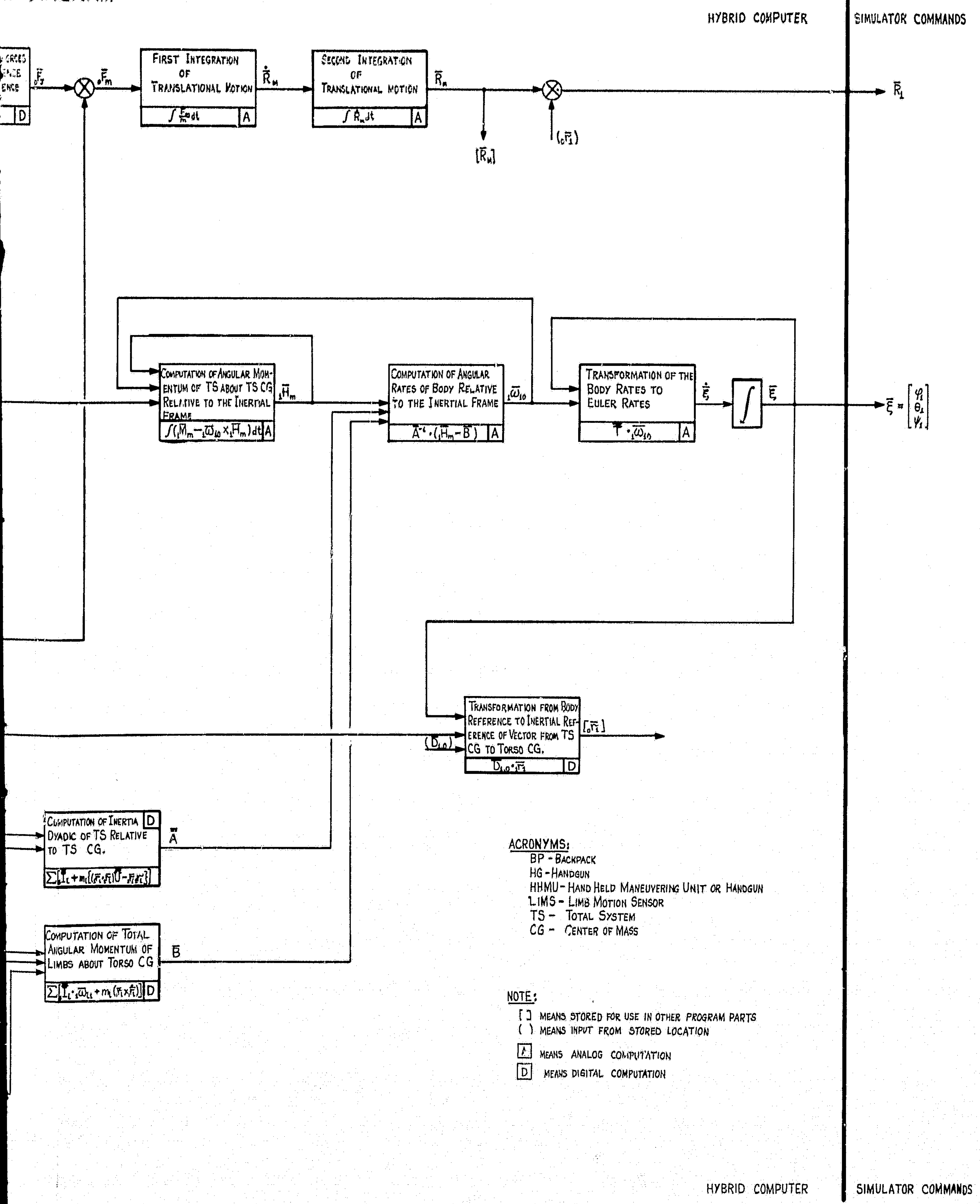

...puter Program Flow Diagram

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SECTION V

DATA

Data from the runs for evaluating the IMLSS performance are discussed in this section. The IMLSS configurations are those presented in Section III and, the tasks are those presented in Section II. All data is coded according to: configuration number, task number, and the perturbation as required. The test subject was Major C. E. Whitsett, Jr. The testing was performed in the following order: 1) Configuration 1, 2) Configuration 2, 3) Configuration 3, 4) Configuration 1 with c.g. shift, 5) Configuration 1 with inertia cross products, and 6) Configuration 4. The data presented in this section is grouped according to this configuration breakdown. Table VII is a summary of the inertia and mass properties used during each part of the study. These properties were held constant for each part.

The subject performed the tasks suspended in the gimbaled head of the simulator as shown in Figure 18. His hands were positioned on the controllers as shown. Figure 18 shows the subject performing the moving inspection (Task 1). Figures 19, 20, and 21 show the subject performing, respectively, the translate around corner (Task 2), workshop excursion (Task 3), and LM-CM transfer (Task 4).

Before any data was taken, the subject was given ample time to practice flying a given configuration and task. This time allowed the subject to become familiar with the performance of a configuration for a particular task. The subject then flew three successive practice runs during which data was taken. This data was then summarized and discussed with the subject. The purpose was to aid the subject in flying the tasks consistently for the five data runs. The data for the study follows.

1. IMLSS CONFIGURATION 1 DATA

The subject's translational motions for tasks 1, 2, 3, and 4, flying IMLSS configuration 1, are shown in figures 22, 23, 24, and 27, respectively. Strip chart continuous data for Task 3 are shown in Figure 25 and 26. Figure 25 contains the parameters recorded on recorders 1 and 2. Recorder 1 parameters include the body moments, angular rates, and angles. Recorder 2 parameters include the inertial forces, velocities, and displacements. Figure 26 contains the parameters recorded on recorders 3 and 4. Recorder 3 parameters include translational impulse, rotational impulse, total impulse, yaw attitude angle, Z displacement. Recorder 4 parameters include the six hand controller signals. The end conditions, maximum rates, and average rates for tasks 1, 2, 3, and 4 are shown in Table VIII, IX, X, and XI, respectively. Both the practice and data run values are summarized in the tables. In task 1 the subject read one word wrong. There were no mockup contacts in tasks 1 or 2, and the object in task 2 was picked up successfully each time.

Table VII Summary of Man-IMLSS Inertias and Mass

Configuration	Inertia (Slug-Ft^2)						Total System Mass (Slugs)
	I_{xx}	I_{yy}	I_{zz}	I_{xy}	I_{xz}	I_{yz}	
1) Configuration 1	18.76	18.76	4.78	0	0	0	10.3
2) Configuration 2	18.76	18.76	4.78	0	0	0	10.3
3) Configuration 3	18.76	18.76	4.78	0	0	0	10.3
4) Configuration 1							
a)With c.g.shift #1	19.411	18.766	5.429	0.0	0.0	0.0	10.3
b)With c.g.shift #2	21.398	21.399	4.782	0.0	0.0	0.0	10.3
5) Configuration 1 with inertia cross-products	18.76	18.76	4.78	0	-4.0	0	10.3
6) Configuration 4	18.76	18.76	4.78	0	0	0	10.3

Figure 18   Subject Performing Task 1 with IMLSS

Figure 19   Subject Performing Task 2 With IMLSS

Figure 20 Subject Performing Task 3 with IMLSS

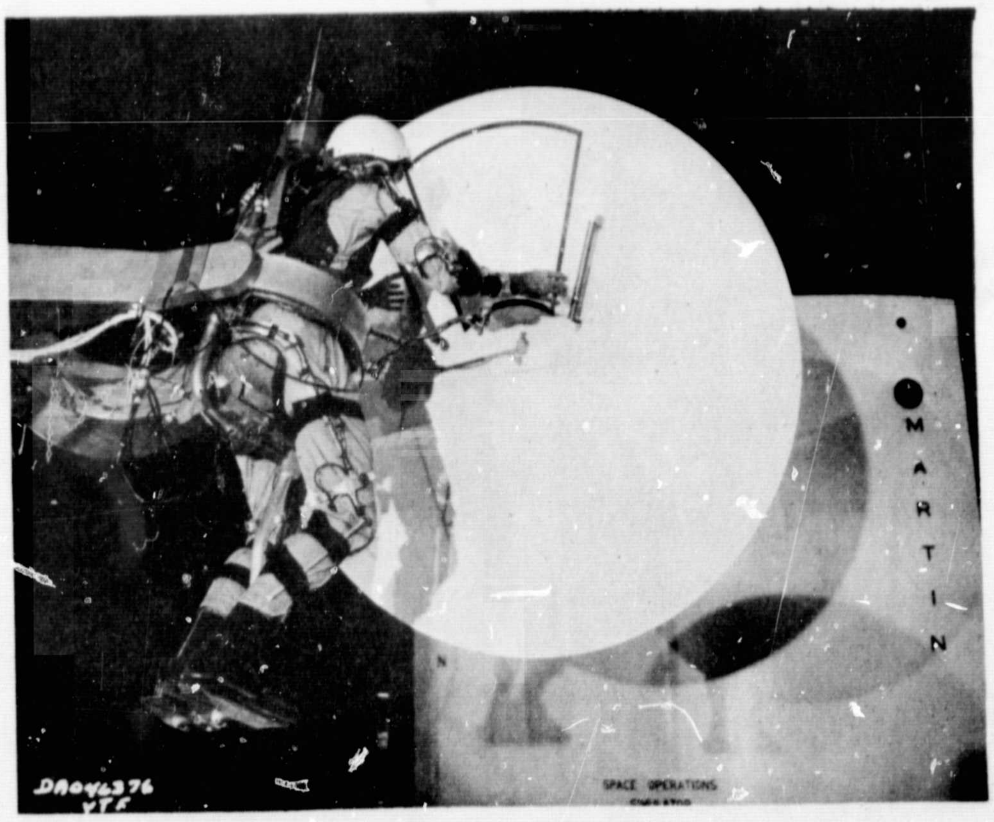


Figure 21 Subject Performing Task 4 with IMLSS

2. IMLSS CONFIGURATION 2 DATA

The subject's translational motions for tasks 1, 2, 3, and 4, flying IMLSS configuration 2, are shown in Figures 28, 29, 30, and 33, respectively. Strip chart continuous data for task 3 are shown in Figures 31 and 32. The end conditions, maximum rates, and average rates for tasks 1, 2, 3, and 4 are shown in Tables XII, XIII, XV, respectively. The subject completed all visual tasks successfully. The object in task 2 was picked up successfully, and there were no mockup contacts

3. IMLSS CONFIGURATION 3 DATA

The subject's translational motions for tasks 1, 2, 3, and 4, flying IMLSS configuration 3, are shown in Figures 34, 35, 36, and 39, respectively. Strip chart continuous data for task 3 are shown in Figures 37 and 38. The end conditions, maximum rates, and average rates for tasks 1, 2, 3, and 4 are shown in Tables XVI, XVII, XVIII, and XIX, respectively. The subject completed all visual tasks successfully. The object in task 2 was picked up successfully, and there were no mockup contacts.

4. IMLSS CONFIGURATION 1 WITH C.G. SHIFT

Two c.g. shifts were investigated. Performance of the IMLSS for configuration 1 was investigated for tasks 3 and 4.

a. Lateral c.g. Shift - The backpack mass was shifted 0.5 ft. to the left (negative Y). This shifted the system c.g. 0.25 ft. to the left. For this c.g. shift, firing the longitudinal thrusters causes yaw rotational coupling, and firing the vertical thrusters causes a roll rotational coupling. The subject's translational motions for tasks 3 and 4 are shown in Figures 40 and 43, respectively. Strip chart continuous data for task 3 are shown in Figures 41 and 42. The end conditions, maximum rates, and average rates for tasks 3 and 4 are shown in Tables XX and XXI, respectively.

b. Vertical c.g. Shift - The backpack mass was shifted 1.0 ft. up (negative Z). This shifted the system c.g. 0.5 ft. up. For this c.g. shift, firing the longitudinal thrusters causes a pitch rotational coupling, and firing the lateral thrusters causes a roll rotational coupling. The subject's translational motions for tasks 3 and 4 are shown in Figures 44 and 47, respectively. Strip chart continuous data for task 3 are shown in Figures 45 and 46. The end condition, maximum rates, and average rates for tasks 3 and 4 are shown in Tables XXII and XXIII, respectively.

5. IMLSS CONFIGURATION 1 WITH INERTIA CROSS-PRODUCTS

The performance of the IMLSS (Config. 1) was investigated for one inertia dyadic change. I_{xz} was made equal to a negative 4 slug-ft^2. The other cross-product terms were kept zero. Also, the principle inertias were not changed (I_{zz} = 4.78 slug-ft^2 and I_{yy} = I_{xx} = 18.76 slug-ft^2). Introducing the I_{xz} cross-product rotated the principle axes of the new system up fifteen degrees from the man's torso reference axes. A derivation of the equations required for this computation appear in Appendix II.

The subject's translational motions for tasks 3 and 4 are shown in Figures 48 and 51, respectively. Strip chart continuous data for task 3 are shown in Figures 49 and 50. The end conditions, maximum rates, and average rates for tasks 3 and 4 are shown in Tables XXIV and XXV, respectively.

6. IMLSS CONFIGURATION 4 DATA

After investigating the first three IMLSS configurations, a fourth configuration was evolved. It was based mainly on the test subject's opinion of flying quality for configurations 1, 2, and 3. The translational accelerations used were 0.3 ft/sec^2 in all three directions. The rotational accelerations used were 16 deg/sec^2 in yaw and 11 deg/sec^2 in roll and pitch.

The subject's translational motions for tasks 3 and 4 are shown in Figures 52 and 55, respectively. Strip chart continuous data for task 3 are shown in Figures 53 and 54. The end conditions, maximum rates, and average rates for tasks 3 and 4 are shown in Tables XXVI and XXVII, respectively.

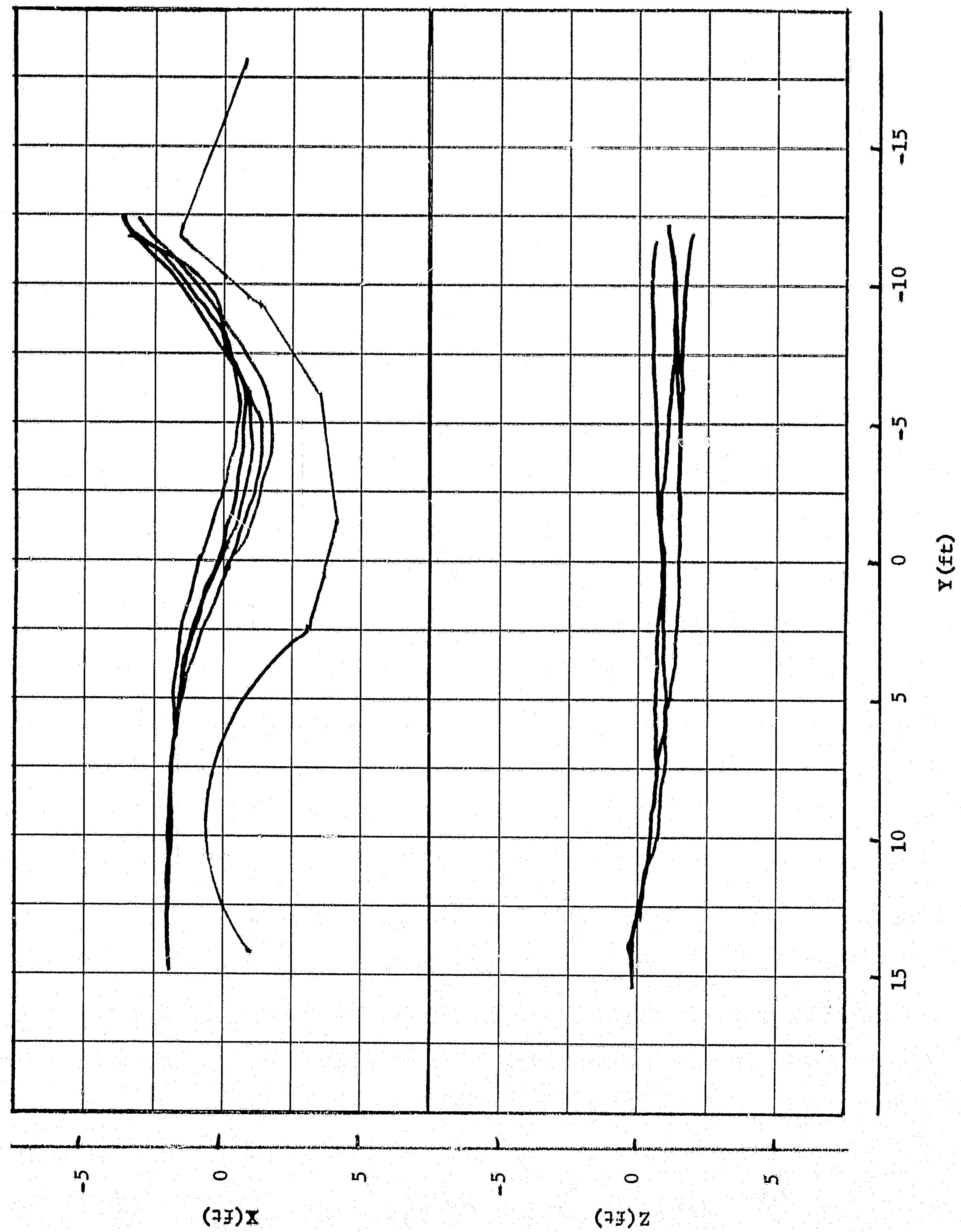


Figure 22 IMLSS Configuration 1 - Task 1: X-Y and Y-Z Motions

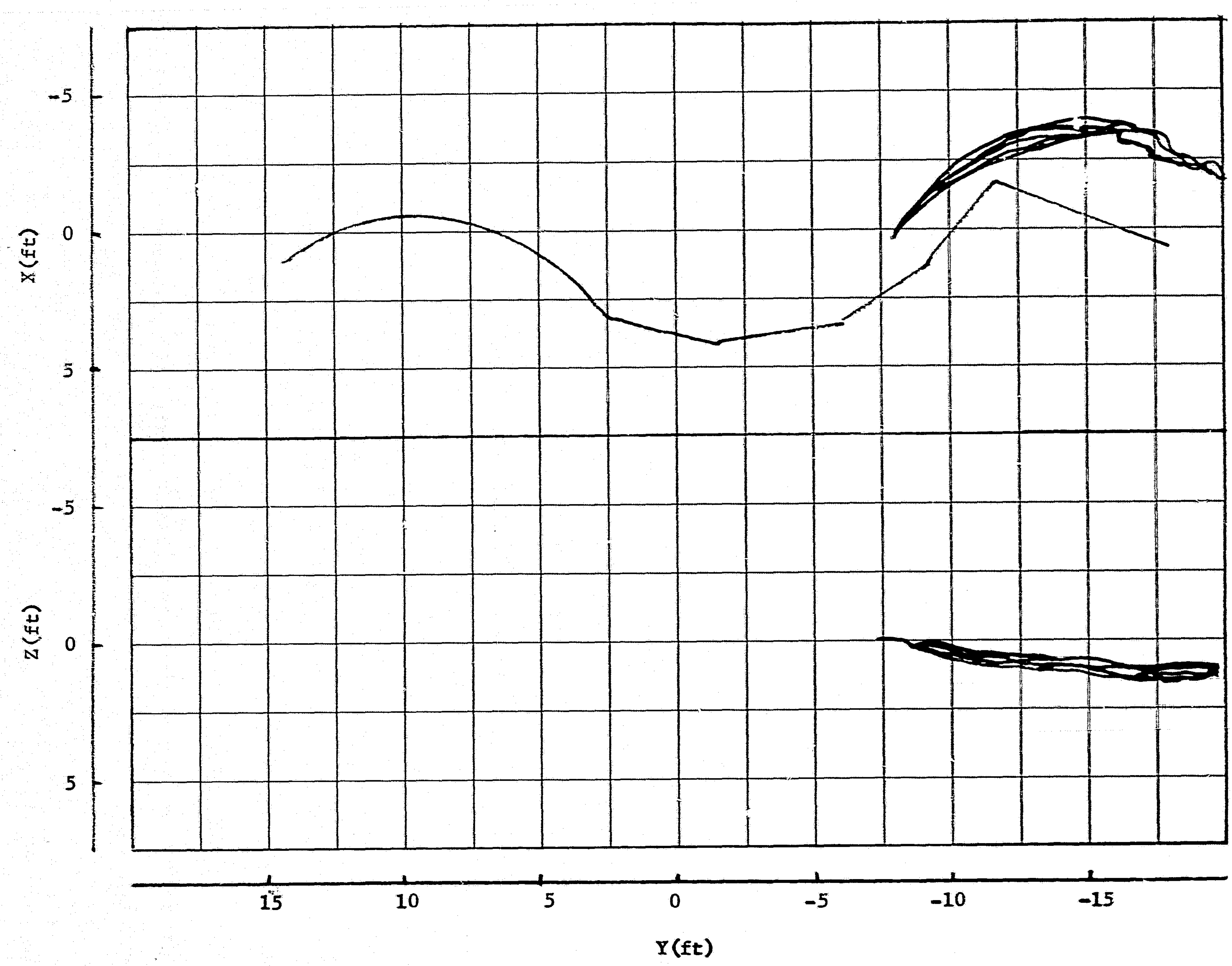


Figure 23 IMLSS Configuration 1 - Task 2: X-Y and Y-Z Motions

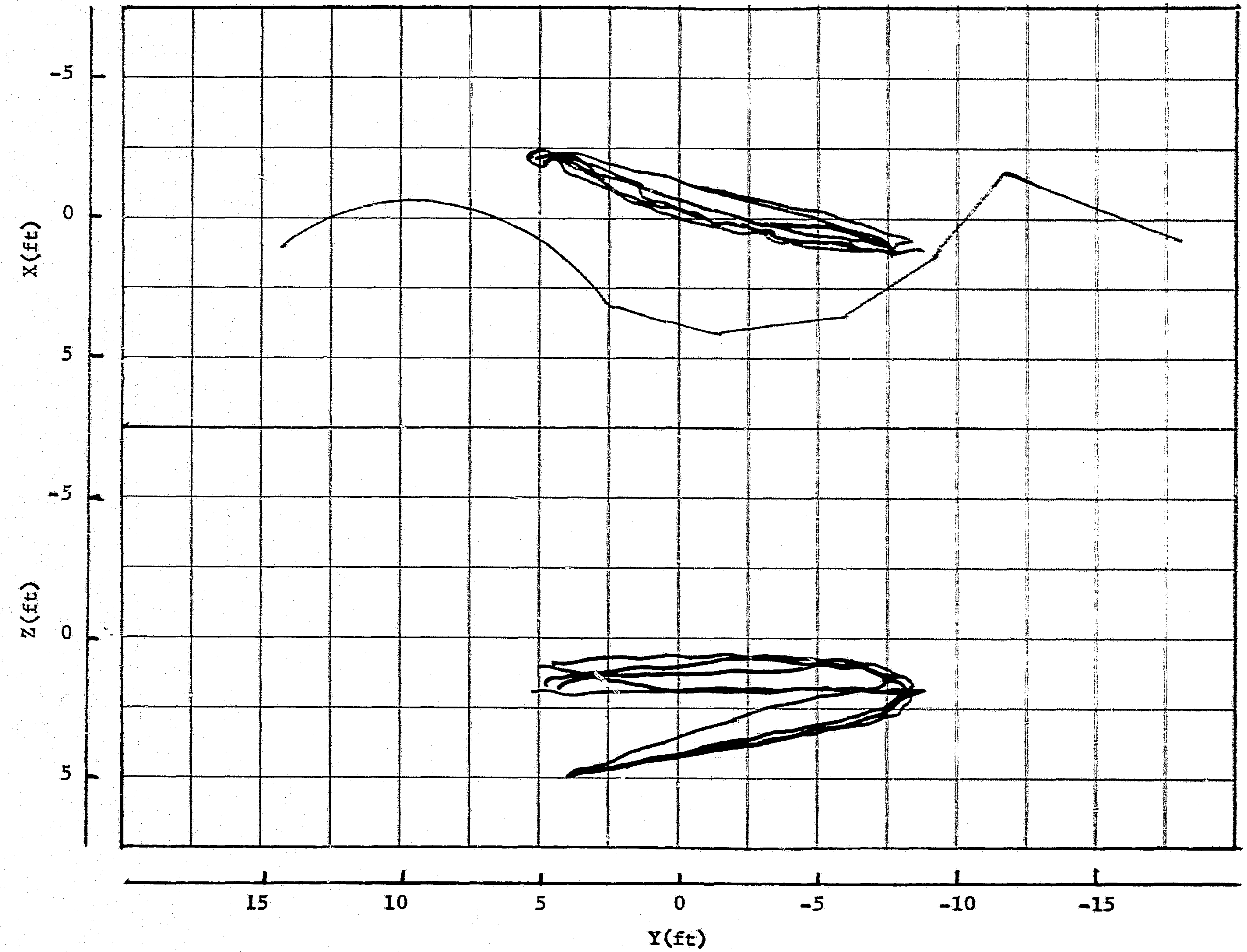
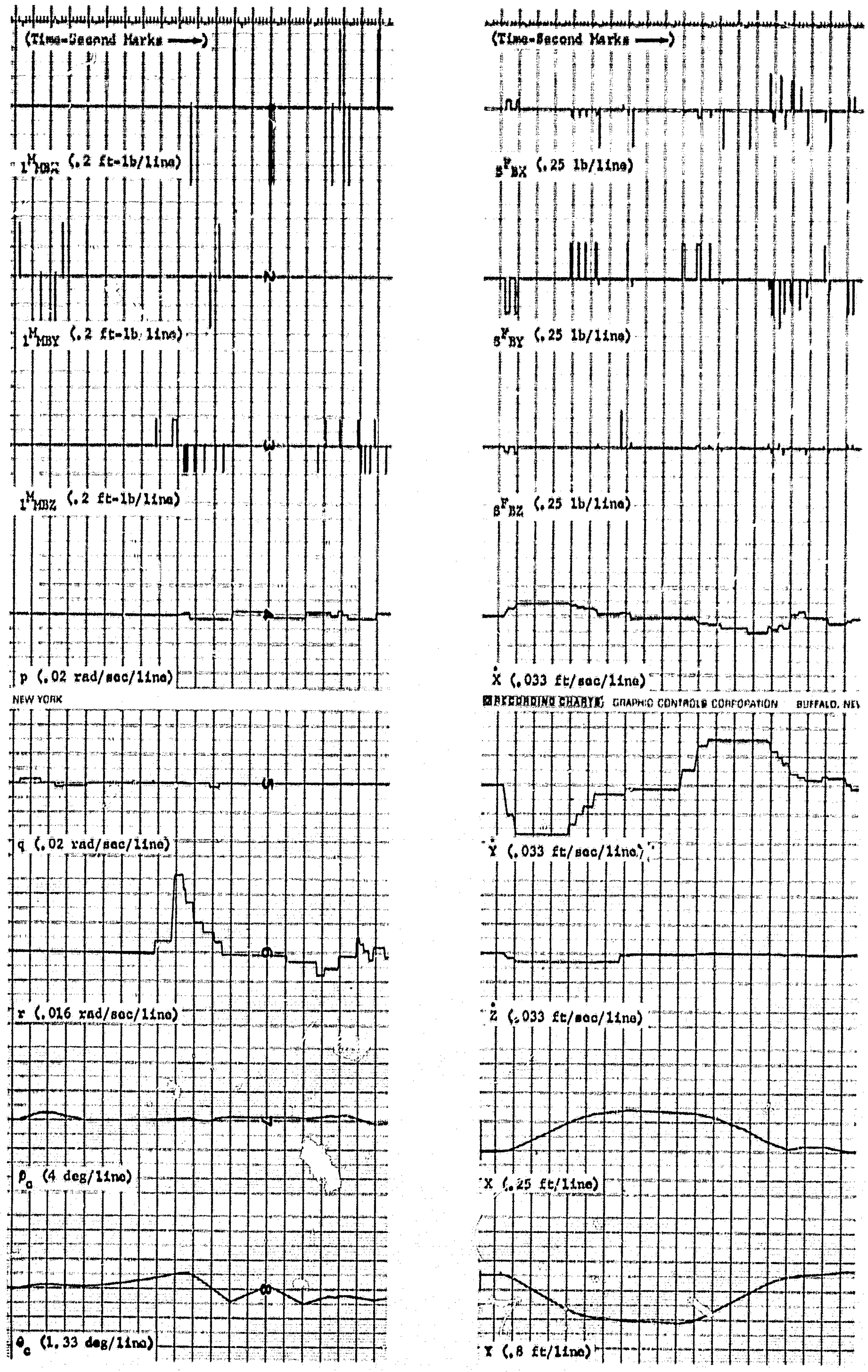
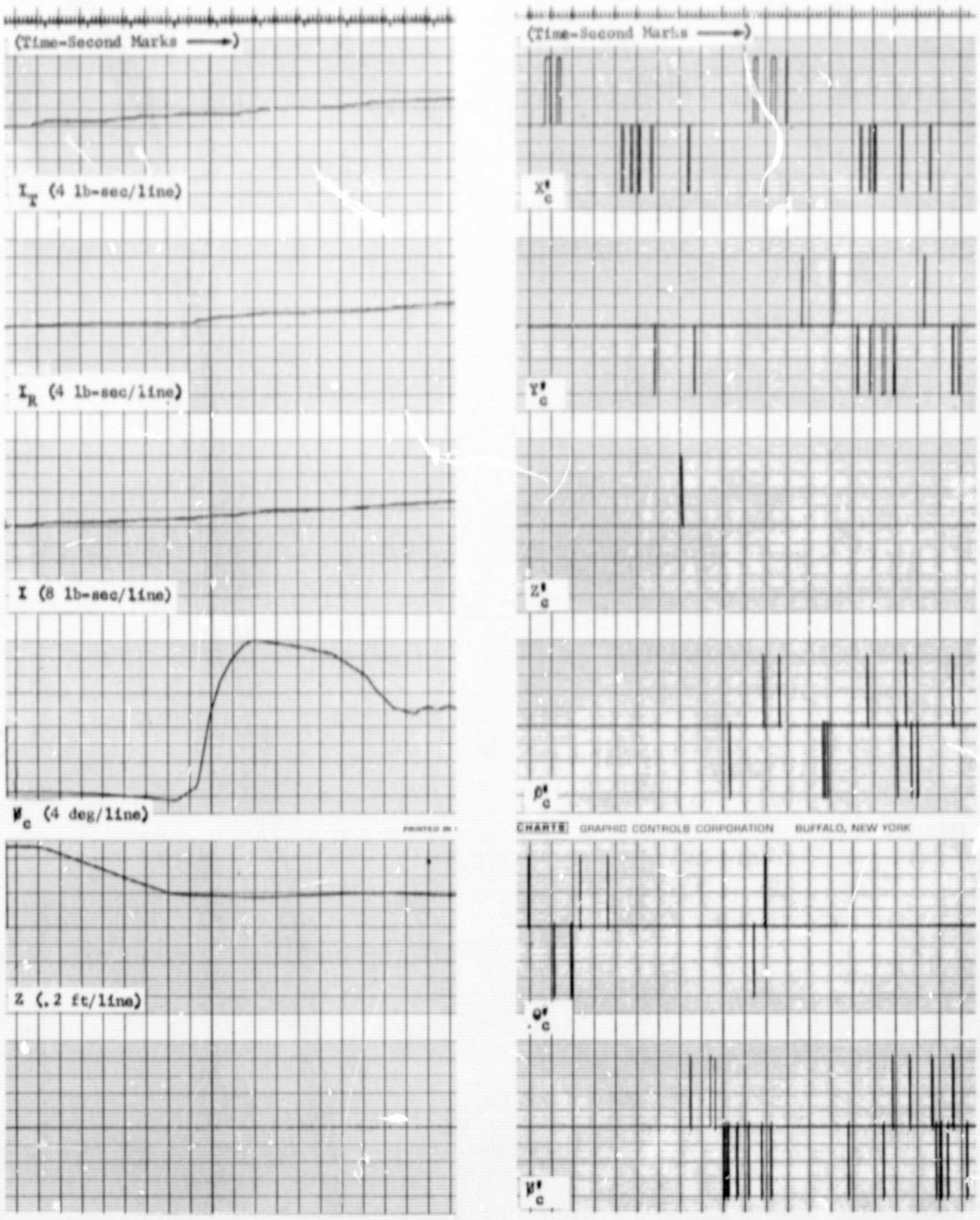


Figure 24 IMLSS Configuration 1 - Task 3: X-Y and Y-Z Motions



Recorder #1 **Recorder #2**

Figure 25 IMLSS Configuration 1 - Task 3: Strip Chart Data (R - 1&2)



Recorder #3 | Recorder #4

Figure 26 IMLSS Configuration 1 - Task 3: Strip Chart Data (R - 3&4)

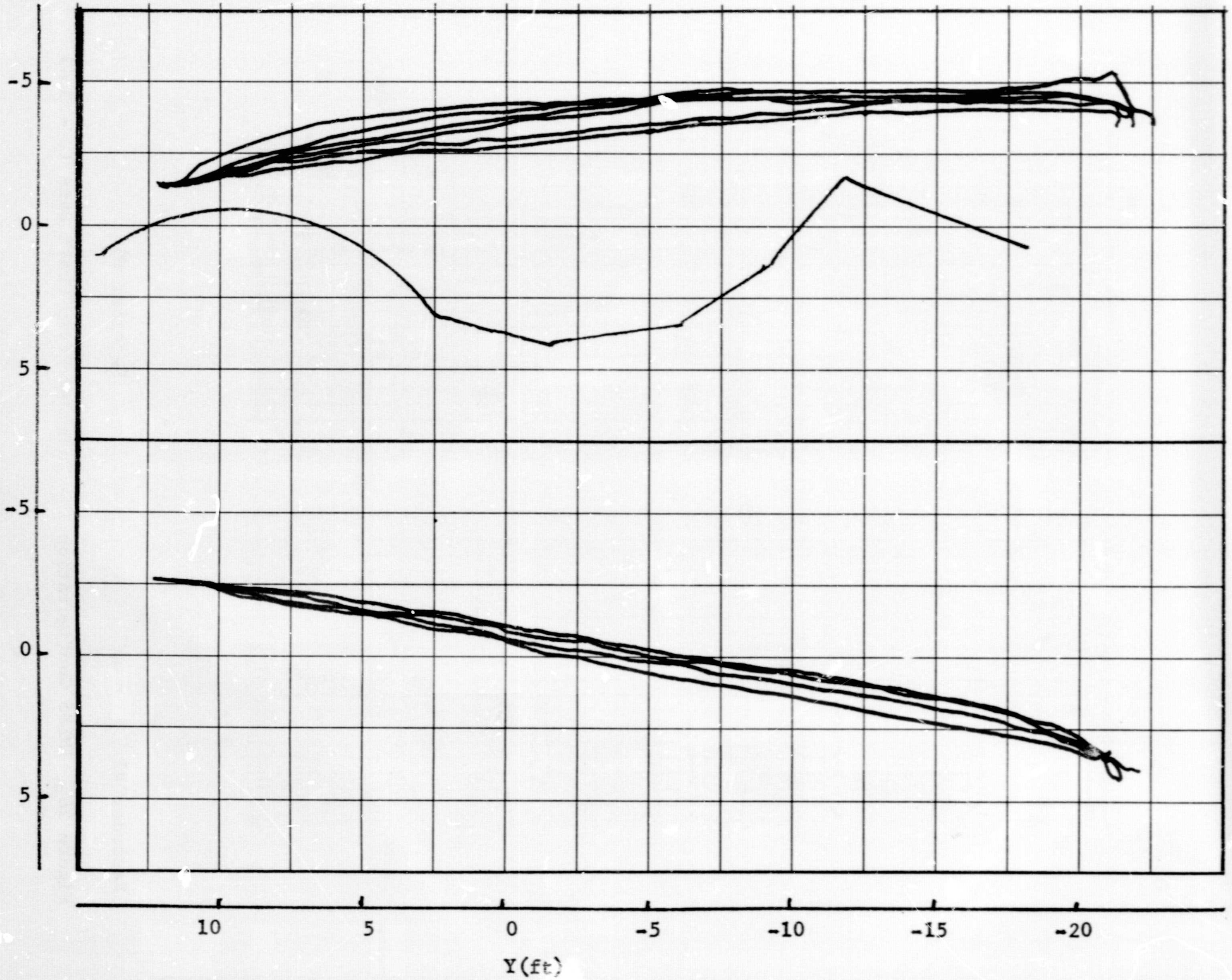


Figure 27 IMLSS Configuration 1 - Task 4: X-Y and Y-Z Motions

Table VIII IMLSS Configuration 1 - Task 1 Data

	Run	Time sec	Impulse (lb-sec) Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rct.	Total	Time X Impulse	Position ft X	Y	Z	Velocity ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg ϕ_c	θ_c	ψ_c
Practice	1	99	12.2	1.5	1.5	15.1	10.4	6.3	6.1	22.9	38.0	3748	-4.3	-12.2	.6	-.15	-.23	-.02	-1.9	-7.9	-33.6
	2	80	10.5	2.7	3.7	17.0	3.2	5.3	6.2	14.6	31.6	2534	-3.6	-12.2	.3	-.22	-.27	.02	-4.3	-2.6	-59.6
	3	92	10.1	3.4	3.6	17.1	14.3	12.8	4.2	31.3	48.5	4459	-3.8	-11.9	.3	-.18	-.18	.00	-5.4	-.4	-55.8
	Avg	90	10.9	2.8	3.0	16.4	9.3	8.1	5.5	22.9	39.1	3580	-3.9	-12.1	.4	-.18	-.23	.00	-3.9	-3.6	-49.7
	1	78	11.4	1.8	1.2	14.4	4.5	1.3	3.4	9.2	23.6	1837	-3.3	-11.7	.7	-.26	-.15	.00	-3.5	1.6	-77.0
	2	82	8.6	2.3	1.8	12.6	3.5	1.4	1.5	6.4	19.0	1563	[illegible]	-12.2	.3	-.20	-.26	-.01	-.2	2.2	-65.2
	3	63	11.5	2.1	2.1	15.9	3.0	2.4	2.9	8.2	24.2	1514	-3.9	-12.5	1.1	-.27	-.36	-.04	.8	-3.4	-65.8
	4	72	9.7	4.4	1.8	15.9	2.2	1.6	1.4	5.2	21.1	1524	-3.2	-12.8	1.1	-.31	-.34	-.03	-2.7	5.5	-61.8
	5	71	9.5	1.7	1.4	12.6	3.0	1.4	2.5	6.9	19.5	1394	-3.1	-12.1	2.1	-.26	-.27	-.03	4.4	9.8	-68.0
	Avg	74	10.1	2.4	1.7	14.3	3.2	1.6	2.3	7.2	21.5	1566	-3.3	-12.3	1.0	-.28	-.27	-.01	-.1	3.1	-61.6

	Run	End conditions Body rates deg/sec P	Q	R	Maximum rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R	Average rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R
Practice	1	2.5	-2.1	5.6	.23	.40	.07	3.6	2.2	9.5	.02	-.28	.01	.0	-.2	.6
	2	.9	-.9	1.2	.23	.43	.11	2.3	1.9	10.1	-.02	-.33	.00	[illegible]	-.2	.3
	3	.7	-2.0	1.6	.25	.39	.11	3.6	2.8	7.8	-.02	-.29	.00	-.2	-.1	.5
	Avg	1.4	-1.7	2.8	.24	.41	.10	3.2	2.3	9.1	-.01	-.30	.00	-.1	-.2	.5
	1	-.1	.3	.2	.26	.44	.06	1.7	1.3	6.1	-.02	-.34	.01	.0	-.1	.3
	2	-.2	.4	-2.2	.21	.40	.06	1.1	1.0	4.1	-.01	-.33	.00	-.1	-.1	.3
	3	-.7	-.2	-.8	.28	.56	.08	1.2	1.0	5.1	-.03	-.44	.02	.0	-.1	.3
	4	-.8	.3	-1.0	.32	.47	.01	1.4	.9	4.8	-.02	-.37	.02	-.2	-.1	.4
	5	-.8	.3	-1.0	.27	.45	.07	2.2	.9	5.8	.02	-.38	.03	-.1	.0	.4
	Avg	-.5	.3	-1.0	.26	.46	.06	1.5	1.0	5.1	-.02	-.37	.02	-.1	-.1	.3

Table IX IMLSS Configuration 1 - Task 2 Data

		End conditions																				
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	73	12.2	12.7	2.5	27.4	10.7	2.2	11.4	24.4	51.8	3786	-2.0	-19.2	1.2	-.01	.00	-.02	-2.7	4.5	18.1
	2	94	9.0	9.2	2.3	20.5	3.3	32.0	4.2	11.6	32.1	3007	-2.0	-20.2	.7	-.01	.02	-.26	-.8	-3.7	23.6
	3	71	9.0	7.7	1.2	17.9	4.5	.9	2.6	7.7	25.8	1834	-2.4	-19.4	1.1	-.02	.04	-.02	-1.4	-1.6	21.6
	Avg	79	10.0	9.8	2.0	21.9	6.2	11.7	6.0	12.6	36.6	2875	-2.1	-19.6	.9	-.01	.02	-.09	-1.5	-.3	21.1
	1	94	10.1	8.5	1.0	19.6	5.1	4.7	3.2	13.0	32.6	3056	-2.4	-19.4	1.2	.01	.02	.00	.4	-3.2	14.5
	2	80	9.5	9.2	.7	19.4	7.2	6.0	2.3	15.5	35.0	2804	-2.0	-19.7	.8	-.02	.06	-.02	-6.5	-5.7	34.1
	3	79	6.7	9.6	1.6	17.9	5.8	1.3	3.4	10.5	28.4	2255	-2.7	-19.4	.6	-.02	.02	-.05	-3.6	-4.9	31.4
	4	83	7.7	9.1	2.1	19.0	5.8	4.8	5.5	16.0	35.0	2906	-2.1	-19.0	1.2	.03	.06	.00	-4.0	2.7	25.1
	5	85	6.2	8.4	1.6	16.1	4.3	5.9	2.9	13.0	29.2	2486	-2.2	-19.3	1.1	.02	.08	.03	.3	1.2	20.1
	Avg	84	8.1	8.9	1.4	18.4	5.6	4.6	3.5	13.6	32.0	2701	-2.2	-19.4	1.1	.00	.04	-.01	-2.7	-1.2	25.1

		End conditions			Maximum rates						Average rates					
	Run	Body rates														
		deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.2	-.0	1.8	.30	.38	.06	3.4	1.4	19.1	-.03	-.15	.02	-.2	-.0	1.8
	2	-.1	-.1	1.7	.27	.34	.05	1.6	1.0	8.5	-.02	-.13	.01	-.1	-.1	1.7
	3	-.2	-.1	2.2	.25	.43	.05	1.9	.9	8.4	-.04	-.16	.02	-.2	-.1	2.2
	Avg	-.2	-.1	1.9	.27	.38	.05	2.3	1.1	12.0	-.03	-.14	.02	-.2	-.1	1.9
	1	-.3	.4	-1.3	.23	.35	.04	1.8	1.5	7.1	-.03	-.12	.01	-.1	-.2	1.6
	2	-.8	.8	-1.0	.24	.38	.05	2.1	1.6	5.7	-.03	-.15	.01	-.3	-.2	2.1
	3	-.1	.3	-.2	.23	.35	.06	2.9	1.0	7.2	-.03	-.14	.01	-.3	-.2	2.0
	4	-.1	.3	.6	.24	.35	.06	3.2	1.9	8.2	-.03	-.13	.01	-.3	-.0	2.0
	5	.6	.3	-1.2	.23	.29	.06	1.8	1.4	6.8	-.03	-.13	.01	-.1	-.1	1.8
	Avg	-.2	.4	-.9	.23	.35	.05	2.4	1.5	7.0	-.03	-.13	.01	-.2	-.1	1.9

Table X IMLSS Configuration 1 - Task 3 Data

End conditions																					
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	142	14.7	4.8	3.2	22.7	16.9	16.5	11.9	45.2	67.9	9,642	-2.6	6.0	1.7	.17	.41	.14	-3.7	-1.8	5.5
	2	115	16.6	4.4	6.5	22.7	17.0	16.5	12.6	31.9	59.6	6,854	-2.7	5.0	1.0	.15	.43	.23	1.8	-3.1	9.1
	3	145	19.1	7.8	4.4	31.4	18.2	2.3	9.8	36.0	67.4	9,773	-2.2	4.5	1.5	.14	.50	.10	-4.0	6.6	25.6
	Avg	134	16.8	5.7	3.7	27.3	17.3	7.9	11.4	37.7	64.9	8,697	-2.5	5.2	1.4	.15	.44	.16	-1.9	0.6	13.4
	1	106	20.3	4.9	2.6	27.8	9.7	3.4	7.2	20.2	48.0	5,083	-2.0	4.5	1.8	.16	.60	.12	-.4	.1	30.1
	2	94	20.3	6.8	.5	27.7	5.1	2.9	12.5	25.4	53.1	4,975	-2.3	4.3	1.2	.18	.54	.11	-.5	-2.0	31.0
	3	90	18.9	10.8	1.7	31.4	5.5	3.6	19.0	28.1	59.5	5,341	-2.2	5.2	1.0	.25	.54	.10	-2.3	-3.1	17.7
	4	100	20.3	6.8	1.8	28.8	9.0	11.3	9.1	29.4	58.2	5,801	-2.2	4.9	1.6	.20	.62	.20	-1.1	-4.7	20.0
	5	104	21.9	7.5	.7	30.3	8.0	5.4	12.9	26.3	56.6	5,882	-2.4	5.3	1.9	.18	.56	.10	-1.6	-5.5	20.6
	Avg	99	20.3	7.4	1.5	29.2	7.4	5.3	12.1	25.9	55.1	5,417	-2.2	4.8	1.5	.18	.57	.13	-1.2	-3.0	23.9

	Run	End conditions			Maximum rates						Average rates					
		Body rates deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.8	.4	-.5	.17	.41	.14	3.3	5.8	13.2	.00	.01	-.02	-.1	.1	.7
	2	.0	.4	-1.4	.15	.43	.23	10.5	1.5	29.8	.00	.00	-.03	.0	-.1	1.0
	3	1.0	.6	-.4	.14	.50	.10	4.3	2.4	14.5	.00	.00	-.02	-.1	.2	.7
	Avg	.1	.5	-.7	.15	.44	.16	6.0	3.2	17.7	.00	.00	-.02	.0	.1	0.8
	1	-.5	.5	-.46	.16	.60	.12	1.4	2.0	15.3	.001	.00	-.03	-.2	.0	1.1
	2	1.0	.5	.1	.18	.54	.11	2.7	2.6	29.9	.00	.00	-.04	-.1	.0	1.8
	3	.1	.6	-.4	.25	.54	.10	1.9	2.1	34.7	.00	.01	-.03	-.2	.0	1.1
	4	-.6	1.3	-1.5	.20	.62	.20	3.0	4.9	20.8	.00	.01	-.03	.1	.0	1.0
	5	.7	.2	-1.6	.18	.56	.10	2.1	1.7	26.1	.00	.01	-.03	-.3	.0	1.0
	Avg	.1	.6	-.8	.18	.57	.13	2.2	2.6	25.3	.00	.01	-.03	-.1	.0	1.2

Table XI IMLSS Configuration 1 - Task 4 Data

		End conditions																					
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	99	22.4	5.8	6.2	34.4	7.0	12.5	4.5	23.9	58.3	5607	-4.2	-21.4	3.5	.04	-.03	.00	.0	6.9	-93.0
	2	81	18.7	5.1	5.5	29.2	2.1	8.0	4.0	14.1	43.3	3527	-4.1	-21.5	4.1	.03	-.05	.00	2.0	5.7	-92.0
	3	81	22.5	6.9	3.8	32.7	5.7	4.1	11.3	21.1	53.8	4390	-3.8	-21.8	3.6	.02	-.02	-.03	8.4	6.3	-90.0
	Avg	86	21.2	5.9	5.3	32.1	4.9	8.2	6.6	19.7	57.8	4507	-4.0	-21.5	3.7	.03	-.03	-.01	3.5	6.3	-91.6
	1	79	22.2	4.0	2.7	29.0	5.7	4.5	7.2	17.4	46.4	3678	-3.9	-21.6	3.8	.01	-.03	-.01	2.2	3.7	-98.0
	2	71	21.0	4.8	5.8	31.6	4.8	5.0	6.0	15.8	47.4	3384	-3.9	-21.4	3.4	.03	-.06	.02	5.3	4.5	-95.0
	3	72	22.5	2.0	.6	25.1	5.0	3.3	8.6	16.9	42.0	3020	-4.0	-21.5	4.0	.04	-.06	.12	5.0	6.9	-97.8
	4	83	22.3	6.3	4.0	32.5	8.6	9.1	10.0	27.8	60.4	5025	-3.8	-21.5	3.7	.02	.03	-.03	-1.1	8.5	-90.0
	5	62	25.3	4.8	5.8	35.9	10.6	5.8	7.1	23.5	59.3	3676	-3.9	-21.4	4.0	.06	-.08	.02	13.2	2.6	-100.[illegible]
	Avg	73	22.7	4.4	3.8	30.8	6.9	5.5	7.8	30.3	51.3	3757	-3.9	-21.6	3.8	.03	-.05	.02	5.0	5.4	-96.1

	Run	End conditions			Maximum rates						Average rates					
		Body rates														
		deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.4	- .1	- .5	.16	1.04	.25	3.5	4.2	8.5	-.03	-.35	.06	.2	.1	-1.8
	2	-.4	- .1	- .2	.16	.94	.28	2.7	2.2	11.1	-.03	-.41	.08	-.2	.2	-2.0
	3	-1.0	.4	- .2	.19	1.09	.20	2.4	1.7	15.8	-.03	-.42	.08	.2	.3	-2.2
	Avg	- .6	.1	- .3	.17	1.02	.24	2.8	2.7	11.8	-.03	-.39	.07	.1	.3	-2.0
	1	.2	.4	- .3	.13	1.09	.21	2.9	2.2	14.4	-.03	-.42	.08	.2	.2	-2.2
	2	- .5	.1	- .2	.19	.98	.20	3.4	2.6	18.1	-.03	-.47	.08	.2	.3	-2.7
	3	- .7	.3	- .8	.17	1.10	.17	3.8	1.7	16.3	-.03	-.47	.09	.2	.2	-2.1
	4	- .6	-1.3	- .5	.17	1.05	.18	4.1	2.5	19.7	-.03	-.40	.08	.1	.2	-2.0
	5	- .3	- .1	- .8	.25	1.20	.30	3.3	3.6	17.7	-.04	-.55	.10	.3	.4	-2.6
	Avg	- .3	- .1	- .5	.16	1.08	.22	3.5	2.5	16.8	-.03	-.47	.09	.2	.3	-2.3

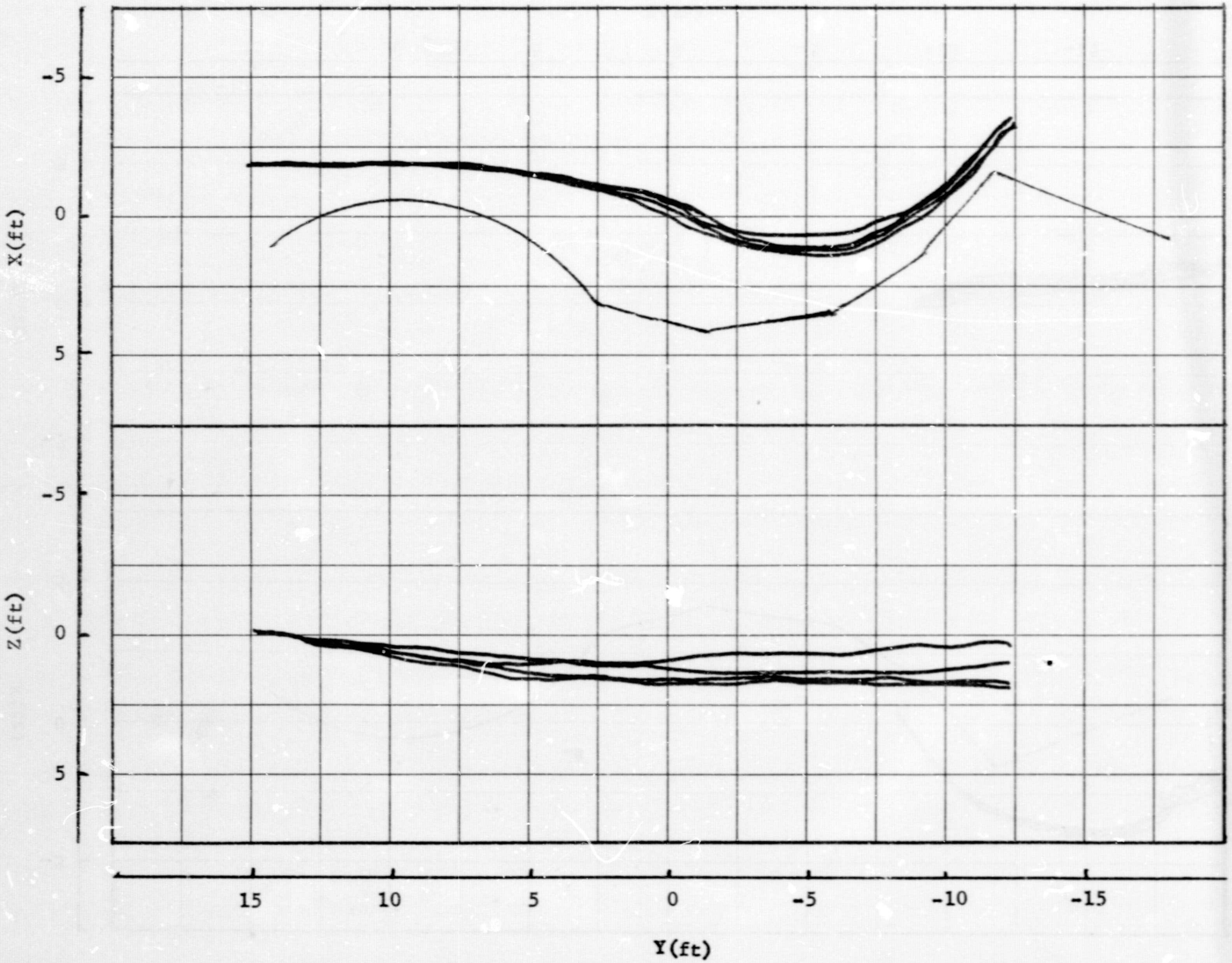


Figure 28 IMLSS Configuration 2 - Task 1: X-Y and Y-Z Motions

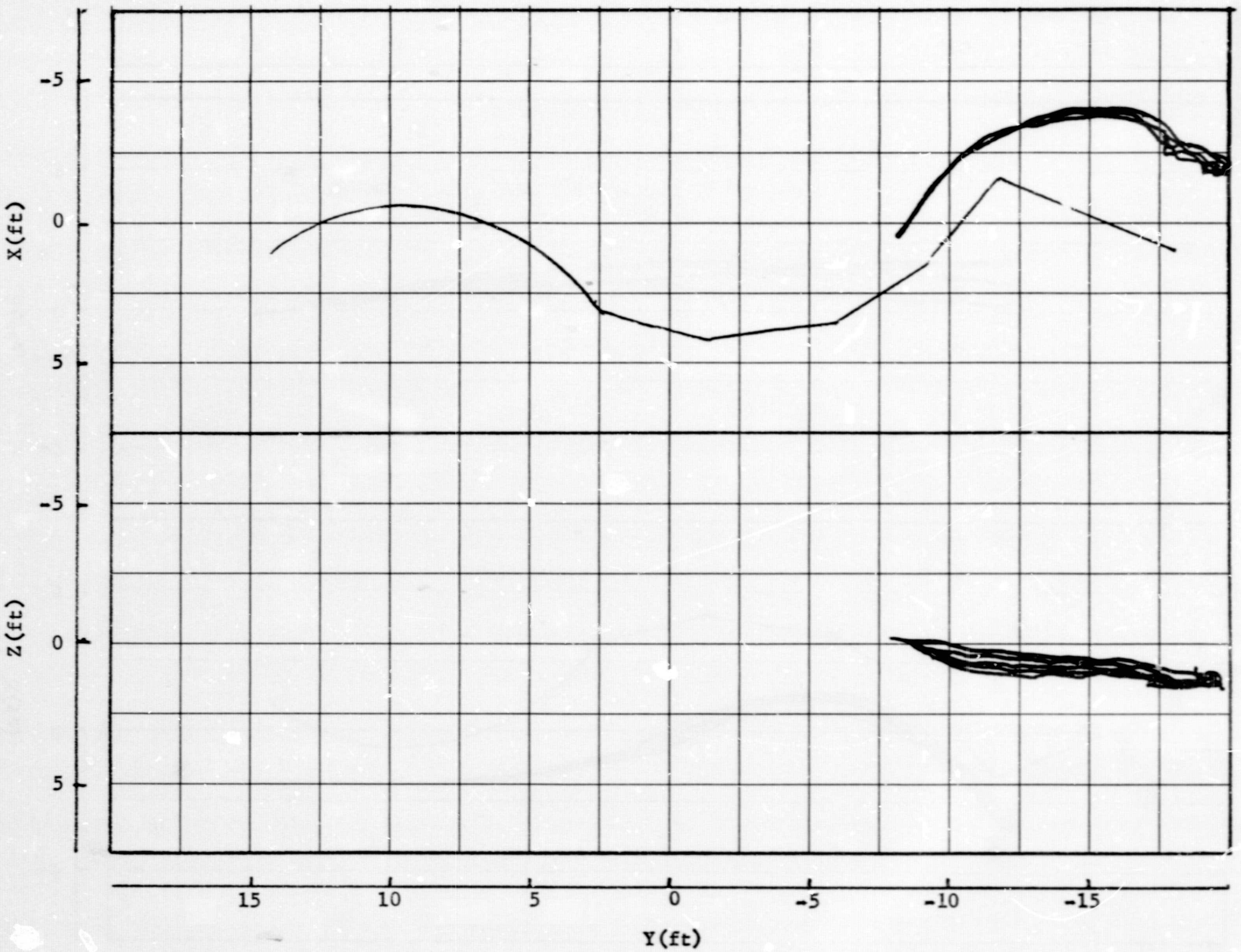


Figure 29 IMLSS Configuration 2 - Task 2: X-Y and Y-Z Motions

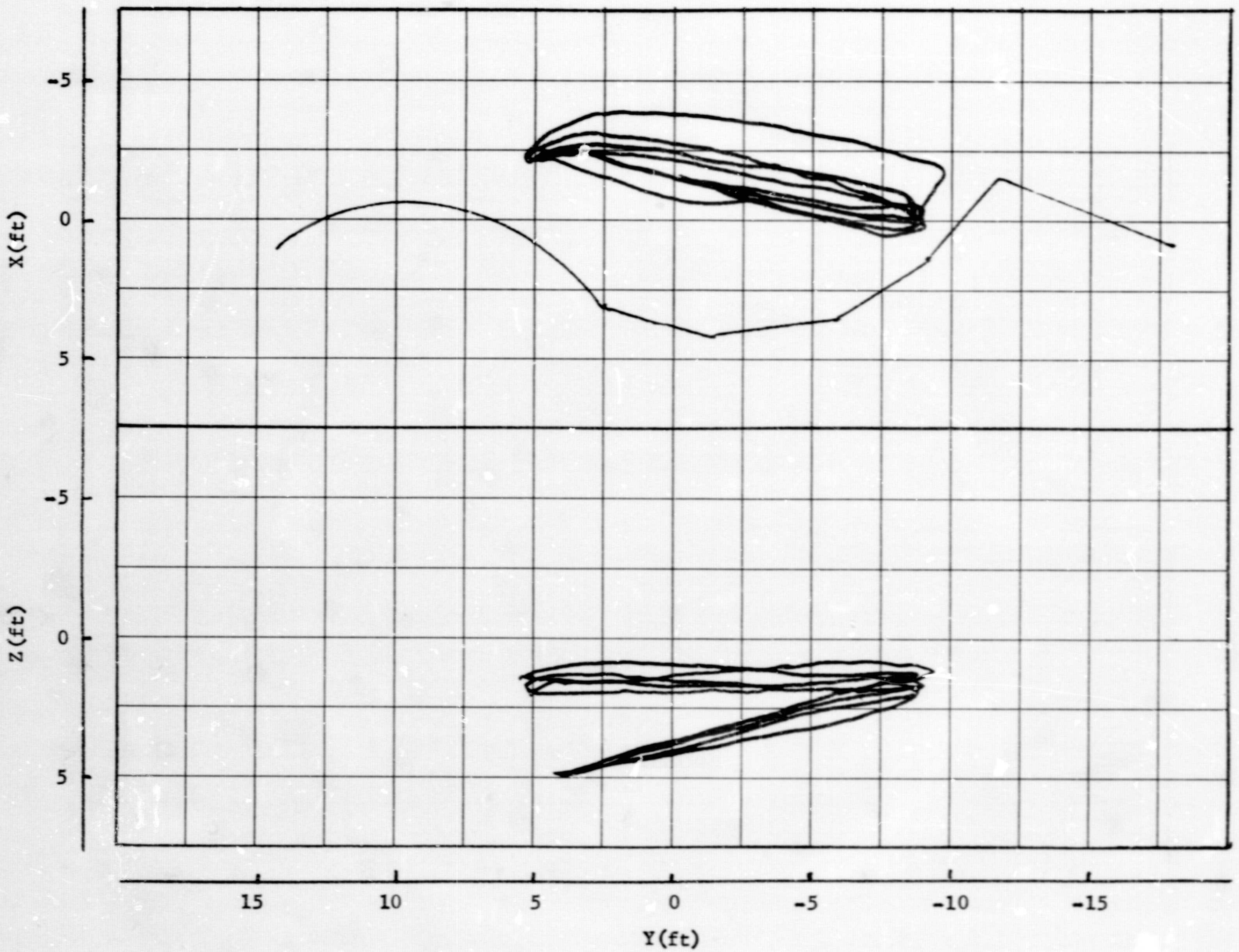
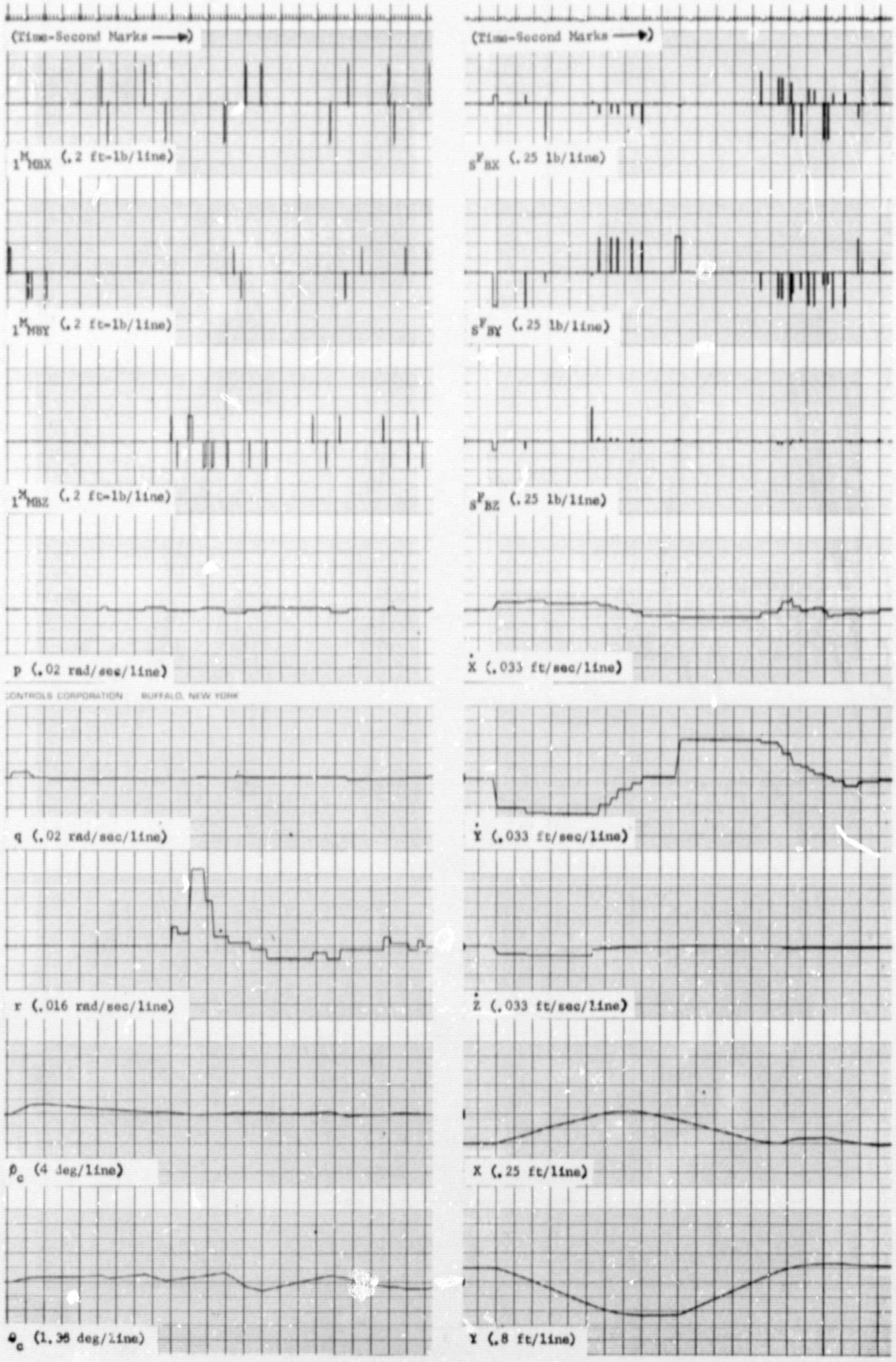
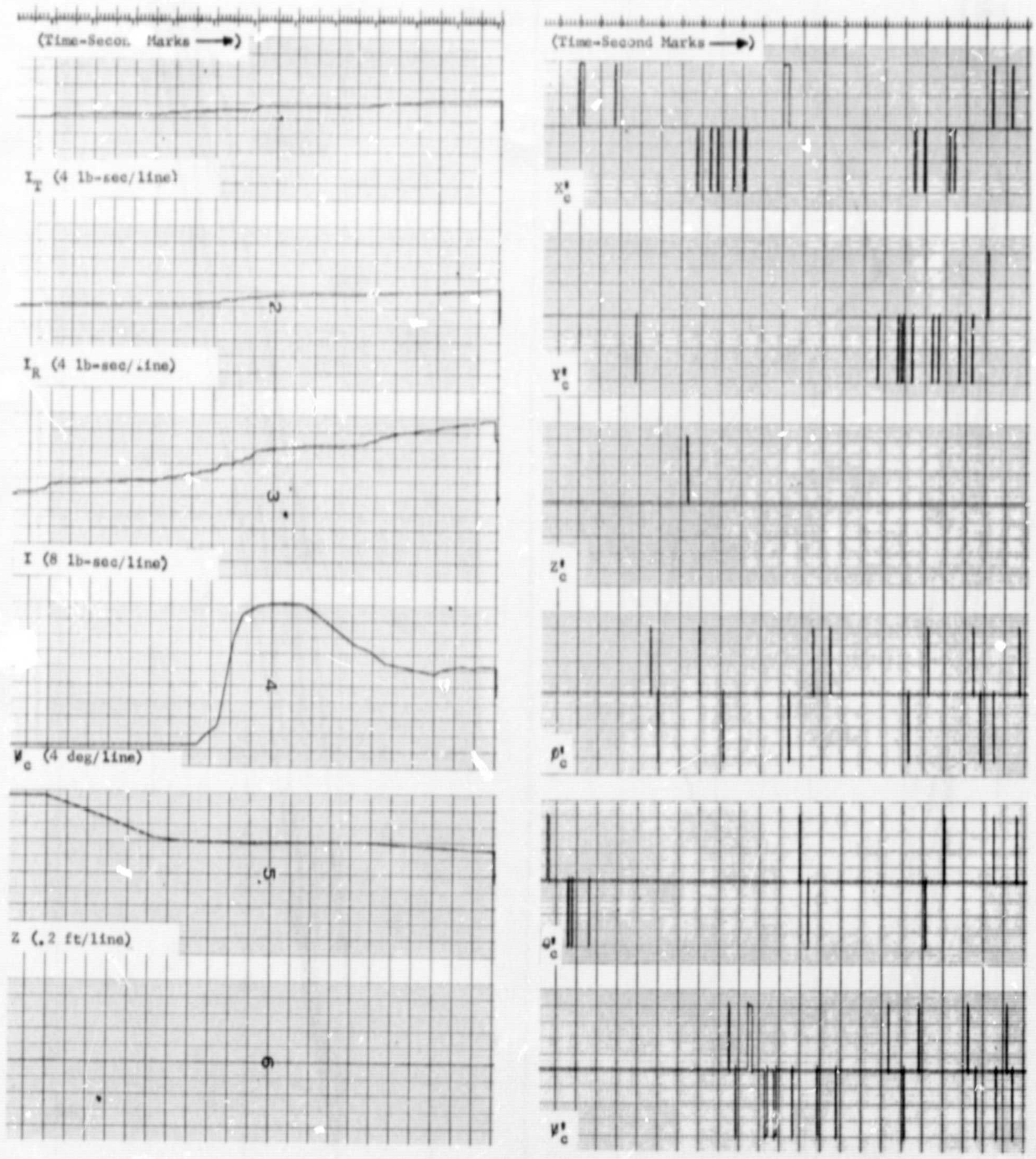


Figure 30 IMLSS Configuration 2 - Task 3: X-Y and Y-Z Motions



Recorder #1 Recorder #2

Figure 31 IMLSS Configuration 2 - Task 3: Strip Chart Data (R - 1&2)



Recorder #3 Recorder #4

Figure 32 IMLSS Configuration 2 - Task 3: Strip Chart Data (R - 3&4)

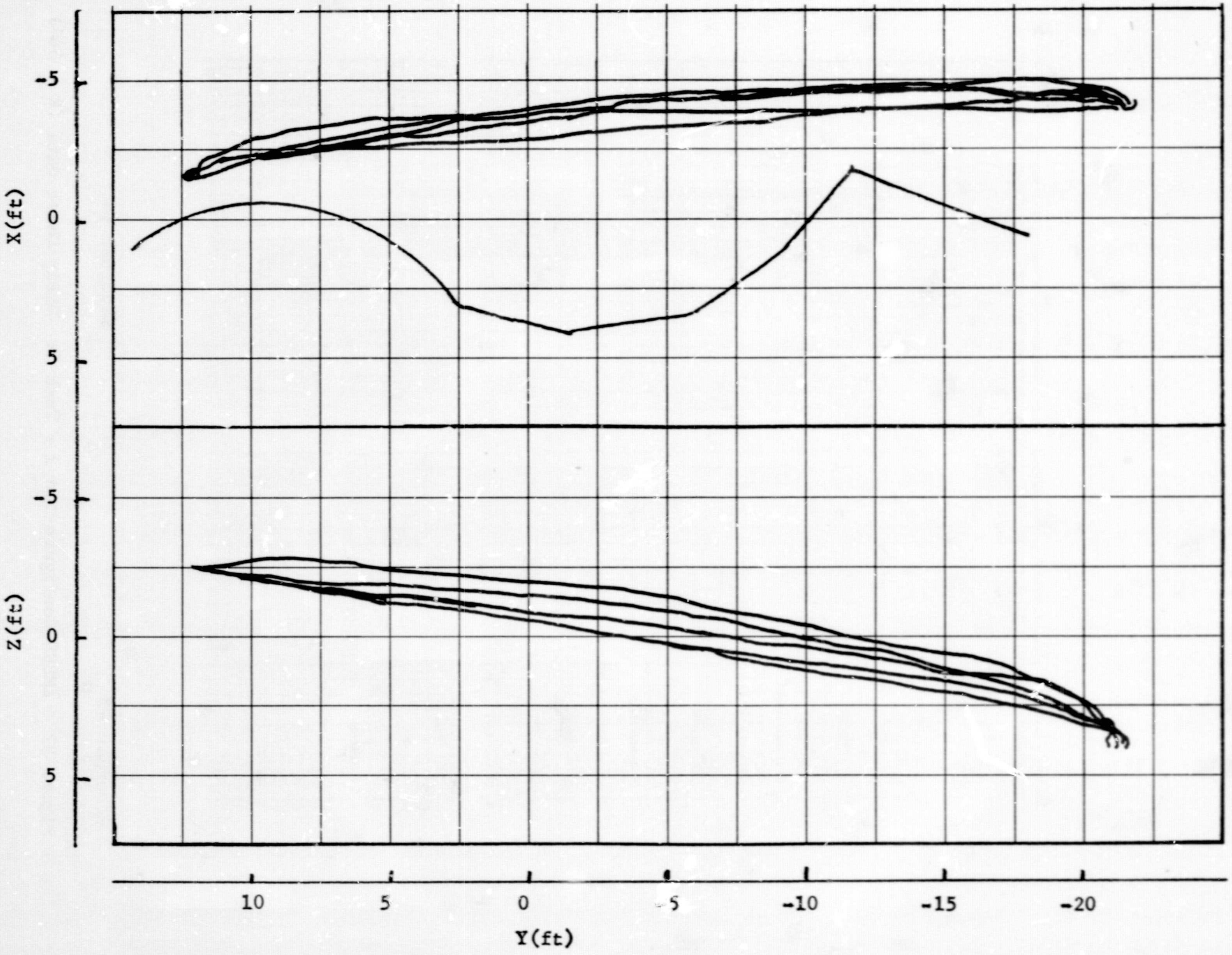


Figure 33 IMLSS Configuration 2 - Task 4: X-Y and Y-Z Motions

Table XII IMLSS Configuration 2 - Task 1 Data

	Run	Time sec	Impulse (lb-sec) Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot.	Total	Time X Impulse	Position ft X	Y	Z	Velocity ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg ϕ_c	θ_c	ψ_c
Practice	1	60	12.3	1.6	3.4	17.3	5.8	1.2	5.7	12.7	30.6	1800	-3.7	-12.0	.6	-.32	-.33	.02	-1.4	-.33	-54.4
	2	66	13.9	4.5	2.5	21.0	1.0	.4	6.7	8.0	29.2	1927	-3.5	-11.9	.9	-.35	-.26	.02	-1.4	-1.4	-60.5
	3	56	19.0	4.0	1.6	24.6	4.6	.4	6.3	11.2	35.8	2019	-3.5	-12.7	.9	-.35	-.39	-.03	3.4	2.6	-63.2
	Avg	61	15.1	3.4	2.5	21.0	3.8	.7	6.2	10.6	31.7	1915	-3.6	-12.2	.8	-.34	-.31	.00	.2	.3	-59.4
	1	72	11.7	.7	2.0	14.4	4.2	.4	5.6	10.1	24.5	1764	-3.6	-12.4	.4	-.30	-.30	.03	.6	2.8	-64.6
	2	71	12.1	.6	2.8	15.5	4.6	1.2	5.7	11.5	27.0	1890	-3.7	-12.3	-.9	-.33	-.32	-.04	4.1	4.2	-74.[illegible]
	3	73	11.1	1.3	1.2	13.6	1.9	1.3	5.6	8.8	22.4	1635	-3.4	-12.3	1.8	-.29	-.27	-.02	5.6	9.7	-65.6
	4	73	11.9	1.1	2.8	15.8	3.4	.5	6.4	10.4	26.2	1913	-3.4	-12.3	1.6	-.33	-.29	-.01	3.0	2.8	-61.0
	5	61	14.3	.6	1.2	16.1	3.7	1.0	5.9	10.6	26.7	1629	-3.4	-12.0	1.7	-.36	-.35	.00	2.0	2.6	-72.8
	Avg	70	12.2	1.4	2.0	15.1	3.6	.9	5.8	10.3	25.4	1766	-3.5	-12.3	.9	-.32	-.30	-.0[illegible]	3.1	4.4	-67.4

	Run	End conditions Body rates deg/sec P	Q	R	Maximum rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R	Average rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R
Practice	1	.5	.3	-1.0	.33	.53	.09	3.6	1.0	8.8	-.03	-.45	.01	-.3	-.1	.7
	2	-.4	-.2	-.2	.35	.52	.06	1.6	.5	7.4	-.02	-.40	.01	-.1	-.1	.4
	3	1.3	-.3	1.6	.35	.67	.08	2.3	.5	10.3	-.03	-.50	.02	-.2	-.0	.4
	Avg	.4	-.1	.1	.34	.57	.08	2.3	.7	8.8	-.03	-.45	.01	-.2	-.1	.5
	1	.3	-.4	-.1	.31	.49	.06	2.3	.5	11.8	-.02	-.38	.00	-.2	.0	.4
	2	-1.3	.6	-1.3	.33	.48	.09	2.2	.8	10.7	-.02	-.39	.01	-.3	-.1	.3
	3	.1	.1	.9	.29	.45	.04	1.3	1.0	7.8	-.02	-.37	.03	-.3	.1	.3
	4	-.9	-.4	1.7	.33	.49	.06	2.0	1.1	12.0	-.02	-.36	.02	-.1	-.0	.5
	5	-1.1	.1	1.0	.37	.60	.07	2.7	1.0	10.7	-.02	-.45	.03	-.2	-.1	.2
	Avg	-.6	.0	.4	.33	.50	.06	2.1	.9	10.6	-.02	-.39	.02	-.2	.0	.3

Table XIII IMLSS Configuration 2 - Task 2 Data

			End conditions																		
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot X$	$\dot Y$	$\dot Z$	ϕ_c	θ_c	ψ_c
Practice	1	77	10.7	12.2	3.0	25.9	4.4	2.2	6.6	13.1	39.0	3003	-2.1	-19.2	1.3	.02	.03	-.01	-1.4	4.9	19.9
	2	75	6.1	12.4	.9	19.4	3.7	2.3	7.4	13.5	32.9	2500	-2.4	-19.5	1.4	.02	-.02	-.01	3.2	1.3	27.5
	3	67	6.6	12.7	2.3	21.7	2.0	1.6	2.2	5.9	27.6	1877	-2.4	-18.4	1.4	-.01	.04	-.01	-.4	2.7	18.0
	Avg	74	7.7	12.2	2.1	22.3	3.4	2.0	5.4	10.8	33.2	2460	-2.3	-19.1	1.4	.01	.02	-.01	.5	3.0	21.8
	1	86	8.1	11.4	4.1	23.6	.9	3.1	5.2	9.2	32.8	2821	-2.4	-19.3	1.1	-.02	-.02	.00	.5	-.4	27.4
	2	89	9.6	11.2	2.2	23.0	3.3	1.8	5.3	10.4	33.4	2973	-2.5	-19.3	1.0	-.01	.03	.00	4.0	-3.6	24.3
	3	83	9.0	10.6	2.4	22.0	3.1	.3	3.9	7.2	29.2	2423	-2.1	-19.1	1.3	-.02	-.01	-.01	-2.8	-.4	29.2
	4	77	7.6	12.4	2.5	22.4	1.6	.3	3.2	5.1	27.6	2125	-2.2	-18.8	1.0	-.03	-.01	-.03	3.3	1.3	22.4
	5	77	7.2	10.5	3.3	21.0	1.7	.6	2.7	5.0	26.0	2002	-2.3	-19.1	1.5	.00	.01	.01	2.2	3.5	25.9
	Avg	81	8.3	11.2	2.9	22.4	2.1	1.2	4.1	7.4	29.8	2469	-2.2	-19.1	1.1	-.02	.00	.00	1.4	-.1	25.8

		End conditions														
	Run	Body rates			Maximum rates						Average rates					
		deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot X$	$\dot Y$	$\dot Z$	P	Q	R	$\dot X$	$\dot Y$	$\dot Z$	P	Q	R
Practice	1	-.3	-.2	-1.0	.25	.47	.08	1.6	.9	10.0	-.03	-.15	.02	-.2	.1	1.9
	2	.3	.0	-.1	.25	.35	.05	1.0	.6	8.7	-.04	-.15	.02	-.1	-.1	2.1
	3	.4	.0	-2.1	.21	.37	.07	1.6	.7	6.0	-.04	-.15	.02	-.2	.0	2.1
	Avg	.1	-.1	-1.1	.24	.40	.07	1.4	.8	8.2	-.04	-.15	.02	-.2	.0	2.0
	1	-.6	-.2	-.3	.21	.37	.08	.7	.9	6.9	-.03	-.13	.01	-.2	.0	1.9
	2	-.6	.3	.1	.23	.43	.05	2.0	.9	8.8	-.03	-.13	.01	-.2	-.1	1.7
	3	-.1	-.2	.0	.23	.39	.09	1.7	.4	8.1	-.03	-.13	.01	-.2	.0	2.1
	4	-.5	-.3	-.1	.26	.49	.08	1.6	.5	9.9	-.03	-.14	.01	-.1	.0	2.0
	5	-.1	-.5	.1	.20	.39	.06	1.3	.9	6.4	-.03	-.15	.02	-.2	.0	2.1
	Avg	-.4	-.2	.0	.22	.40	.07	1.5	.7	8.0	-.03	-.14	.01	-.2	.0	2.0

Table XIV IMLSS Configuration 2 - Task 3 Data

	End conditions																				
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	102	18.6	8.6	2.0	29.2	2.1	5.1	7.9	15.2	44.2	4508	-2.3	5.1	1.7	-.01	.04	-.01	1.0	1.6	17.0
	2	102	16.3	11.4	3.0	28.2	8.7	3.8	8.7	15.5	43.7	4413	-2.1	4.8	1.9	-.05	.00	-.02	2.1	-3.0	23.1
	3	123	23.1	8.6	2.7	32.7	4.0	5.5	10.0	19.5	54.3	6678	-2.3	5.0	1.5	.03	.00	-.02	3.2	2.7	9.9
	Avg	108	19.4	9.5	2.6	30.7	4.9	4.8	8.8	16.7	47.4	5200	-2.2	5.0	1.7	-.01	.00	-.02	2.1	.4	16.6
	1	103	17.0	7.0	2.3	26.3	4.4	5.6	12.4	22.5	48.8	5026	-2.1	5.3	1.5	.01	-.02	.03	1.7	2.3	17.1
	2	106	20.9	9.1	3.0	33.0	4.6	4.6	10.2	19.4	52.4	5554	-2.1	5.1	1.9	.03	-.01	.04	.7	3.3	13.8
	3	106	19.0	4.0	1.9	24.9	4.2	5.2	11.1	20.5	45.4	4767	-2.0	5.0	1.6	.03	.02	.02	-1.7	-2.0	15.5
	4	120	17.5	6.0	.7	24.2	5.7	5.6	12.6	23.8	48.0	5736	-2.5	4.7	1.5	.01	-.02	-.01	1.0	-2.5	23.8
	5	109	16.1	5.6	1.1	22.8	5.9	4.1	13.9	23.9	46.7	5067	-2.0	5.1	1.4	.04	.04	.02	.9	2.3	10.8
	Avg	108	18.1	6.3	1.8	26.2	5.0	5.0	12.0	22.0	48.3	5230	-2.1	5.0	1.6	.02	.00	.03	.5	1.1	16.2

	End conditions			Maximum rates						Average rates					
	Run	Body rates deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	Z	P	Q	R
Practice	1	-.5	.2	-2.0	.00	.01	-.03	-.1	-.1	.9	.00	.01	-.03	-.1	-.1	.9
	2	-.5	-.1	.3	.01	.01	-.03	-.0	.0	.8	.01	.01	-.03	-.1	.0	.8
	3	-.1	-.1	-.2	.00	.01	-.03	-.1	.0	.6	.00	.01	-.03	-.1	.0	.6
	Avg	-.4	.1	-.6	.00	.01	-.03	-.1	.0	.8	.00	.01	-.03	-.1	.0	.8
	1	-.3	-.3	-.1	.15	.52	.12	1.4	2.2	26.6	.00	.01	-.03	.0	.0	.9
	2	-.3	.2	-.6	.21	.58	.13	1.1	1.6	22.3	.00	.01	-.03	.0	-.1	.8
	3	.6	.7	-.6	.13	.57	.11	1.8	1.8	21.6	.01	.01	-.03	-.1	.0	.8
	4	.4	.7	-.1	.14	.44	.11	1.8	2.4	26.0	.00	.01	-.03	-.1	.0	.8
	5	.0	-.1	-.2	.14	.50	.08	1.8	1.7	25.5	.01	.01	-.03	-.1	.0	.8
	Avg	.1	.2	-.3	.15	.52	.11	1.6	1.9	24.4	.00	.01	-.03	-.1	.0	.8

Table XV IMLSS Configuration 2 - Task 4 Data

			End conditions																		
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	90	18.0	3.5	3.7	25.2	7.1	5.2	7.0	19.2	44.5	4005	-3.9	-21.3	3.1	.03	-.01	.03	.2	3.1	-93.1
	2	72	23.9	11.2	3.2	38.3	4.5	2.4	6.1	13.0	51.4	3701	-3.9	-21.2	3.7	.01	.00	.01	-1.2	-2.8	-96.5
	3	81	24.9	5.8	3.9	34.7	4.8	1.1	8.8	14.6	49.3	3993	-4.3	-21.1	3.0	-.01	-.05	.00	1.6	2.4	-90.0
	Avg	81	19.2	6.9	3.6	32.7	5.4	2.9	7.3	15.6	48.4	3900	-4.1	-21.2	3.3	.01	-.02	.01	.2	.9	-93.2
	1	72	20.4	3.1	2.5	26.1	3.8	1.4	9.5	14.4	40.7	2930	-4.0	-21.4	3.8	.04	-.05	.04	3.8	3.1	-88.9
	2	78	21.8	2.2	4.9	29.0	4.5	2.0	11.0	17.5	46.6	3634	-4.1	-21.4	3.4	.00	-.04	.08	1.9	4.6	-92.8
	3	71	22.1	6.1	7.0	35.2	3.6	2.0	8.7	14.2	49.4	3527	-4.3	-21.7	3.9	-.05	.03	-.03	9.6	-.1	-97.7
	4	66	22.1	3.8	2.7	28.6	3.1	1.5	7.7	12.3	40.9	2699	-4.2	-21.6	3.8	.04	-.06	.04	7.2	1.1	-91.2
	5	72	25.6	5.6	3.9	35.1	4.8	.9	10.9	16.6	51.7	3722	-3.9	-21.0	3.9	.02	-.01	.01	3.6	4.7	-88.8
	Avg	72	22.4	4.2	4.2	29.6	4.0	1.6	9.6	15.0	45.9	3322	-4.1	-21.5	3.8	.01	-.03	.03	5.2	2.7	-91.9

		End conditions			Maximum rates						Average rates					
	Run	Body rates deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.3	.4	-.2	.13	.87	.17	3.0	1.9	14.8	-.03	-.37	.06	.2	.1	-1.7
	2	.3	-.2	.0	.38	1.16	.21	2.9	1.9	12.8	-.03	-.46	.09	.3	.1	-2.4
	3	-.2	.2	.1	.16	1.15	.22	3.5	1.1	17.6	-.04	-.41	.07	.2	.1	-2.0
	Avg	-.1	.1	.0	.22	1.06	.20	3.1	1.6	13.4	-.03	-.41	.07	.2	.1	-2.0
	1	-2.1	.1	1.1	.16	.99	.17	2.7	1.3	15.6	-.03	-.46	.09	.2	.2	-2.5
	2	-.1	.1	.1	.19	1.06	.23	2.8	3.4	18.8	-.03	-.47	.08	.2	.3	-2.2
	3	.9	.6	-.3	.17	1.06	.30	2.5	1.3	17.1	-.04	-.47	.09	.2	.3	-2.5
	4	-.3	.5	.1	.14	1.08	.20	2.8	1.1	19.7	-.04	.51	.10	.3	.2	-2.5
	5	-.7	.1	1.0	.16	1.15	.25	2.7	.8	15.3	-.03	-.46	.10	.2	.2	-2.3
	Avg	-.5	.3	.4	.16	1.07	.23	2.7	1.6	17.3	-.03	-.47	.09	.2	.2	-2.4

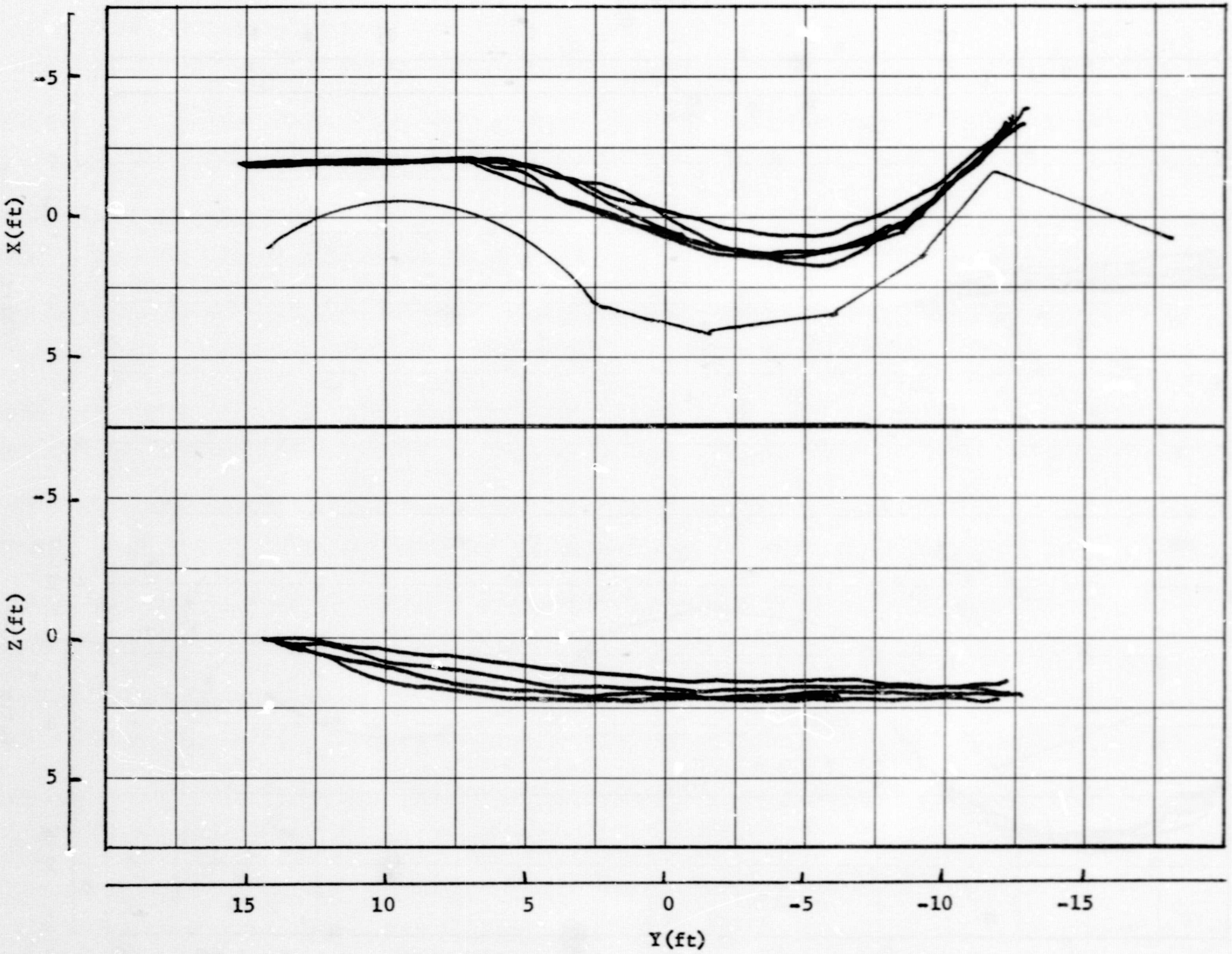


Figure 34 IMLSS Configuration 3 - Task 1: X-Y and Y-Z Motions

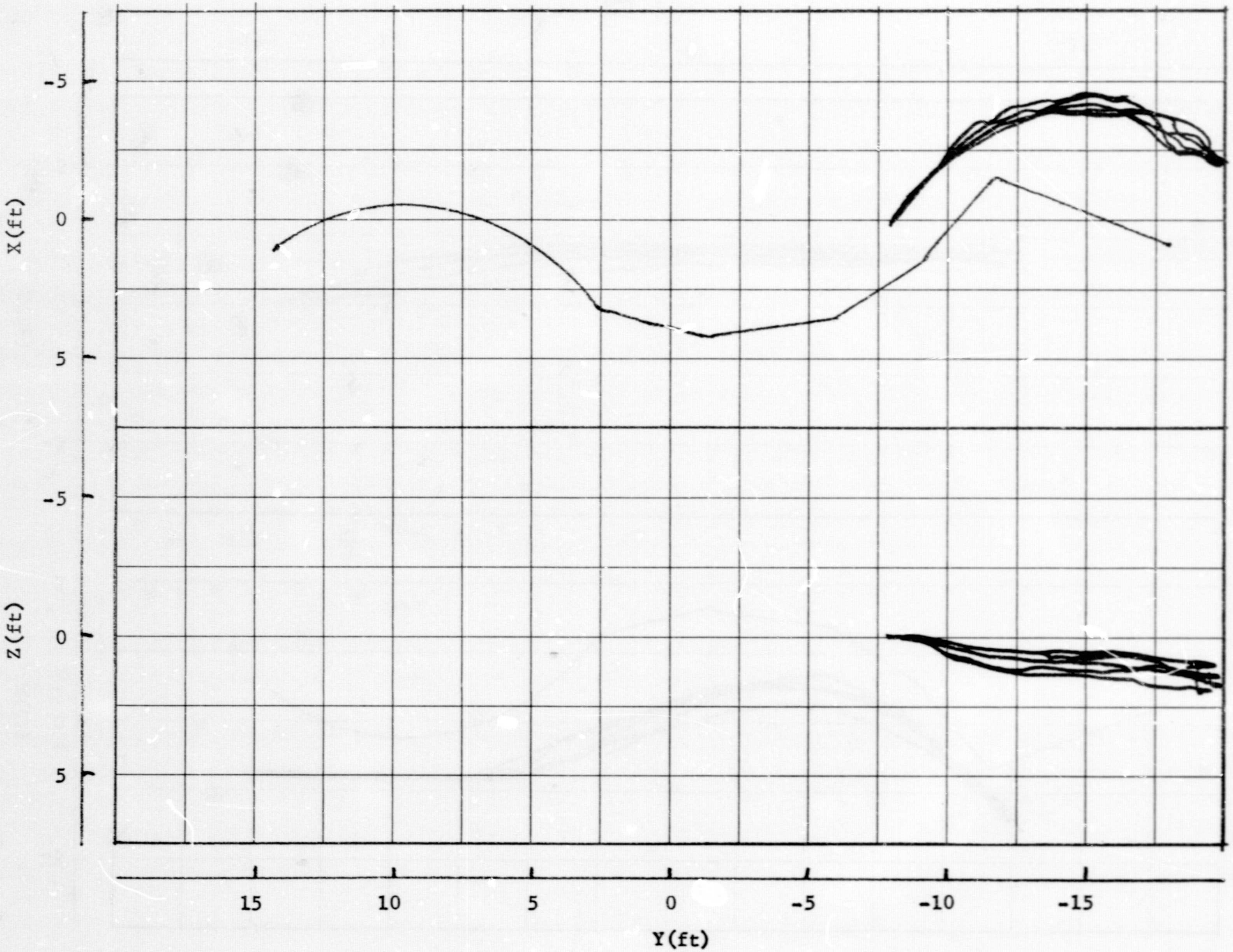


Figure 35 IMLSS Configuration 3 - Task 2: X-Y and Y-Z Motions

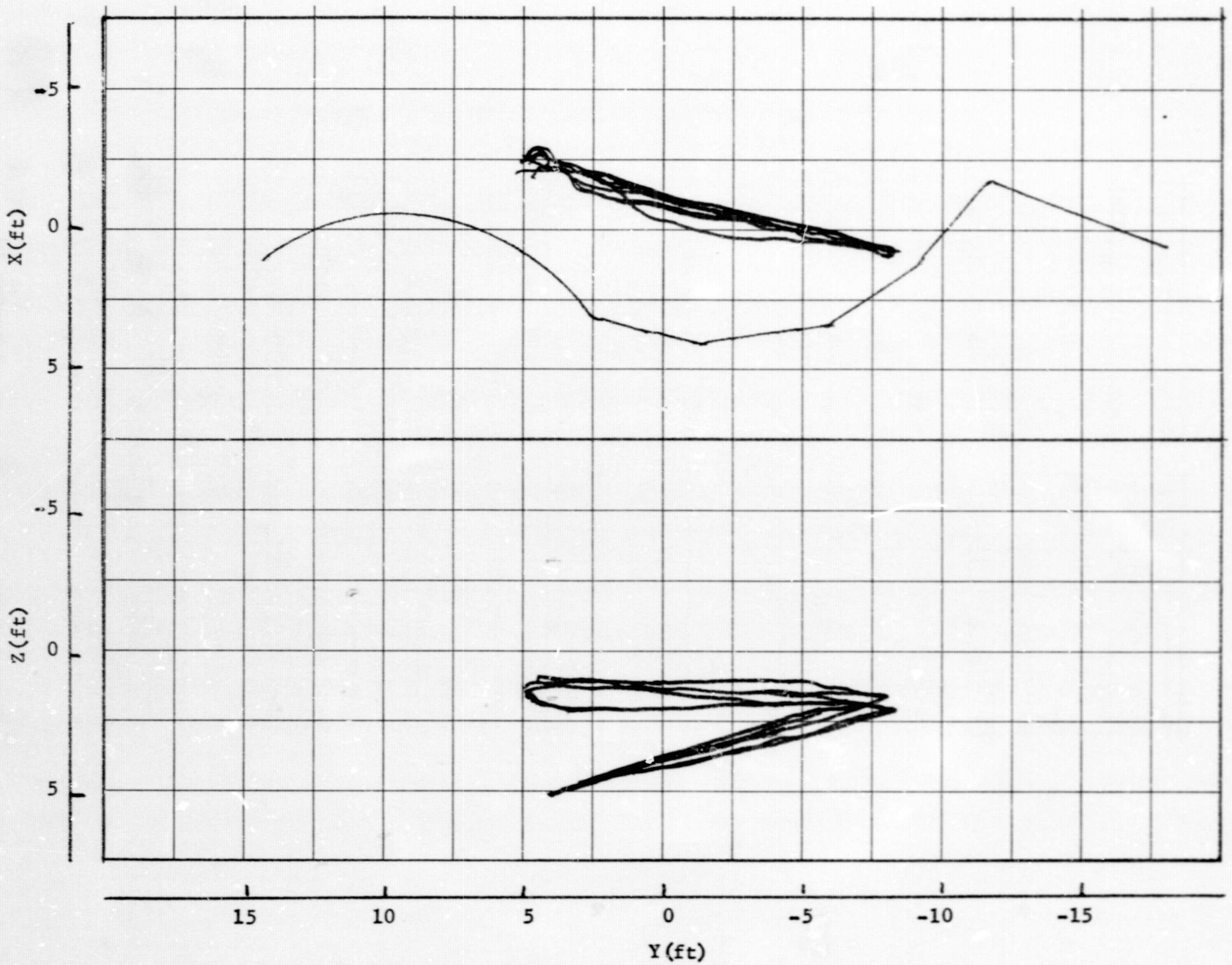
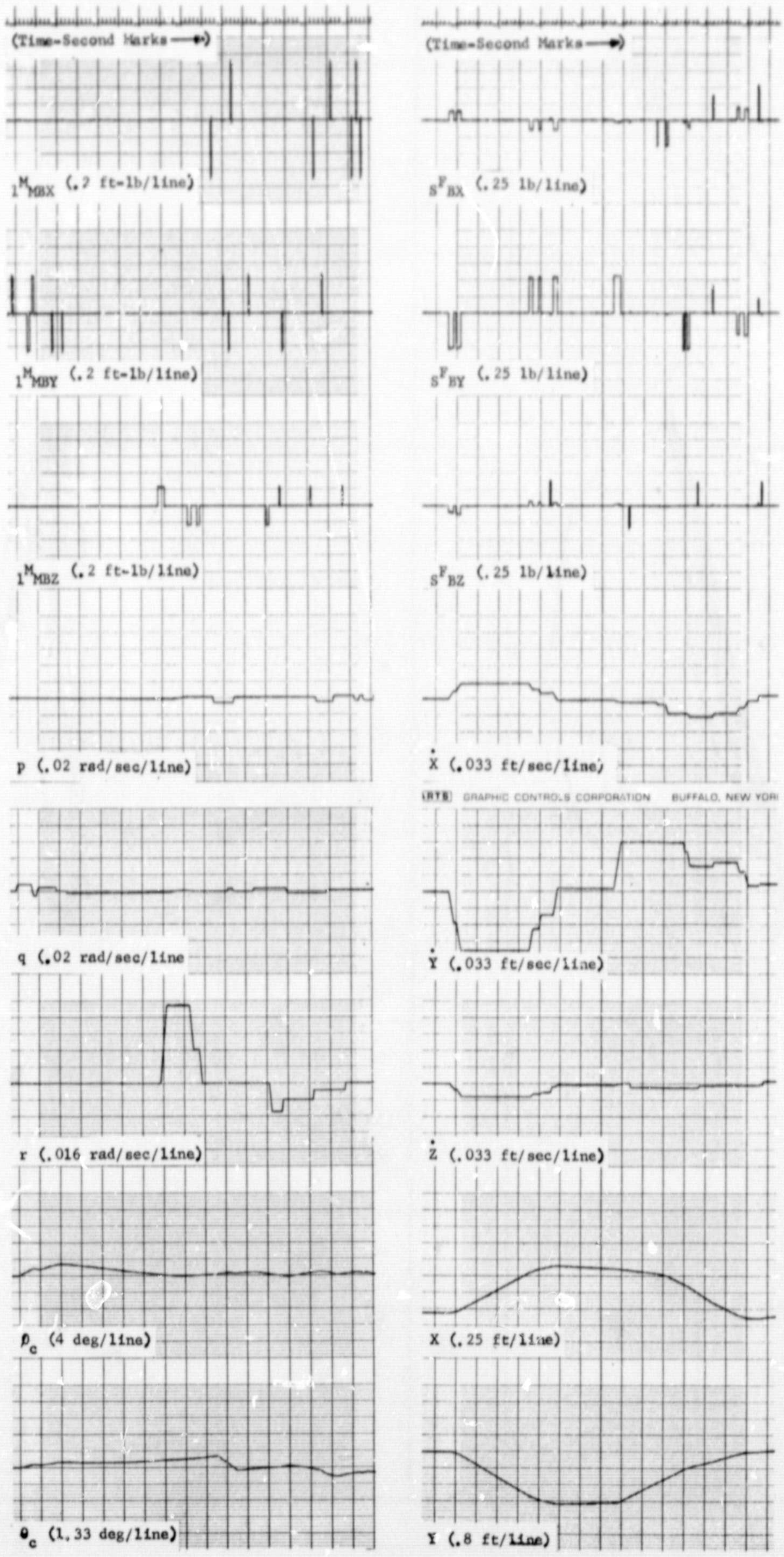


Figure 36 IMLSS Configuration 3 - Task 3: X-Y and Y-Z Motions



Recorder #1 Recorder #2

Figure 37 IMLSS Configuration 3 - Task 3: Strip Chart Data (R - 1&2)

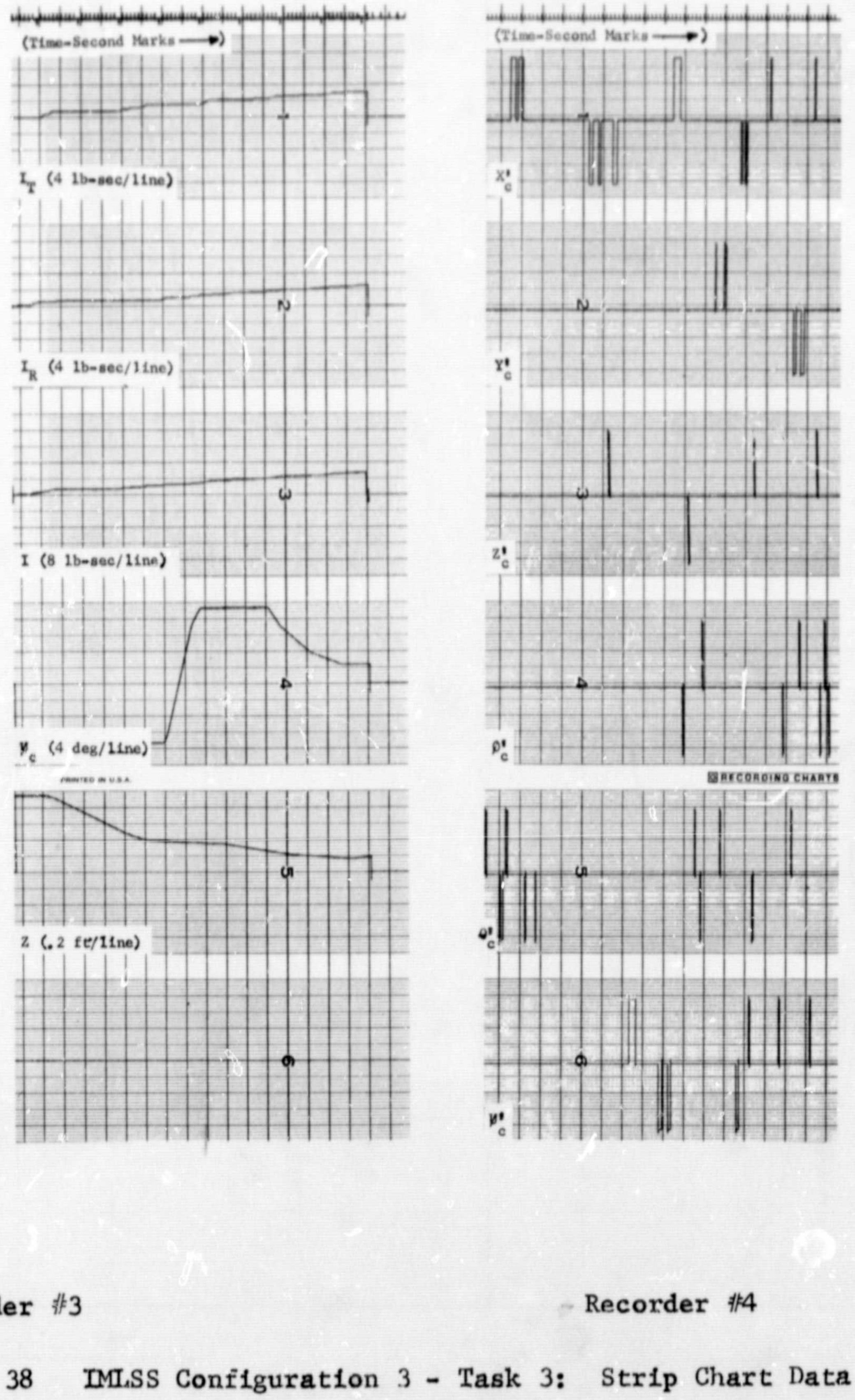


Figure 38 IMLSS Configuration 3 - Task 3: Strip Chart Data (R - 3&4)

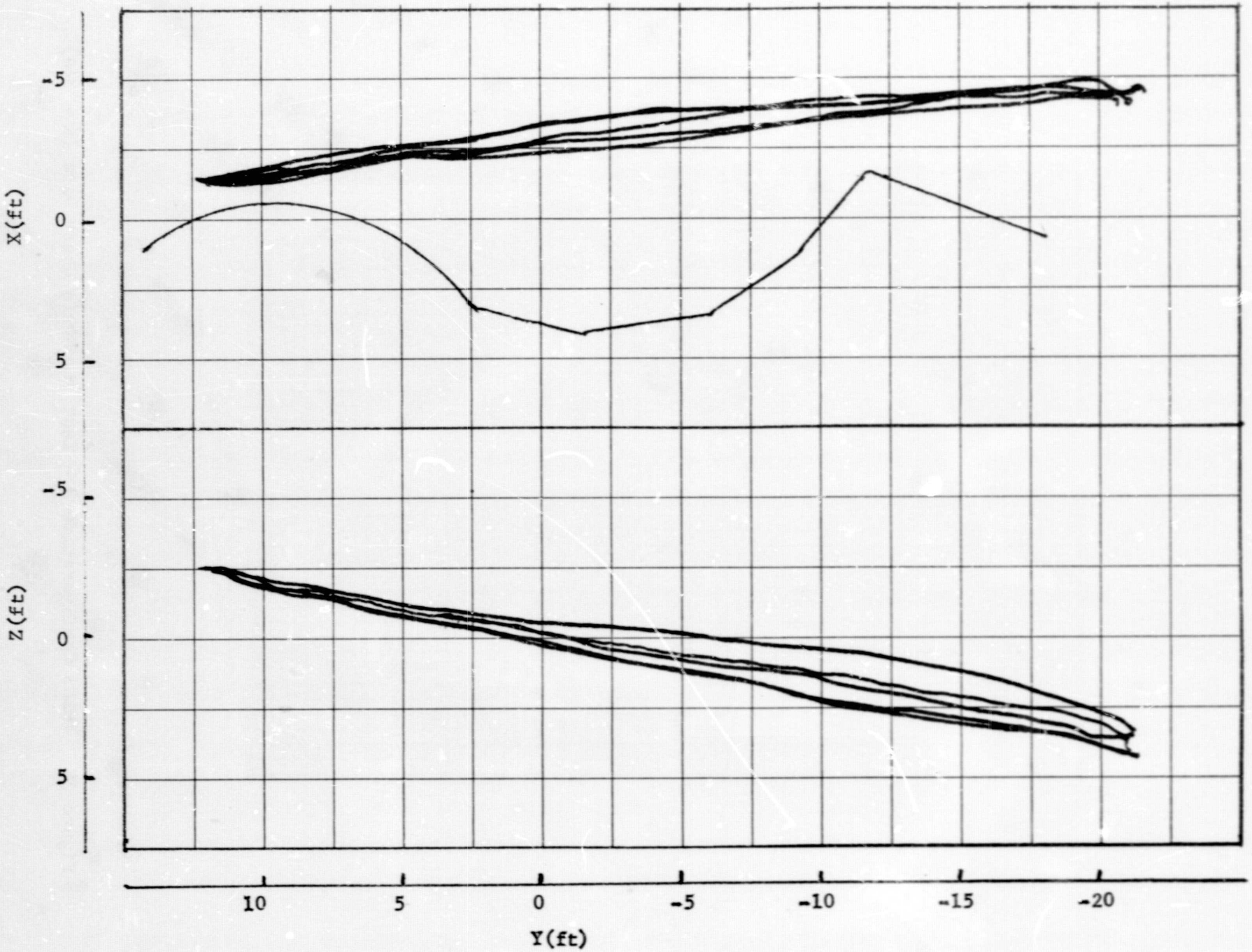


Figure 39 IMLSS Configuration 3 - Task 4: X-Y and Y-Z Motions

Table XVI IMLSS Configuration 3 - Task 1 Data

		End conditions																		
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	66	14.2	1.5	3.9	19.5	3.7	.5	7.7	11.9	31.4	2084	-3.2	-12.2	1.8	-.23	-.24	.00	-.7	4.1	-4[illegible].8
	2	66	13.7	2.9	2.3	19.0	2.6	.6	6.4	9.5	28.5	1867	-3.3	-11.9	1.8	-.32	-.27	-.01	1.7	1.3	-62.4
	3	66	10.1	2.8	3.5	16.4	3.9	.6	7.7	12.1	28.5	1870	-3.6	-12.5	1.8	-.30	-.36	-.03	.3	1.5	-49.7
	Avg	66	12.7	2.4	3.2	18.3	3.1	.6	7.6	11.2	29.5	1940	-3.4	-12.2	1.8	-.28	-.24	-.01	.4	2.3	-52.9
	1	77	11.7	3.8	2.6	18.1	7.5	1.5	9.9	18.9	37.0	2834	-3.6	-12.4	1.5	-.27	-.20	-.03	1.8	6.2	-52.5
	2	67	10.9	1.7	3.8	16.4	3.7	1.9	6.0	11.6	28.0	1870	-3.4	-12.8	2.0	-.25	-.37	.02	3.9	4.8	-58.3
	3	75	12.7	3.1	[illegible].1	16.9	2.8	1.5	5.8	[illegible]0.0	26.9	2016	-3.9	-12.9	2.1	-.35	-.29	.03	4.1	-.3	-48.6
	4	64	12.0	4.7	3.3	20.0	4.8	1.5	5.2	11.5	31.5	2016	-3.5	-12.3	1.9	-.34	-.31	.00	3.5	2.8	-68.6
	5	62	13.2	3.1	2.6	18.9	1.3	.2	5.3	6.8	25.8	1599	-3.3	-12.0	2.2	-.36	-.32	.00	6.4	6.4	-71.0
	Avg	70	12.1	3.3	[illegible].7	18.1	4.0	1.3	6.4	11.8	2[illegible].8	2067	-3.5	-12.5	1.9	-.31	-.20	.00	3.9	3.4	-54.8

		End conditions			Maximum rates						Average rates					
	Run	Body rates deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.6	-.4	2.8	.23	.57	.16	1.3	.7	13.4	-.02	-.40	.03	-.1	-.1	.5
	2	-.2	-.7	.0	.33	.52	.09	1.5	.9	13.0	-.02	-.40	.03	-.1	-.1	.4
	3	-.1	-.7	.1	.30	.50	.12	2.0	.9	15.9	-.02	-.42	.03	-.1	-.1	.5
	Avg	-.3	-.6	.7	.29	.53	.12	1.6	.8	14.1	-.02	-.41	.03	-.1	-.1	.5
	1	-.3	.3	3.2	.27	.50	.08	2.5	1.2	9.0	-.02	-.36	.02	-.1	.0	.5
	2	.9	-.4	3.3	.25	.51	.14	2.9	.8	10.4	-.02	-.42	.03	-.2	.0	.4
	3	-1.3	.6	3.9	.36	.44	.05	1.3	.9	7.3	-.03	-.37	.03	.0	-.1	.6
	4	-1.0	.3	-.7	.34	.51	.12	1.8	1.1	9.7	-.02	-.43	.03	-.1	.0	.4
	5	-.64	-.1	.0	.36	.56	.09	1.1	.3	10.1	-.02	-.44	.04	-.1	.0	.3
	Avg	-.5	.2	1.9	.32	.50	.09	1.9	.9	9.3	-.02	-.40	.03	-.1	.0	.5

Table XVII IMLSS Configuration 3 - Task 2 Data

		End conditions																			
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	66	11.7	12.4	3.4	30.6	3.1	.0	3.6	6.7	37.2	2455	-2.6	-19.2	1.2	-.01	.04	-.01	-1.8	-1.2	30.0
	2	66	20.9	13.4	2.1	36.3	3.4	.0	6.3	9.6	46.0	3036	-2.4	-18.9	1.0	.05	.04	-.03	-2.0	-.9	27.5
	3	65	13.9	13.0	1.1	28.0	3.2	.0	6.2	9.4	37.4	2431	-2.6	-19.0	1.2	.01	.00	-.03	1.3	2.3	24.4
	Avg	66	16.5	12.9	2.2	31.7	3.2	.0	5.4	8.5	40.2	2653	-2.5	-19.0	1.1	.02	.03	-.02	-0.8	-.2	27.3
	1	63	11.6	9.6	1.7	23.0	3.6	.3	10.5	14.4	37.4	3104	-2.4	-18.9	1.2	.03	.01	-.02	-.2	.6	25.3
	2	75	10.1	11.7	2.7	24.5	1.6	.7	6.7	9.0	33.5	2513	-2.2	-19.0	1.2	.02	-.02	-.03	1.7	3.3	22.5
	3	75	11.5	10.5	3.7	25.9	7.2	.0	3.5	10.7	36.6	2745	-2.5	-19.1	1.3	.00	.00	.00	-2.6	2.2	28.9
	4	78	11.3	10.2	2.7	24.2	5.1	1.7	6.6	13.5	37.8	2948	-2.7	-19.4	1.2	.01	.01	.00	.0	-2.8	36.1
	5	71	11.2	10.3	.4	22.0	1.6	.0	5.4	7.8	29.0	2059	-2.6	-18.9	1.6	.00	.02	.00	2.0	.9	27.1
	Avg	76	11.1	10.5	2.3	23.9	3.8	.5	6.4	10.9	34.9	[illegible]	-2.5	-19.0	1.2	.01	.00	-.01	-.4	.8	26.6

		End conditions			Maximum rates						Average rates					
	Run	Body rates deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.6	.2	-.1	.31	.48	.08	1.7	.0	9.4	-.04	-.17	.02	-.2	.0	2.4
	2	-.5	.2	-.6	.31	.51	.09	1.7	.5	12.6	-.04	-.17	.02	-.2	.0	2.3
	3	-.2	.2	.1	.26	.53	.05	1.4	.3	15.6	-.05	-.17	.02	-.1	.0	2.3
	Avg	-.4	.2	-.2	.29	.51	.07	1.6	.3	12.5	-.04	-.17	.02	-.2	.0	2.3
	1	-.7	-.4	.0	.21	.42	.07	2.0	.6	16.2	-.03	-.13	.02	-.2	.0	1.8
	2	-.6	-.8	-1.3	.23	.39	.10	1.6	.9	15.6	-.03	-.15	.02	-.2	-.1	2.1
	3	-.7	.2	.4	.23	.50	.10	4.2	.3	10.3	-.04	-.15	.02	-.2	.0	2.1
	4	-.2	-.1	.0	.23	.40	.06	2.0	1.6	13.1	-.04	-.15	.02	-.2	.0	1.9
	5	-.2	.2	.0	.25	.38	.03	1.7	.7	10.1	-.04	-.15	.01	-.1	.0	2.4
	Avg	-.5	-.2	-.2	.23	.42	.08	2.3	.9	13.0	-.04	-.15	.02	-.2	.0	2.0

Table XVIII IMLSS Configuration 3 - Task 3 Data

			End conditions																		
	Run	Time sec	Impulse (lb-sec) Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot.	Total	Time X Impulse	Position ft X	Y	Z	Velocity ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg ϕ_c	θ_c	ψ_c
Practice	1	86	24.6	3.9	1.6	30.1	9.7	8.7	12.0	30.4	60.5	5203	-2.6	5.1	1.0	-.01	.04	.01	3.8	-6.6	19.9
	2	107	18.7	5.7	2.6	26.3	15.1	9.0	11.7	36.0	62.3	6666	-2.6	5.0	1.0	.01	-.04	.06	2.9	.5	19.4
	3	97	19.9	6.2	.9	27.0	9.4	6.6	8.5	24.5	51.6	5005	-1.9	4.4	1.4	.04	.00	.01	1.6	-1.8	26.7
	Avg	97	20.7	5.2	1.7	27.8	11.3	8.1	10.7	30.3	58.1	5618	-2.4	4.8	1.1	.01	.00	.03	2.8	-2.7	18.7
	1	101	25.3	4.6	1.6	31.5	2.7	9.5	11.6	23.8	55.3	5585	-2.4	5.0	1.3	.06	.05	.04	3.2	1.4	17.7
	2	90	17.6	4.1	1.4	23.1	7.4	9.8	9.0	26.4	49.4	4446	-2.1	5.1	1.2	.03	.05	.03	-1.4	-3.3	18.6
	3	92	21.7	4.2	3.3	29.2	16.9	11.5	13.5	41.9	71.1	6541	-2.9	4.9	1.3	.00	.02	-.02	.6	1.2	20.3
	4	99	18.9	4.5	2.2	25.6	5.5	11.9	9.0	26.4	52.1	5158	-1.9	4.6	.9	.00	.00	.00	-.5	-3.0	30.9
	5	87	24.1	4.2	1.9	30.3	5.0	10.3	9.2	24.5	54.8	4768	-2.7	4.6	.9	.03	.08	.02	1.9	-3.0	23.3
	Avg	94	21.5	4.3	2.1	27.9	7.5	10.6	10.5	28.6	56.5	5311	-2.4	4.8	1.1	.02	.04	.01	.7	-1.3	22.2

		End conditions Body rates deg/sec			Maximum rates ft/sec			Maximum rates deg/sec			Average rates ft/sec			Average rates deg/sec		
	Run	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	.0	.4	-.7	.16	.62	.15	3.3	3.0	22.8	.00	.01	-.04	-.1	-.1	1.1
	2	-.8	.1	.7	.17	.48	.12	6.9	3.5	20.7	.00	-.1	-.04	-.2	.1	.8
	3	.1	.2	.6	.14	.51	.13	3.1	3.1	17.8	.01	.00	-.04	-.2	.0	1.0
	Avg	-.2	.2	.2	.15	.54	.13	4.4	3.2	20.1	.00	.01	-.02	-.2	.0	1.0
	1	-.1	.1	-.7	.19	.50	.14	2.5	2.8	17.9	.00	.01	-.04	.0	.0	[illegible]
	2	.2	.1	-1.3	.18	.46	.13	3.2	3.4	21.3	.01	.01	-.04	-.2	.0	1.0
	3	-.2	-.5	-.5	.16	.57	.14	5.3	3.4	21.4	.00	.01	-.04	-.1	.0	1.0
	4	.2	-1.0	.6	.12	.45	.10	2.4	3.1	21.4	.01	.01	-.04	-.2	.0	1.0
	5	-.1	.3	.1	.18	.59	.13	1.8	2.9	21.2	.00	.01	-.05	-.2	.0	1.0
	Avg	.0	-.2	-.4	.16	.51	.13	3.0	3.1	20.6	.00	.01	-.04	-.1	.0	1.0

Table XIX IMLSS Configuration 3 - Task 4 Data

			End conditions																		
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	66	24.6	3.9	2.1	30.6	8.0	2.7	9.5	20.2	50.8	3340	-4.1	-21.2	3.1	.05	.04	.06	-6.9	3.2	-92.9
	2	82	30.4	13.2	3.3	46.8	8.7	10.2	10.5	29.4	76.7	6257	-4.1	-21.4	3.4	.00	.05	.00	1.7	4.9	-87.7
	3	79	24.0	6.6	.8	31.4	7.6	6.7	8.3	22.6	54.0	4266	-4.3	-21.0	3.6	.02	.06	.00	1.0	.6	-88.1
	Avg	76	26.3	7.9	2.2	36.2	8.1	6.5	9.5	24.1	56.5	4464	-4.2	-21.2	3.4	.02	.05	.02	-1.4	2.9	-89.6
	1	75	20.5	2.5	1.6	24.7	8.3	3.2	7.2	18.7	43.4	3264	-4.0	-20.8	3.6	.02	.02	-.04	- .8	1.1	-93.6
	2	74	20.6	2.8	1.9	23.4	1.5	1.3	6.5	9.3	34.6	2553	-4.4	-21.7	4.3	.04	-.02	.01	4.7	2.5	-92.4
	3	76	20.2	6.5	.8	27.5	4.4	1.3	7.3	13.0	40.6	3073	-4.0	-21.3	3.6	.05	.04	-.01	-4.9	5.3	-95.2
	4	77	19.5	3.1	2.0	24.6	9.1	5.0	5.6	19.7	44.4	3432	-4.3	-21.4	3.4	-.01	-.05	.04	-1.1	4.5	-91.9
	5	79	22.2	3.2	3.3	28.7	3.6	3.1	8.4	15.0	43.7	3461	-4.0	-21.2	3.6	.02	-.01	-.06	-1.2	7.9	-90.4
	Avg	76	20.6	3.6	1.9	25.7	5.4	2.8	7.0	15.1	41.3	3157	-4.1	-21.3	3.7	.03	.00	.00	- .6	4.4	-92.7

		End conditions			Maximum rates						Average rates					
	Run	Body rates														
		deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	- .3	.1	1.9	.21	1.15	.24	5.1	1.8	18.5	.04	-.50	.09	.3	.1	-2.7
	2	- .4	.5	1.5	.19	1.15	.17	3.3	2.6	18.3	-.03	-.40	.07	.2	.1	-2.1
	3	-1.4	-.1	.6	.19	1.12	.16	4.1	2.3	16.3	-.04	-.42	.07	.2	.2	-2.4
	Avg	- .7	.2	1.3	.20	1.13	.19	4.2	2.2	17.7	-.01	-.44	.08	.2	.1	-2.4
	1	- .1	.0	- .1	.12	.91	.15	3.6	1.1	15.0	-.03	-.44	.08	.2	.2	-2.4
	2	- .3	.3	- .1	.13	.98	.19	2.2	1.3	16.3	-.04	-.46	.09	.2	.2	-2.4
	3	- .4	-.1	- .1	.20	.90	.17	2.1	1.5	14.5	-.03	-.44	.08	.2	.1	-2.2
	4	-1.4	-.1	- .2	.14	.95	.19	2.5	2.0	13.7	-.04	-.43	.08	.2	.2	-2.1
	5	- .4	-.7	1.8	.09	1.00	.20	2.7	1.1	14.1	-.03	-.42	.08	.1	.1	-2.1
	Avg	- .7	.1	.3	.14	.95	.18	2.6	1.4	14.7	-.03	-.44	.08	.2	.2	-2.2

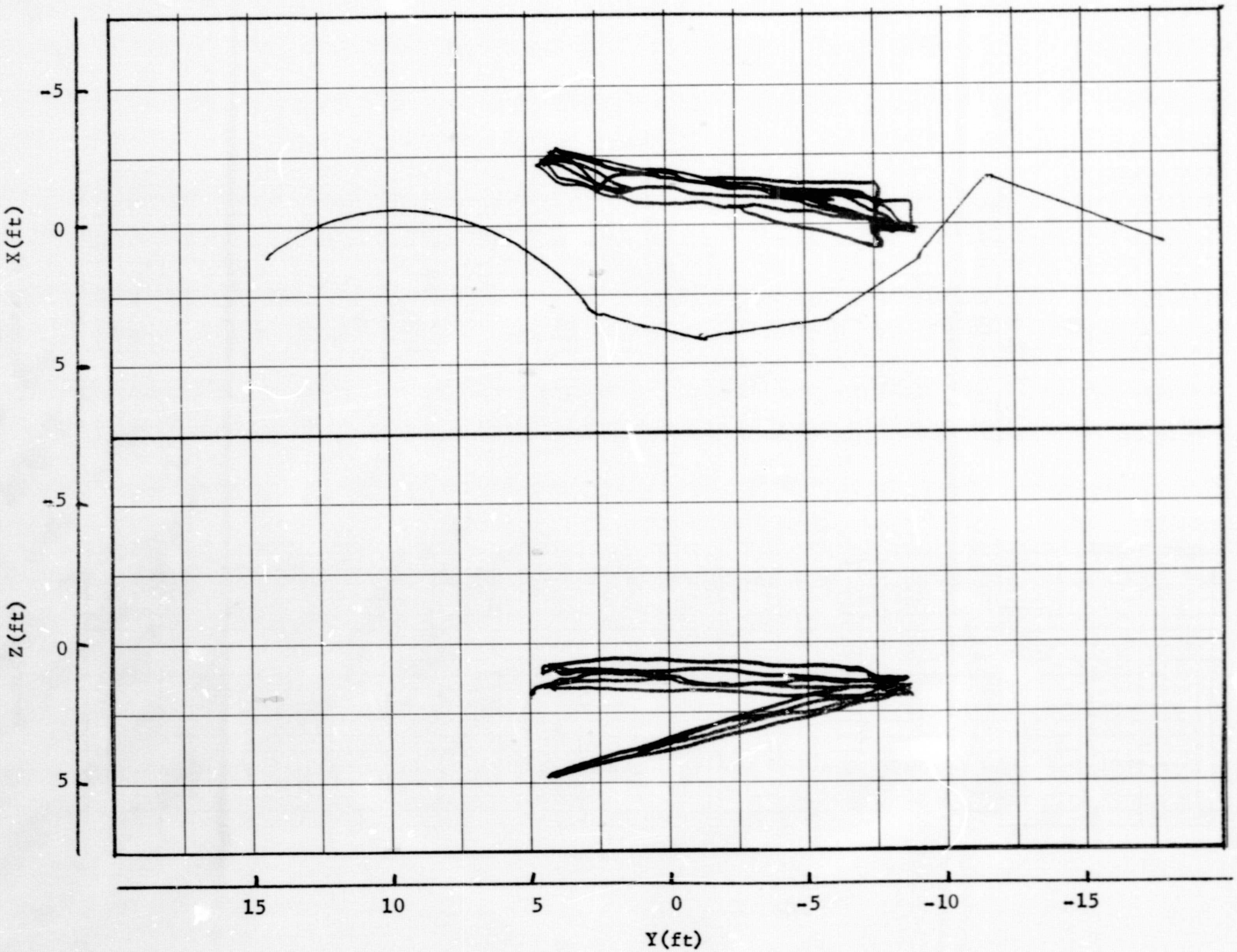
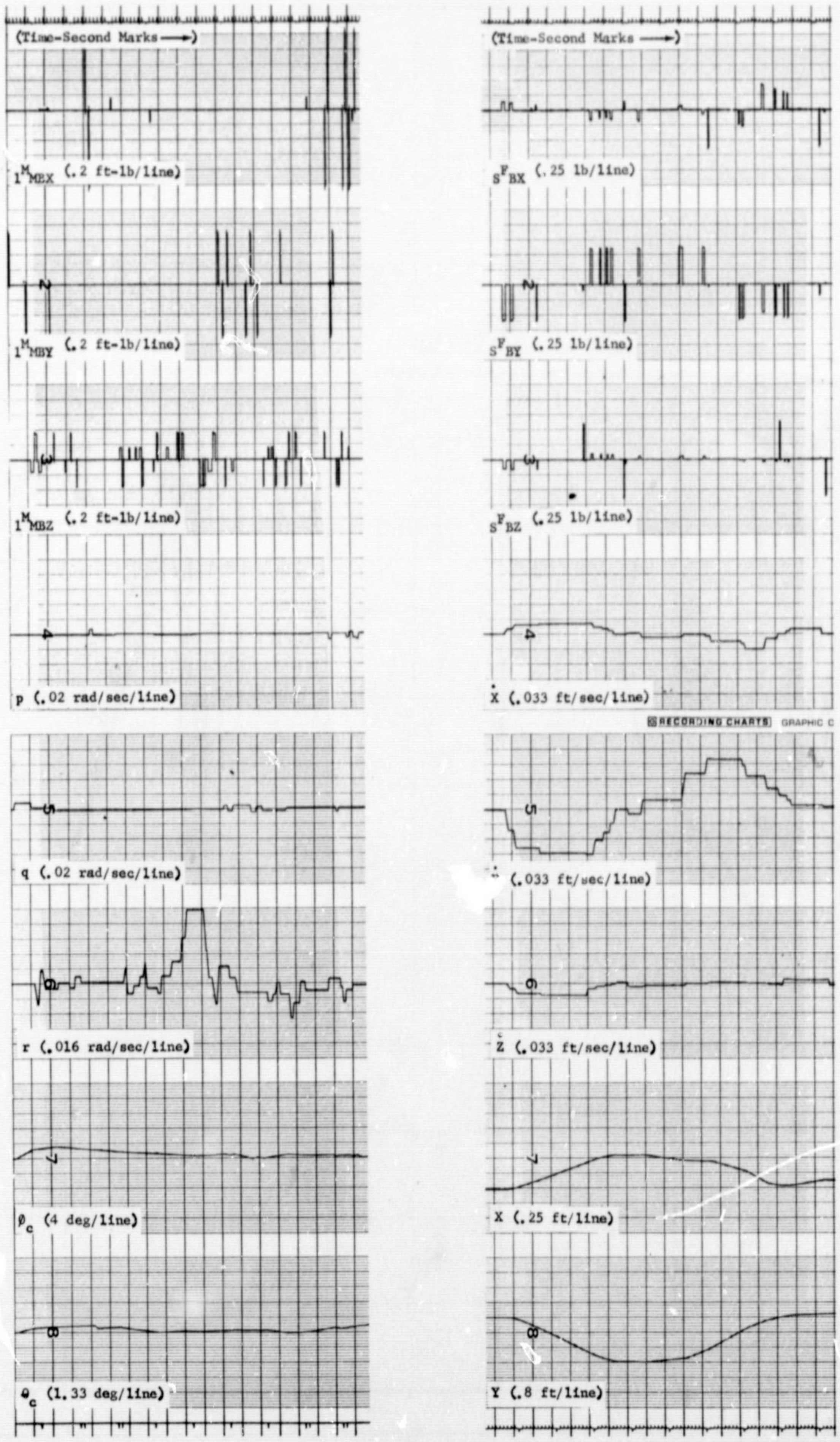
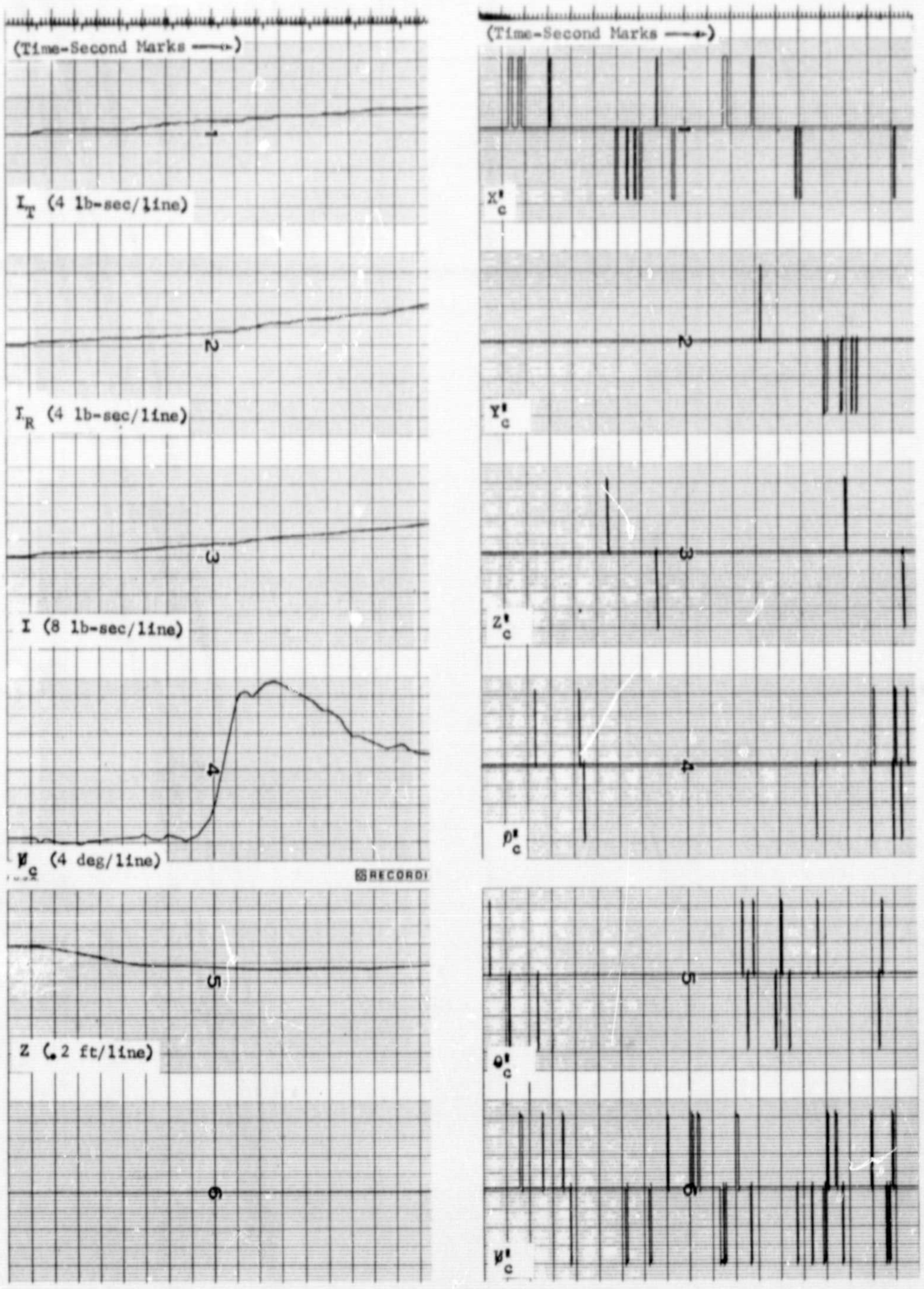


Figure 40 IMLSS Configuration 1 - Task 3 (c.g. shift #1): X-Y and Y-Z Motions



Recorder #1 Recorder #2

Figure 41 IMLSS Configuration 1 - Task 3 (c.g. Shift #1): Strip Chart Data (R - 1&2)



Recorder #3

Recorder #4

Figure 42 IMLSS Configuration 1 - Task 3 (c.g. Shift #1): Strip Chart Data (R - 3&4)

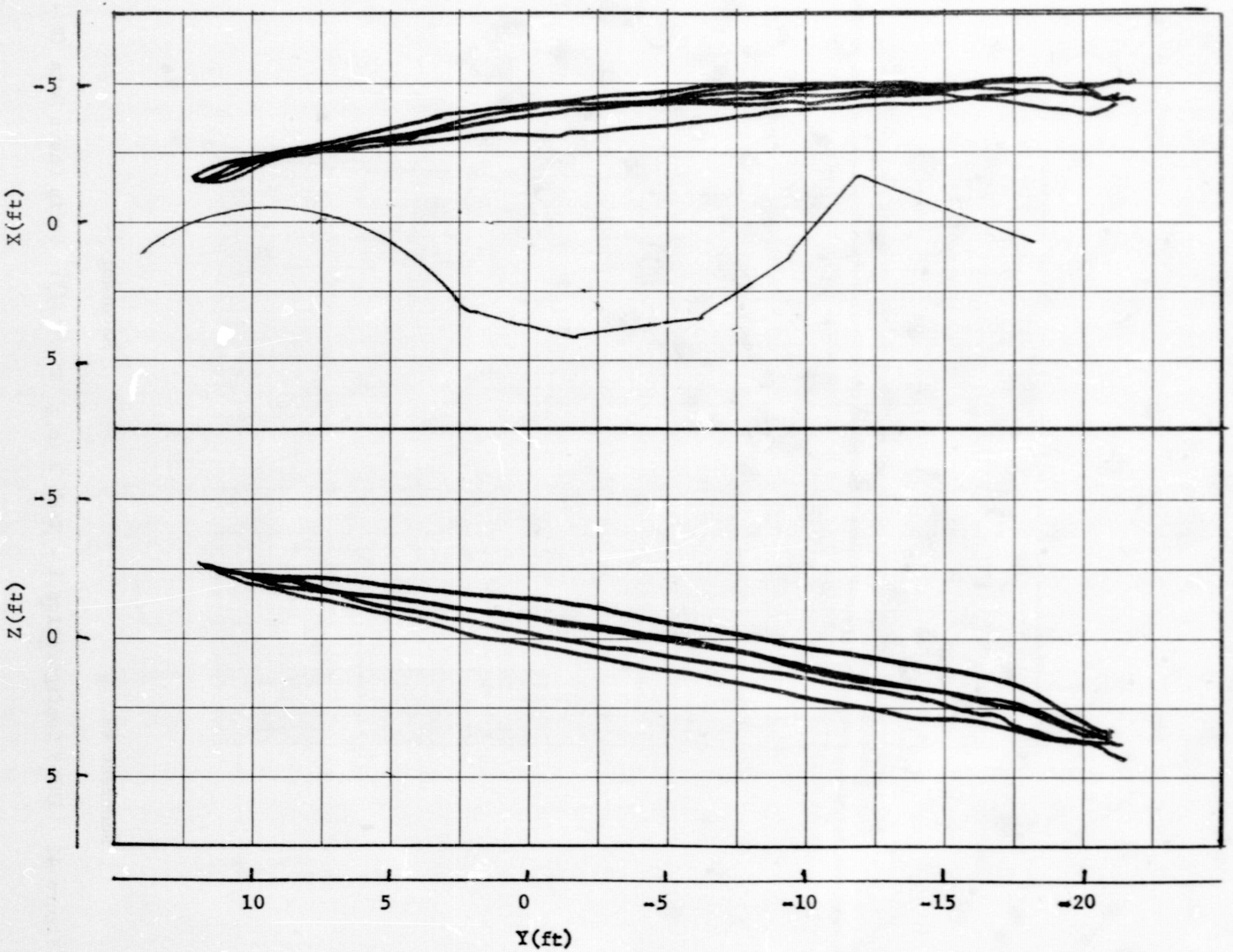


Figure 43 IMLSS Configuration 1 - Task 4 (c.g. shift #1): X-Y and Y-Z Motions

Table XX IMLSS Configuration 1 - Task 3 Data (c.g. shift #1)

		End conditions																			
	Run	Time sec	Impulse (lb-sec) Translation			Total Trans	Rotational			Total Rot.	Total	Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	105	25.3	3.0	3.9	32.2	17.6	18.6	28.3	64.4	96.9	10126	-1.8	4.4	1.3	-.05	.05	.02	4.5	-1.6	20.1
	2	97	22.4	2.6	2.0	27.0	23.4	3.1	27.4	53.7	80.8	7870	-2.3	4.2	1.4	.01	.03	-.02	1.8	-4.8	32.6
	3	96	25.5	7.5	1.9	34.9	11.8	14.7	20.2	46.8	81.7	7835	-2.4	4.3	1.3	.01	-.02	.03	4.1	-3.9	24.6
	Avg	99	24.4	4.4	2.9	31.4	14.3	12.1	25.2	55.0	96.5	8610	-2.2	4.3	1.3	-.01	-.01	.01	3.5	-3.4	25.9
	1	104	23.8	2.2	1.3	27.3	19.3	6.9	23.8	50.0	77.3	8041	-2.2	4.3	1.7	.03	.02	-.02	1.8	-3.2	30.0
	2	90	22.0	3.9	3.7	29.6	13.5	7.8	19.6	40.9	70.5	6331	-2.1	4.7	1.3	-.03	.03	.04	3.0	3.0	16.4
	3	98	22.2	5.7	1.7	29.6	20.3	7.7	24.9	52.9	82.4	8075	-2.1	4.6	1.3	.00	.00	.03	-.2	.1	22.7
	4	94	20.4	4.7	2.4	27.5	7.2	3.1	22.7	43.0	70.5	6627	-1.8	4.9	1.9	-.01	.00	-.03	1.7	4.9	14.5
	5	106	25.8	8.1	3.6	37.5	10.5	13.0	30.2	53.8	91.3	9678	-2.2	4.4	1.7	.02	.07	.02	-2.0	3.0	22.0
	Avg	98	22.8	4.9	2.5	30.3	14.2	9.7	24.2	48.1	78.4	7750	-2.1	4.6	1.6	.00	.03	.01	.9	1.6	21.1

	Run	End conditions Body rates deg/sec			Maximum rates ft/sec			Maximum rates deg/sec			Average rates ft/sec			Average rates deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	1.2	-.1	1.0	.11	.61	.10	4.0	2.6	27.9	.01	.00	-.03	-.1	-.1	.9
	2	.1	.1	-.7	.14	.51	.10	6.4	2.2	21.4	.00	.00	-.04	-.0	-.1	1.0
	3	.0	-.2	.0	.20	.70	.13	2.3	3.8	18.2	.00	.00	-.04	-.1	-.1	1.0
	Avg	.4	-.1	.1	.15	.63	.11	4.2	2.9	22.5	.00	.00	-.04	-.1	-.1	1.0
	1	-.7	-.2	-1.3	.13	.57	.15	6.2	2.1	20.6	.00	.00	-.03	-.2	.1	1.0
	2	-.5	.4	.0	.13	.59	.17	3.2	2.7	23.7	.01	.01	-.04	-.1	.2	.9
	3	.3	.5	-1.2	.15	.62	.14	3.6	1.9	21.7	.00	.01	-.04	-.1	-.1	1.0
	4	.4	.5	-.6	.17	.55	.13	2.1	2.7	21.7	.01	.00	-.03	-.1	.1	.9
	5	.2	.2	-.3	.23	.60	.14	3.6	4.6	19.4	.00	.00	-.03	.0	.0	.8
	Avg	-.1	.3	-.7	.16	.59	.14	3.7	2.8	21.4	.00	.00	-.03	-.1	.1	.9

Table XXI IMLSS Configuration 1 - Task 4 Data (c.g. shift #1)

		End conditions																			
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	111	15.4	4.7	3.6	23.7	18.4	10.5	14.0	42.9	66.6	7373	-4.3	-21.8	3.9	.02	-.01	-.03	6.6	4.8	-86.9
	2	85	16.4	1.2	1.9	19.6	18.1	.0	20.9	39.1	58.7	4995	-4.4	-21.5	3.3	.00	-.08	.04	1.3	- .3	-92.0
	3	87	17.7	3.3	1.0	22.0	16.0	5.5	19.1	10.6	62.6	5471	-4.5	-21.3	3.3	-.04	-.01	.00	6.3	1.9	-90.1
	Avg	94	16.5	3.1	2.2	21.8	17.5	5.3	18.0	30.9	62.6	5909	-4.4	-21.5	3.5	.00	-.03	.00	4.7	2.1	-89.6
	1	87	17.5	6.9	2.8	27.1	18.9	5.3	18.2	42.2	65.9	6074	-4.4	-21.6	3.8	-.02	-.10	.03	8.2	3.1	-90.9
	2	89	18.7	3.0	3.3	25.0	4.7	9.8	19.8	34.3	59.3	5301	-4.1	-21.1	3.4	.03	.02	.00	1.8	2.9	-88.2
	3	75	19.8	5.0	2.6	27.4	10.9	4.7	18.7	34.2	61.6	4638	-4.4	-21.1	3.7	-.02	-.03	.02	1.7	5.6	-90.8
	4	77	19.4	3.3	2.7	25.3	17.4	6.4	18.3	42.2	67.5	5163	-4.4	-21.8	3.9	.00	-.05	.01	5.3	- .6	-89.2
	5	88	20.1	4.9	1.7	26.7	17.0	6.4	16.2	39.6	66.2	5826	-5.0	-21.7	4.2	.03	.00	-.01	1.6	-1.0	-93.5
	Avg	83	19.1	4.6	2.6	26.3	13.8	6.5	18.2	38.5	64.8	5100	-4.5	-21.5	3.6	.00	-.05	.01	4.7	2.1	-90.5

		End conditions			Maximum rates						Average rates					
	Run	Body rates														
		deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.5	-.6	.7	.15	.77	.17	4.3	1.8	10.3	-.03	-.31	.06	.1	.1	-1.6
	2	-.8	.3	.9	.08	.83	.16	3.8	.5	15.1	-.03	-.39	.07	.2	.0	-2.0
	3	-.4	.4	.9	.14	.84	.12	4.3	1.8	15.2	-.03	-.38	.07	.1	.1	-2.0
	Avg	-.6	.0	.8	.13	.81	.15	4.1	1.4	13.5	-.03	-.36	.07	.1	.1	-1.9
	1	.2	.3	.2	.17	.86	.17	4.6	2.1	15.7	-.03	-.38	.07	.2	.2	-1.9
	2	-.2	-.6	1.6	.09	.90	.18	3.4	1.8	18.8	-.03	-.37	.07	.1	.1	-1.8
	3	-.9	.1	-1.4	.16	.96	.20	6.0	1.9	15.9	-.04	-.44	.08	.2	.2	-2.2
	4	.2	-.4	-2.8	.19	.96	.18	6.4	1.6	17.0	-.04	-.44	.08	.2	.2	-2.0
	5	.5	.4	- .6	.14	.96	.16	3.3	1.8	10.7	-.04	-.38	.08	.2	.1	-2.0
	Avg	.0	.0	-. 6	.15	.93	.18	4.7	1.8	15.6	-.04	--.40	.08	.2	.2	-2.0

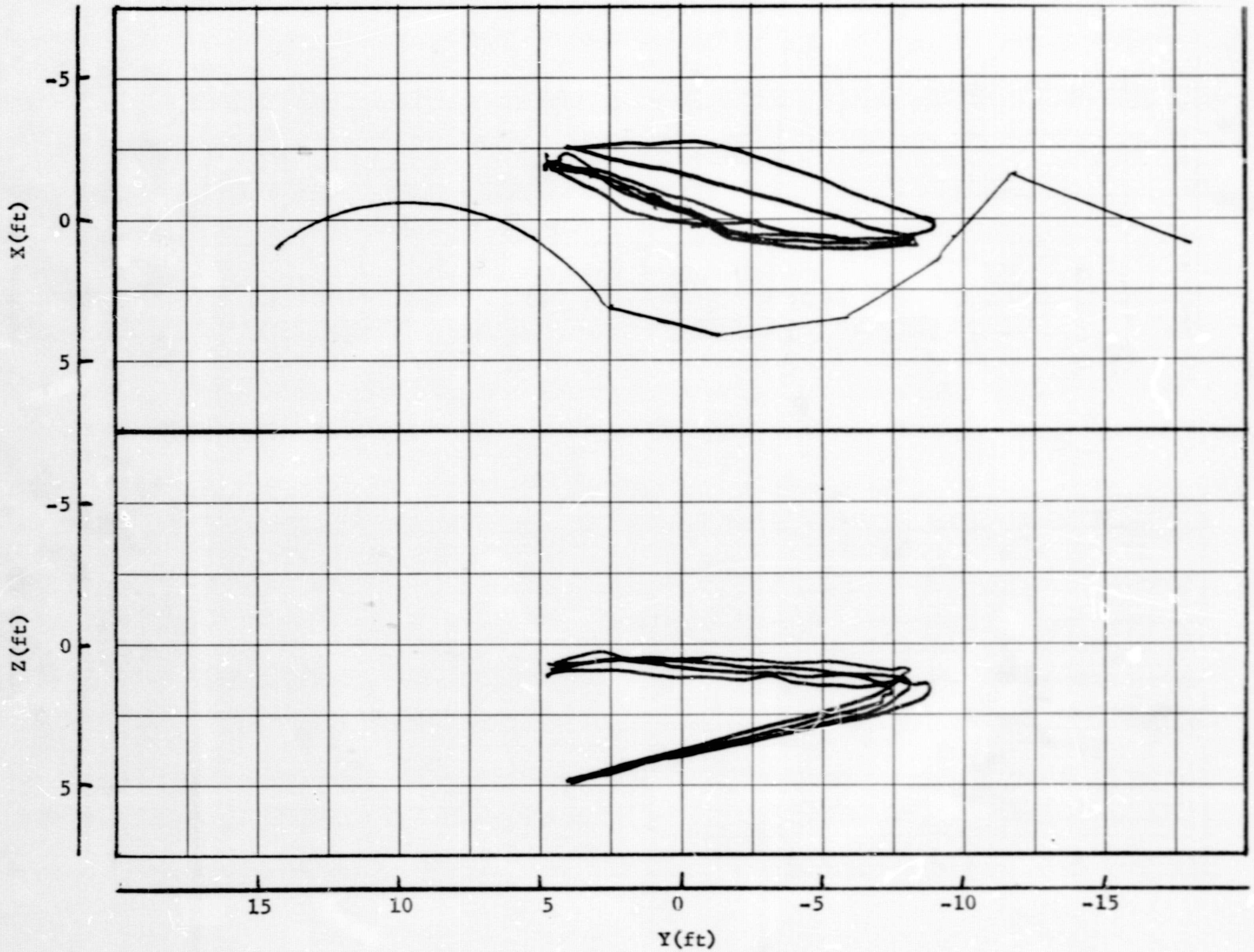


Figure 44 IMLSS Configuration 1 - Task 3 (c.g. shift #2): X-Y and Y-Z Motions

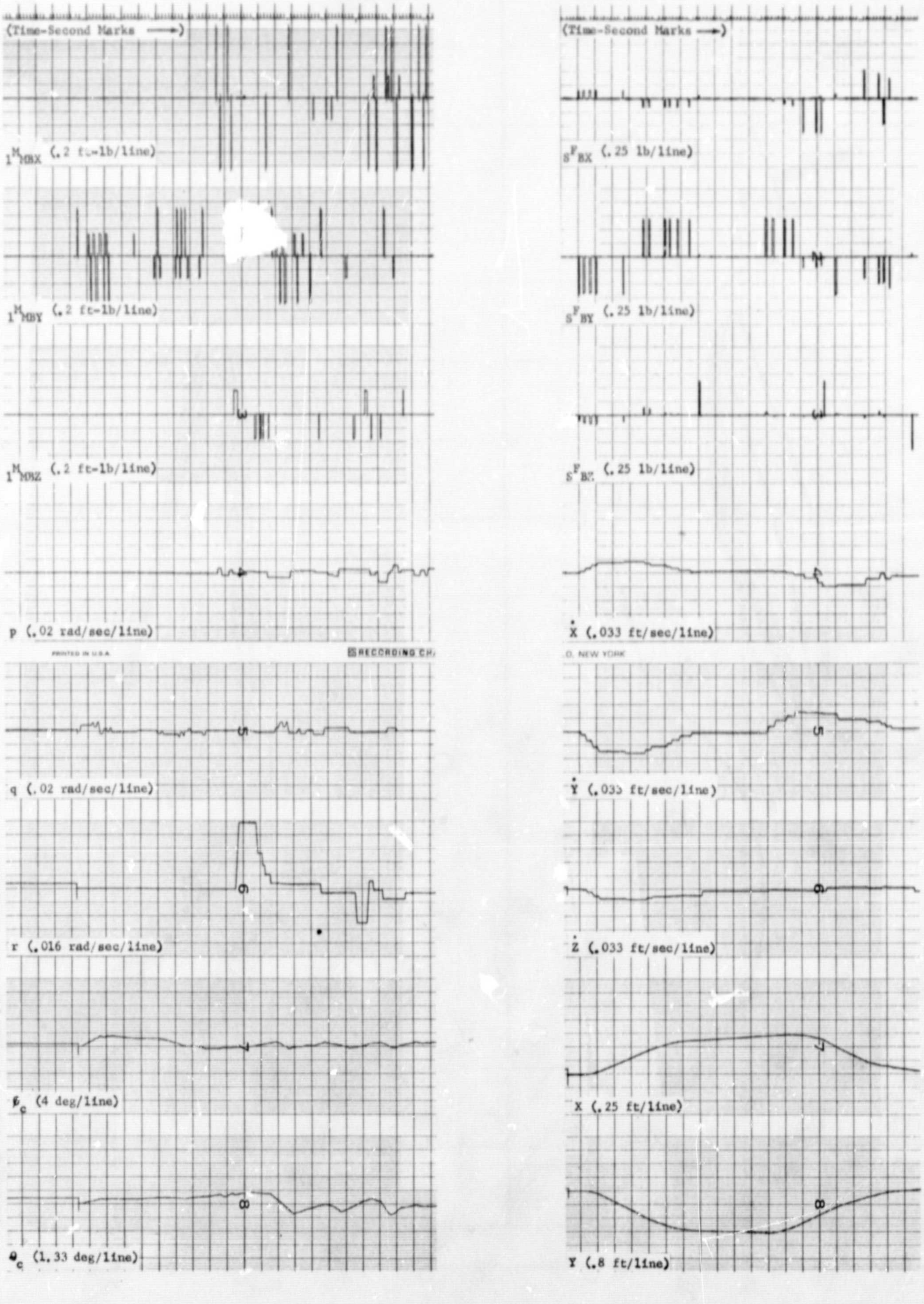
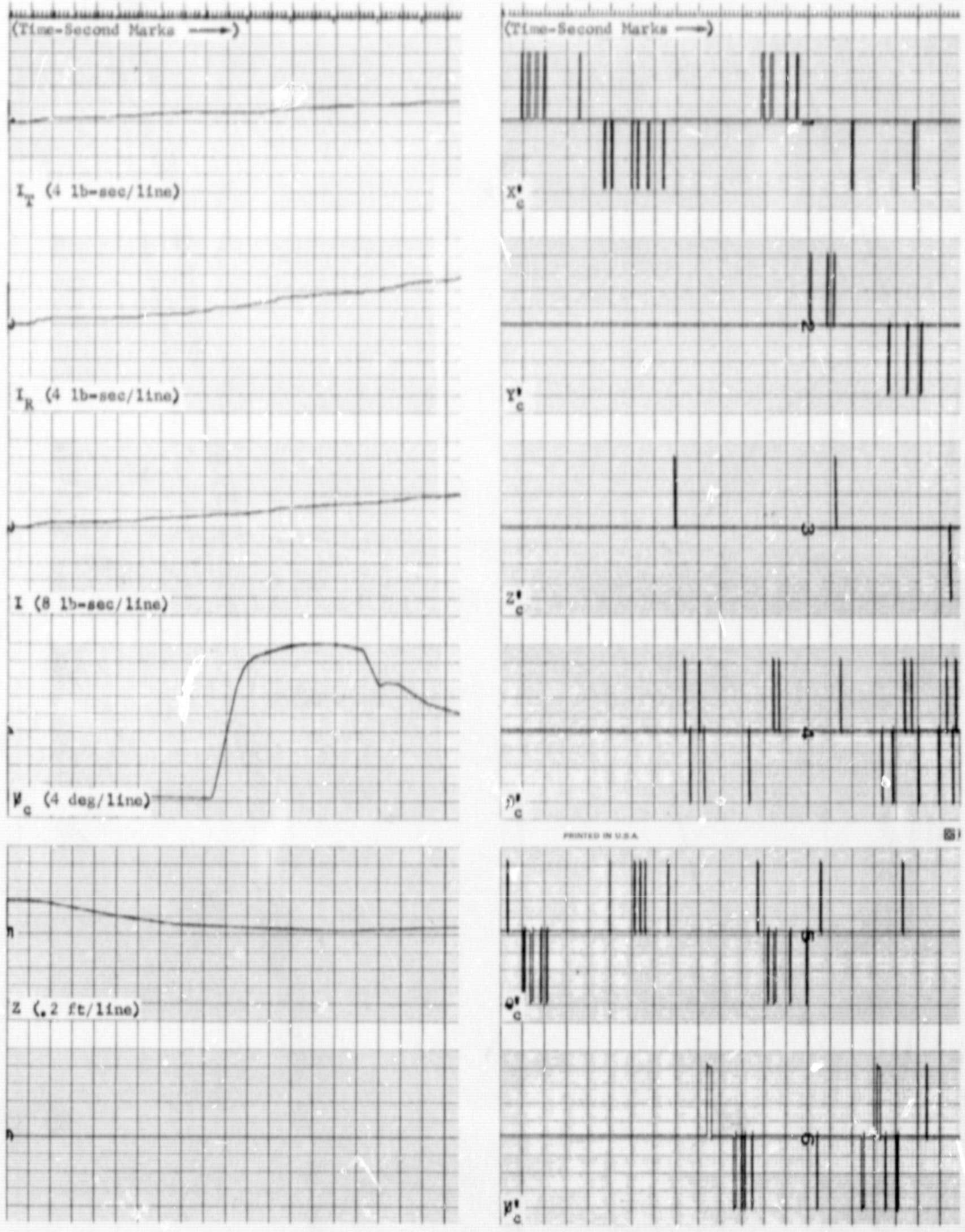


Figure 45 IMLSS Configuration 1 - Task 3 (c.g. Shift #2): Strip Chart Data (R - 1&2)



Recorder #3　　　　　　　　　　Recorder #4

Figure 46　IMLSS Configuration 1 Task 3 (c.g. Shift #2): Strip Chart Data (R - 3&4)

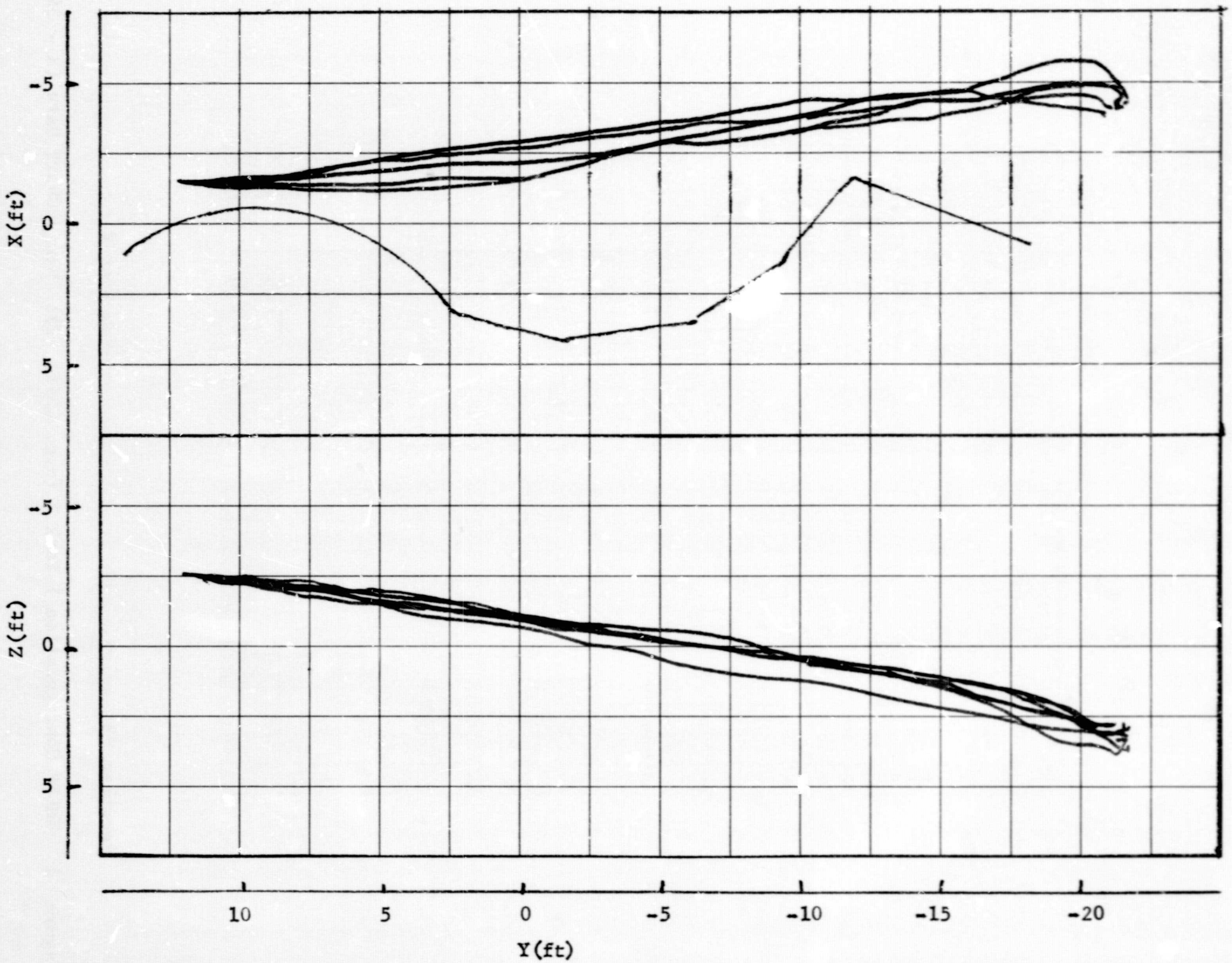


Figure 47 IMLSS Configuration 1 - Task 4 (c.g. shift #2): X-Y and Y-Z Motions

Table XXII IMLSS Configuration 1 - Task 3 Data (c.g. shift #2)

End conditions																					
	Run	Time sec	Impulse (lb-sec) Translation			Total Trans	Rotational			Total Rot.	Total	Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	134	18.6	5.6	5.7	29.9	19.3	26.3	10.2	55.7	85.6	11470	-2.2	5.0	1.1	-.01	.00	.03	-.7	9.2	6.8
	2	122	18.1	4.9	4.2	27.3	10.9	31.2	25.7	67.9	95.2	11610	-2.3	4.9	1.1	-.02	.00	-.01	1.4	-3.5	13.3
	3	112	18.9	5.8	1.9	26.6	10.6	26.3	12.0	49.0	75.6	8470	-2.3	4.8	1.3	.01	.04	.00	4.0	-1.9	4.0
	Avg	123	18.5	5.4	3.4	27.9	13.6	27.9	15.9	57.5	85.5	10540	-2.3	4.9	1.2	-.01	.01	.01	1.6	1.2	6.0
	1	111	18.8	3.0	2.3	24.1	16.6	27.6	9.7	53.9	78.0	8658	-2.2	4.3	.8	.01	.05	.02	-1.1	-.2	32.5
	2	110	18.2	4.5	.7	23.3	12.8	32.6	13.7	59.0	82.4	9048	-2.0	4.8	1.3	-.01	.04	.01	-.2	2.9	26.3
	3	119	19.2	7.3	3.3	30.4	22.9	46.5	15.5	84.9	115.4	13686	-2.3	4.8	.8	-.01	.04	.00	.6	1.6	21.6
	4	110	16.1	5.3	2.9	24.4	14.8	20.1	12.0	46.9	71.3	7814	-2.0	4.8	.9	-.01	.01	.02	3.9	4.0	18.4
	5	104	18.7	4.3	1.8	24.8	17.7	24.6	12.3	54.6	79.4	8258	-2.2	4.6	1.0	-.04	.10	-.03	6.1	-1.7	20.5
	Avg	110	18.3	4.9	2.2	26.4	17.0	30.3	12.6	59.9	85.2	9493	-2.1	4.7	1.0	-.01	.05	.00	1.9	.7	23.9

	Run	End conditions Body rates deg/sec			Maximum rates ft/sec			Maximum rates deg/sec			Average rates ft/sec			Average rates deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	- .1	.4	.3	.13	.45	.15	5.8	3.1	16.9	.00	.01	-.03	-.1	.1	.7
	2	- .1	.7	- .6	.13	.47	.13	5.2	3.0	21.7	.00	.01	-.03	-.2	.0	.6
	3	- .1	.7	.2	.14	.50	.13	3.2	4.1	24.3	.00	.01	-.03	-.1	-.1	.8
	Avg	- .1	.5	.0	.13	.47	.14	4.7	3.4	20.9	.00	.01	-.03	-.1	.0	.6
	1	- .8	-.1	-.2	.13	.48	.12	5.4	3.7	21.7	.00	.00	-.04	-.2	.1	.9
	2	- .5	.3	-.4	.14	.47	.11	3.0	4.1	25.5	.00	.01	-.03	-.1	.1	.9
	3	-1.0	.7	.5	.17	.53	.11	4.6	4.1	26.3	.00	.01	-.03	-.1	.1	.7
	4	.1	.4	1.7	.16	.44	.10	3.6	4.1	23.7	.01	.01	-.07	-.1	.0	.9
	5	1.7	.0	-1.6	.17	.53	.14	4.1	3.9	21.9	.00	.01	-.04	-.1	.0	.9
	Avg	- .1	.3	.0	.15	.47	.12	4.1	4.0	23.8	.00	.01	-.04	-.1	.1	.9

Table XXIII IMLSS Configuration 1 - Task 4 Data (c.g. shift #2)

			End conditions																		
	Run	Time sec	Impulse (lb-sec)									Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	88	21.6	4.3	3.4	29.3	12.7	22.8	10.9	46.4	75.8	6670	-4.4	-21.4	3.5	-.02	-.02	-.03	2.9	-1.9	-84.1
	2	87	24.5	11.2	2.3	38.0	21.8	38.0	12.5	72.2	110.2	9587	-4.2	-21.3	3.1	.05	-.07	-.02	5.2	2.4	-87.6
	3	87	18.9	6.1	3.2	28.1	25.1	39.0	13.5	77.6	105.7	9196	-4.2	-21.5	2.9	.07	-.10	.05	1.8	1.5	-89.4
	Avg	87	21.7	7.2	2.9	31.8	19.9	33.2	12.7	65.4	97.2	8439	-4.3	-21.4	3.2	.03	-.06	.00	3.3	.7	-86.7
	1	91	17.1	7.3	3.0	27.3	25.8	29.2	8.7	63.7	91.0	8272	-4.4	-21.7	2.8	.05	.02	-.02	3.1	2.8	-85.2
	2	71	21.0	2.5	1.0	24.6	8.2	27.0	7.3	42.5	67.2	4798	-3.9	-21.0	3.3	.04	.00	.02	3.6	1.2	-93.4
	3	95	23.2	5.0	5.7	33.9	19.7	30.0	9.7	59.5	93.4	8845	-4.3	-21.3	3.3	-.01	.02	.00	4.7	5.4	-94.0
	4	84	18.6	3.5	1.6	23.8	12.6	25.1	6.5	44.2	64.0	5402	-4.4	-21.8	3.7	.02	-.08	.00	8.2	2.0	-90.3
	5	98	19.1	2.1	1.4	22.6	12.6	35.8	6.7	55.0	77.5	7556	-4.1	-21.2	2.7	.03	-.07	-.01	4.2	6.1	-91.8
	Avg	88	19.8	4.1	2.5	26.4	15.8	29.4	7.8	52.9	78.6	6885	-4.2	-21.4	3.3	.03	-.02	.00	4.8	3.5	-90.9

		End conditions			Maximum rates						Average rates					
	Run	Body rates deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	.3	.5	.9	.13	1.06	.18	3.7	4.4	13.8	-.03	-.38	.07	.2	.2	-1.7
	2	-.4	-.3	-.3	.25	1.15	.19	6.1	6.5	16.2	-.03	-.38	.06	.2	.2	-2.0
	3	-.3	.2	-1.7	.24	.96	.21	6.0	12.6	18.7	-.03	-.38	.06	.2	.1	-1.9
	Avg	-.1	.1	-.4	.21	1.06	.19	5.2	7.8	16.2	-.03	-.38	.06	.2	.2	-1.9
	1	-1.8	-1.2	-.5	.20	.83	.20	5.4	5.5	17.6	-.03	-.37	.06	.2	.1	-1.9
	2	-.3	-.6	-.1	.14	1.00	.14	3.9	3.3	18.8	-.03	-.46	.08	.3	.2	-2.4
	3	.4	-.7	-1.1	.19	1.02	.20	4.4	5.3	17.0	-.03	-.35	.06	.2	.2	-2.0
	4	1.7	-.2	-.2	.12	.95	.14	3.2	3.4	18.0	-.03	-.40	.07	.2	.2	-2.0
	5	-.5	.6	-.2	.10	.91	.13	3.4	6.7	13.7	-.03	-.34	.05	.1	.2	-1.7
	Avg	-.1	-.4	-.3	.15	.94	.16	4.0	4.8	17.0	-.03	-.38	.06	.2	.2	-2.0

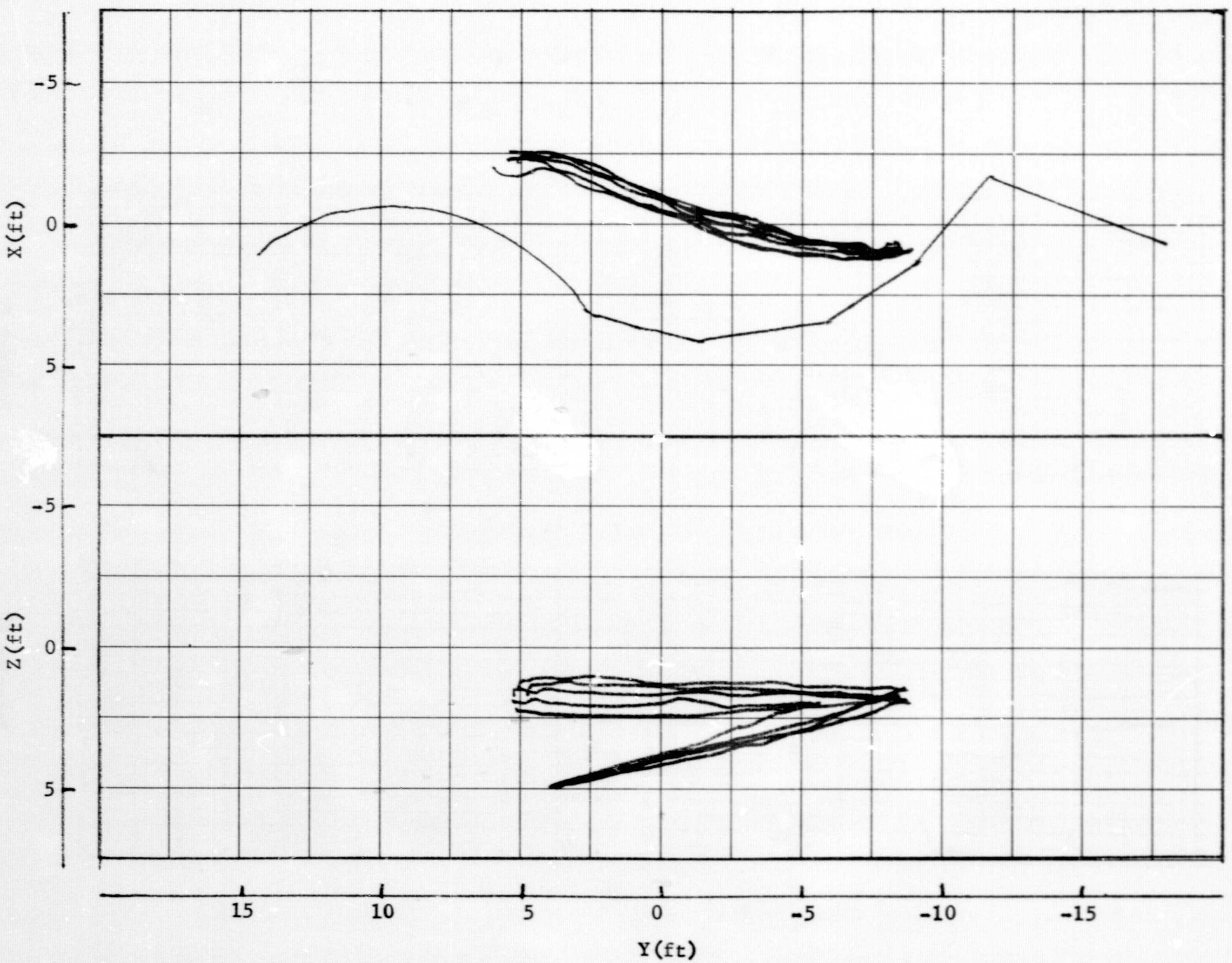
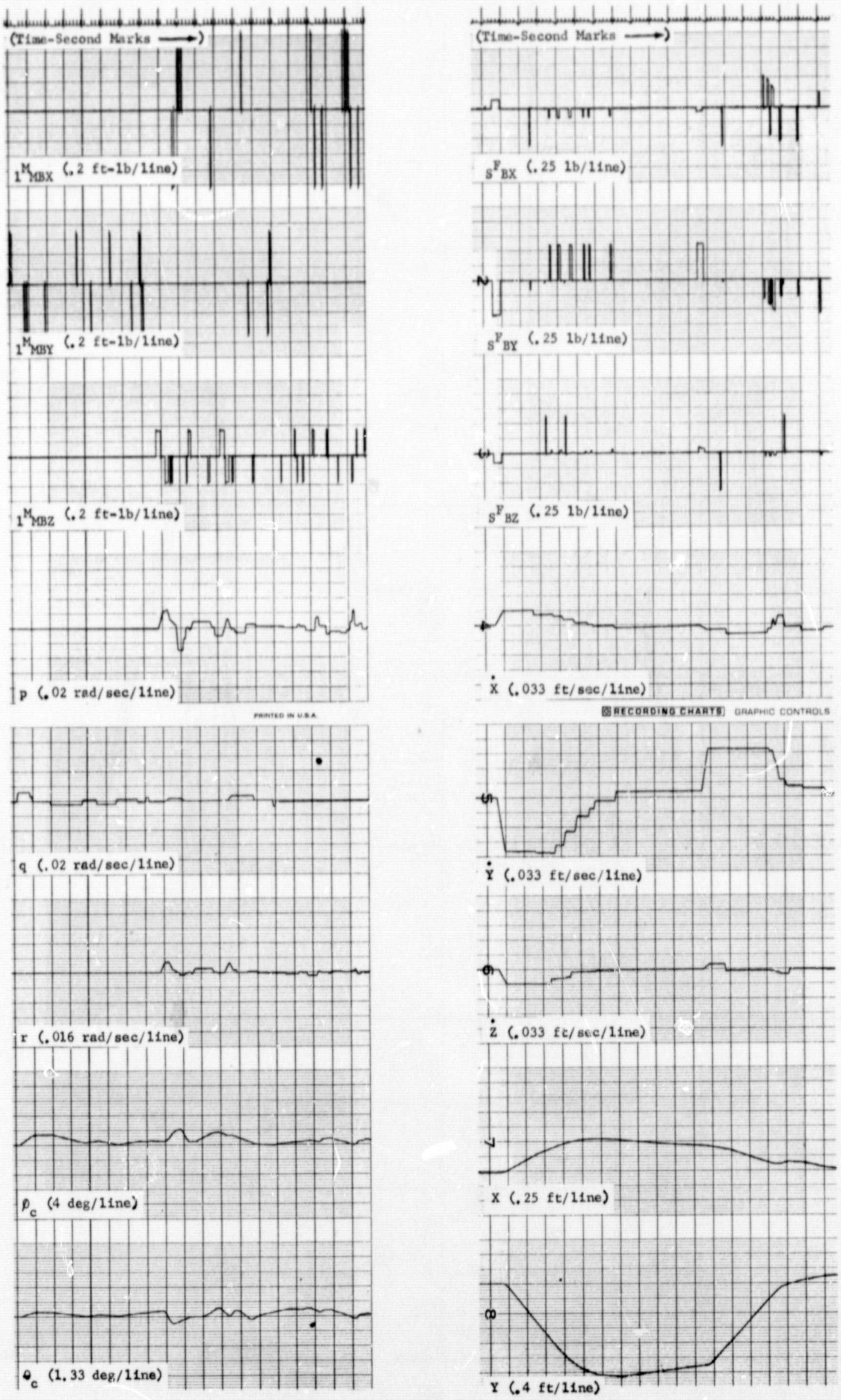
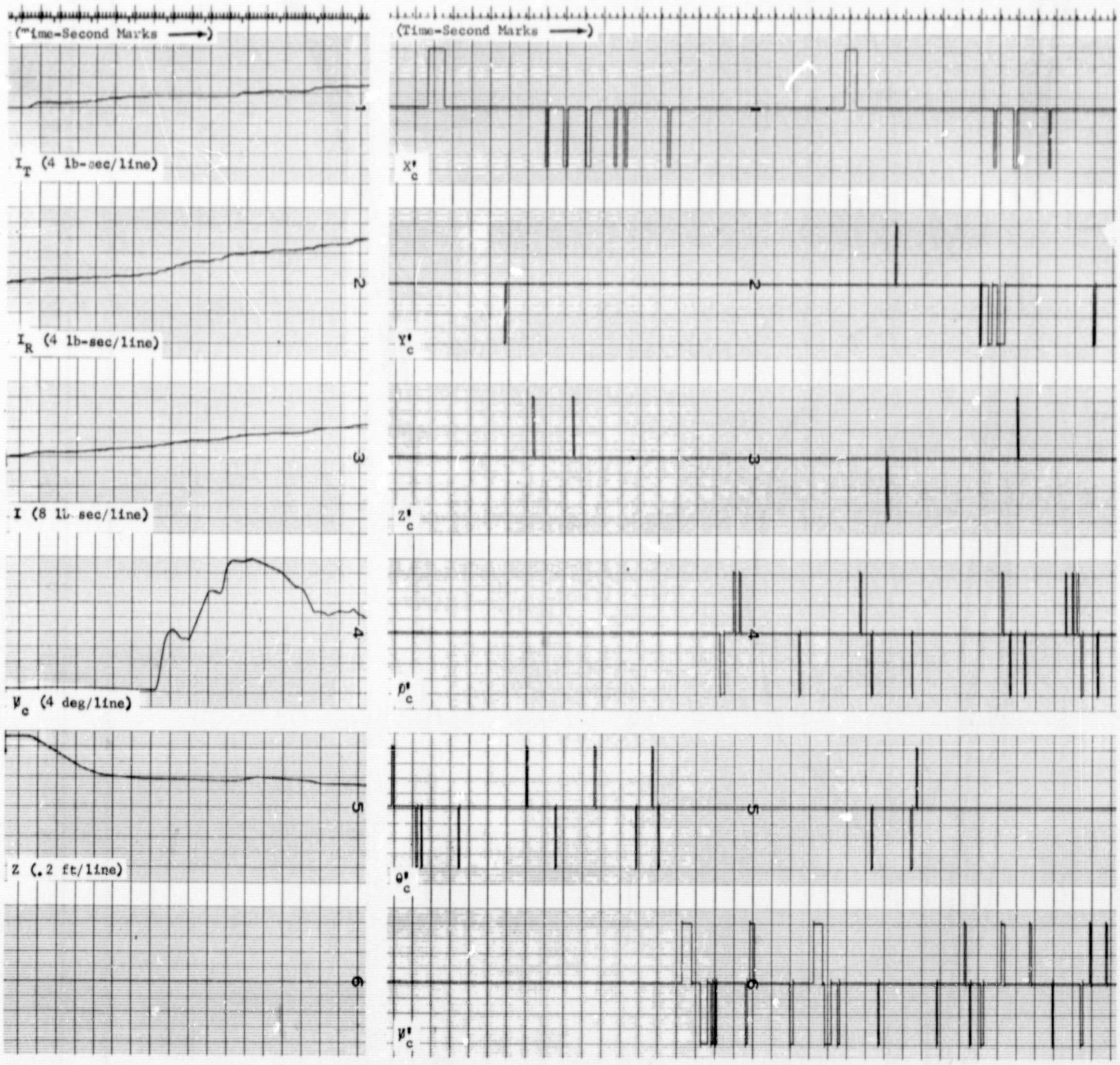


Figure 48 IMLSS Configuration 1 - Task 3 (Inertia Dyadic Change): X-Y and Y-Z Motions



Recorder #1 **Recorder #2**

Figure 49 IMLSS Configuration 1 - Task 3 (Inertia Dyadic Change): Strip Chart Data (R - 1&2)



Recorder #3 Recorder #4

Figure 50 IMLSS Configuration 1 - Task 3 (Inertia Dyadic Change): Strip Chart Data (R - 3 and 4)

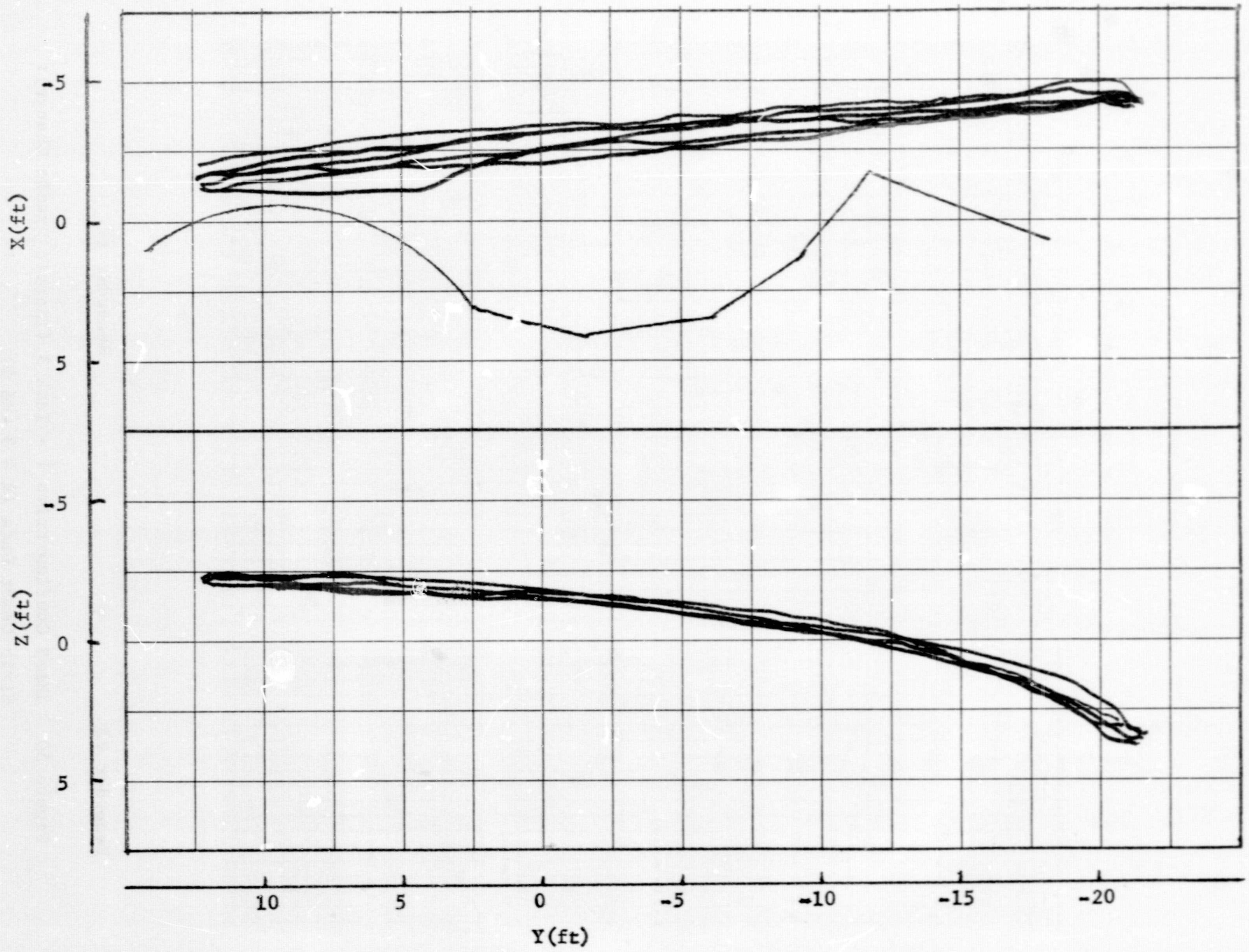


Figure 51 IMLSS Configuration 1 - Task 4 (Inertia Dyadic Change): X-Y and Y-Z Motions

Table XXIV IMLSS Configuration 1 - Task 3 Data (Inertia Dyadic Change)

		End conditions																			
	Run	Time sec	Impulse (lb-sec) Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot.	Total	Time X Impulse	Position ft X	Y	Z	Velocity ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg ϕ_c	θ_c	ψ_c
Practice	1	127	19.8	5.0	2.9	27.7	29.8	21.8	17.7	69.4	97.1	12283	-2.3	4.8	1.3	.03	.05	.01	.8	2.6	11.9
	2	134	18.5	4.5	4.2	27.1	31.9	15.6	18.4	65.8	93.0	12462	-2.0	5.2	1.5	.02	.02	.03	2.0	2.1	15.6
	3	95	20.1	4.3	4.1	28.5	12.4	10.2	13.2	35.7	64.2	6105	-2.1	4.9	2.2	.04	.04	.01	-2.4	.4	33.4
	Avg	119	19.5	4.6	3.7	27.8	24.7	15.9	16.4	57.0	84.8	10283	-2.1	5.0	1.7	.03	.04	.02	.1	1.7	20.3
	1	93	19.4	13.4	1.7	34.5	12.3	11.1	18.7	42.2	76.7	7133	-2.1	4.7	1.4	.05	.02	.04	5.1	-2.9	17.7
	2	98	22.1	5.3	3.7	31.0	18.9	11.9	18.7	49.5	80.6	7899	-2.4	4.7	1.0	.02	.00	-.03	.5	-8.3	25.5
	3	94	24.1	4.9	3.6	32.6	14.1	13.4	17.7	45.2	77.8	7313	-2.6	4.6	1.1	-.03	.00	.02	6.2	-.8	18.5
	4	97	22.0	5.9	2.4	30.4	17.5	15.4	26.3	59.2	89.6	8664	-2.3	5.1	1.5	.03	.03	.01	6.2	.7	20.7
	5	107	23.1	4.8	3.2	31.1	16.0	15.4	16.8	48.2	79.3	8453	-2.2	4.7	1.5	.02	.04	.00	3.0	-1.5	19.3
	Avg	98	22.1	6.7	2.9	32.6	15.8	13.4	19.6	48.9	80.8	7886	-2.3	4.8	1.3	.02	.02	.00	4.2	-2.5	20.3

		End conditions Body rates deg/sec			Maximum rates ft/sec			deg/sec			Average rates ft/sec			deg/sec		
	Run	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.3	-.1	-.1	.14	.49	.12	7.6	5.8	26.7	.00	.01	-.03	-.1	.1	.7
	2	.7	.0	-.2	.16	.48	.10	8.5	2.5	29.6	.00	.01	-.02	-.1	.2	.7
	3	-.0	.6	.1	.20	.58	.12	4.6	3.1	19.3	.00	.01	-.03	.1	.3	1.1
	Avg	.1	.2	-.1	.17	.52	.11	6.9	3.8	25.2	.00	.01	-.03	.0	.2	.8
	1	-.1	-1.2	-.2	.24	.67	.13	5.9	3.6	25.5	.00	.01	-.04	.0	.2	.9
	2	.3	-.1	.9	.17	.63	.14	9.1	3.6	26.8	.00	.01	-.04	-.0	.3	1.1
	3	.3	.4	.1	.19	.68	.15	4.4	3.2	22.9	.00	.01	-.04	.0	.2	1.0
	4	.1	-.1	.9	.17	.62	.16	8.8	3.7	30.4	.00	.01	-.03	.1	.2	1.0
	5	-.8	-.2	-.6	.20	.60	.10	3.6	3.1	19.1	.00	.01	-.03	.0	.1	.8
	Avg	.0	-.4	.2	.19	.64	.14	6.4	3.4	24.9	.00	.01	-.04	.0	.2	1.0

Table XXV IMLSS Configuration 1 - Task 4 Data (Inertia Dyadic Change)

	Run	Time sec	Impulse (lb-sec) Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot.	Total	Time X Impulse	Position ft X	Y	Z	Velocity ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg ϕ_c	θ_c	ψ_c
Practice	1	90	25.0	2.3	3.5	30.8	8.6	10.4	16.6	35.6	66.4	5976	-4.4	-21.2	3.4	.01	.04	.01	4.2	-1.1	-89.7
	2	92	17.1	5.7	2.5	25.3	16.0	5.1	10.1	31.2	56.5	5198	-3.9	-21.4	3.2	-.02	-.10	.04	-.5	2.5	-93.4
	3	81	19.5	5.8	4.3	29.6	10.0	7.2	10.4	27.6	57.2	4633	-4.3	-21.7	3.4	.03	-.01	.02	11.4	8.9	-78.0
	Avg	88	20.5	4.6	3.4	28.6	11.5	7.6	12.6	31.5	60.0	5262	-4.2	-21.4	3.3	.01	-.02	.02	5.0	3.4	-87.0
	1	90	78.6	2.3	2.8	23.6	10.6	14.8	12.0	37.3	61.0	5472	-4.2	-21.3	3.0	.03	-.04	.01	-2.5	-1.7	-96.9
	2	106	27.2	2.4	3.8	33.4	22.9	20.1	19.9	62.9	96.4	10218	-4.1	-21.1	3.1	.01	-.10	.00	-.6	9.6	-86.4
	3	80	17.8	2.3	4.7	24.8	12.8	.94	13.3	27.0	51.9	4152	-4.3	-21.8	3.9	.02	-.14	.03	10.7	8.0	-89.2
	4	77	19.8	3.6	4.1	27.5	12.0	6.3	12.3	30.6	58.2	4481	-4.4	-21.4	3.1	.03	-.10	.02	2.4	2.8	-80.2
	5	88	20.3	1.9	4.1	26.4	18.3	7.6	11.2	37.1	63.5	5575	-4.4	-21.6	3.3	.08	-.05	.04	-.9	-4.1	-83.4
	Avg	88	20.7	2.4	4.1	27.1	15.3	10.0	13.7	39.0	66.2	4912	-4.3	-21.4	3.3	.04	-.09	.02	1.8	2.9	-86.2

	Run	End conditions Body rates deg/sec P	Q	R	Maximum rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R	Average rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R
Practice	1	1.0	-.5	3.0	.11	1.14	.19	3.9	1.9	16.3	-.03	-.37	.07	.1	.2	-1.9
	2	.2	.1	-.5	.13	.89	.17	5.1	2.0	11.6	-.03	-.36	.06	.1	.1	-1.9
	3	.3	-.1	-.9	.19	.90	.23	3.9	2.4	12.8	-.03	-.41	.07	.1	.2	-2.1
	Avg	.5	-.2	.9	.14	.96	.20	4.3	2.1	13.6	-.03	-.38	.07	.1	.2	-2.0
	1	-.3	-.3	-.7	.10	.91	.16	4.4	3.3	16.5	-.03	-.37	.06	.2	.1	-2.0
	2	-.4	-.1	.6	.08	.99	.21	4.3	2.9	11.6	-.02	-.31	.05	.0	.0	-1.6
	3	-1.1	.5	1.6	.09	.94	.26	4.9	2.0	13.7	-.04	-.42	.08	.0	.3	-2.0
	4	-.3	.1	1.3	.14	.99	.21	6.0	4.2	14.1	-.04	-.43	.07	.3	.0	-2.2
	5	1.0	-.2	.2	.12	1.00	.19	5.7	3.9	18.1	-.03	-.38	.07	.5	.0	-2.2
	Avg	-.2	.00	.6	.11	.97	.22	5.1	3.0	14.8	-.03	-.38	.07	.2	.1	-2.0

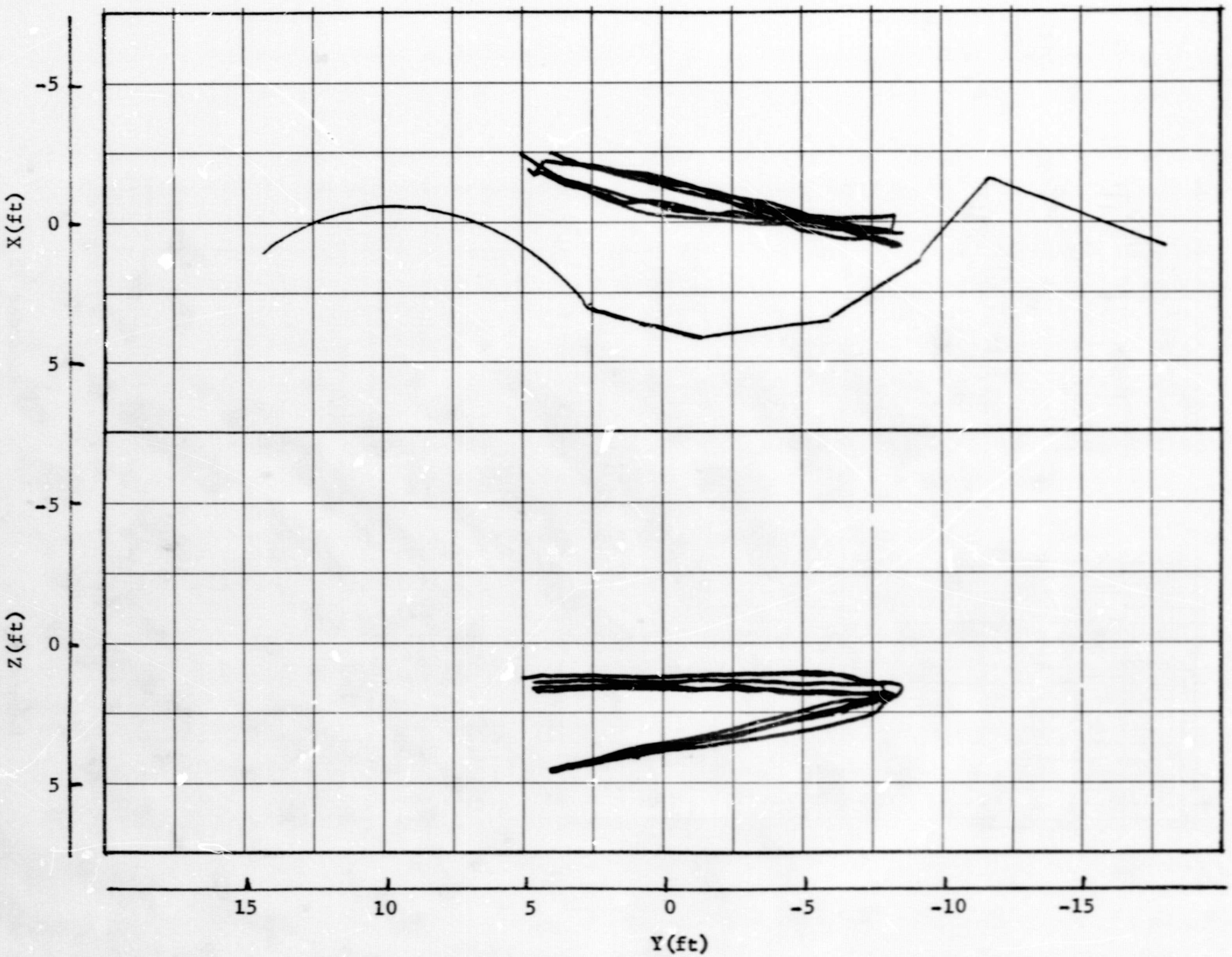
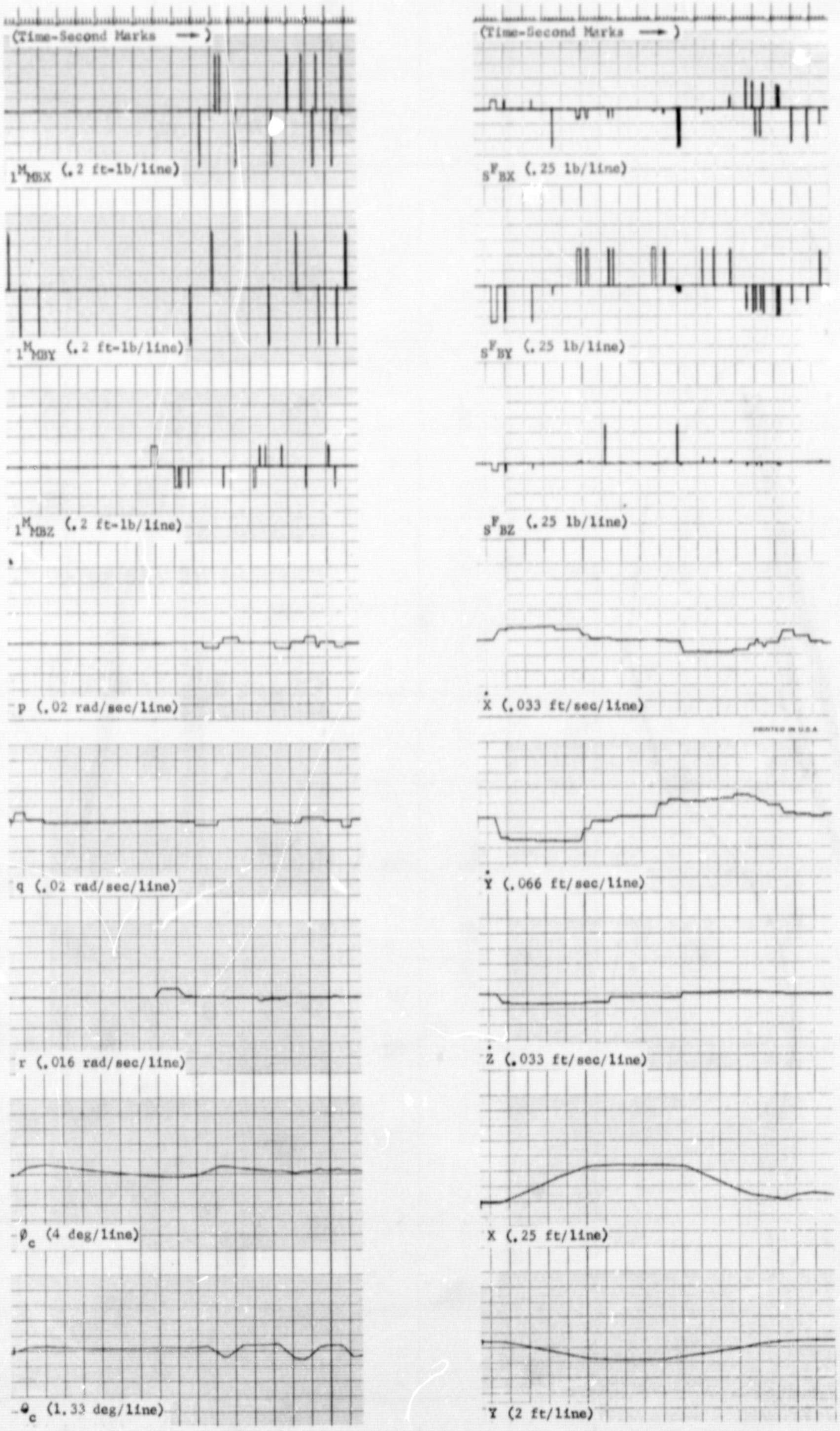
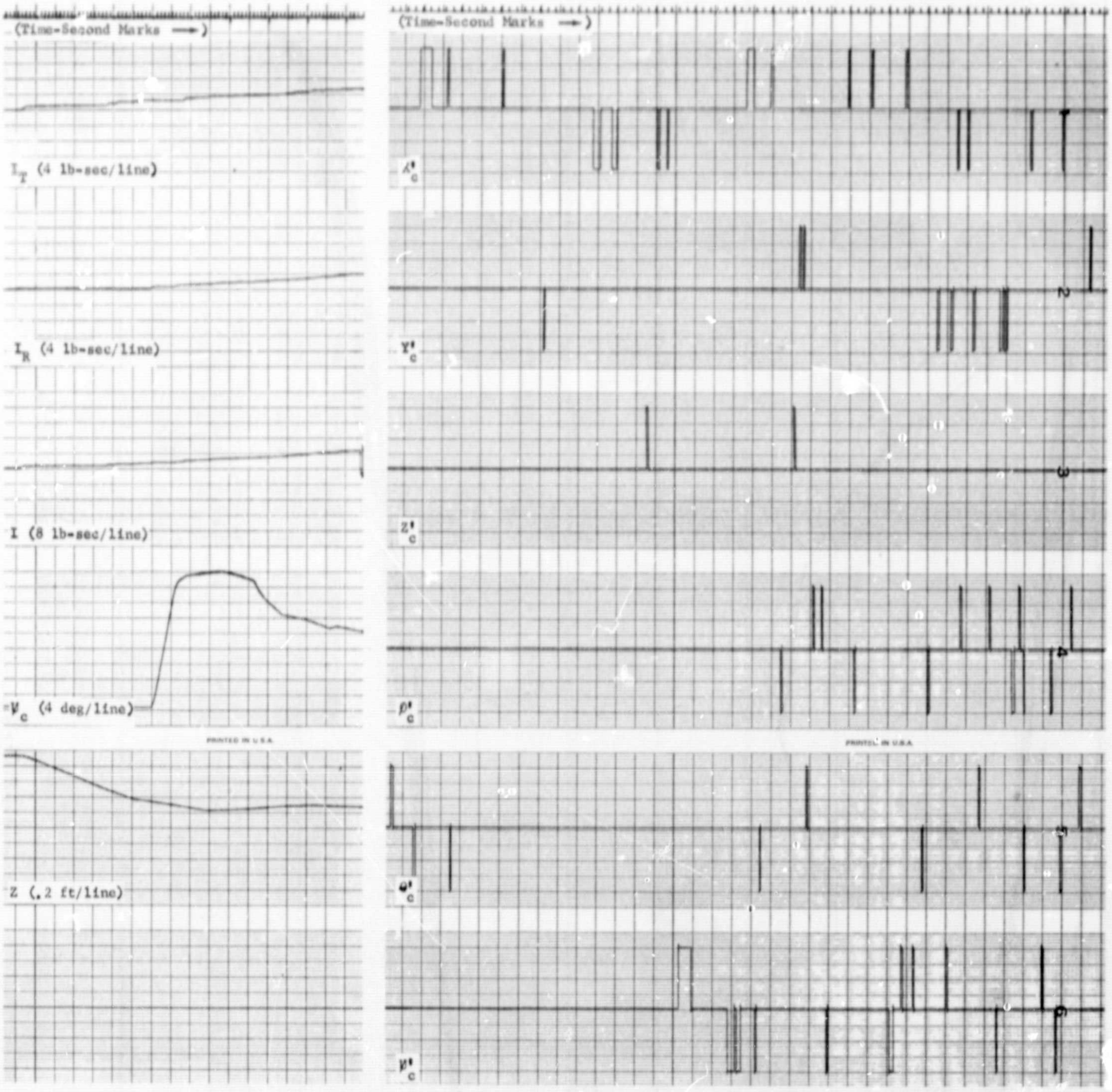


Figure 52 IMLSS Configuration 4 - Task 3; X-Y and Y-Z Motions



Recorder #1 Recorder #2

Figure 53 IMLSS Configuration 4 - Task 3: Strip Chart Data (R - 1&2)



Recorder #3 Recorder #4

Figure 54 IMLSS Configuration 4 - Task 3: Strip Chart Data (R - 3&4)

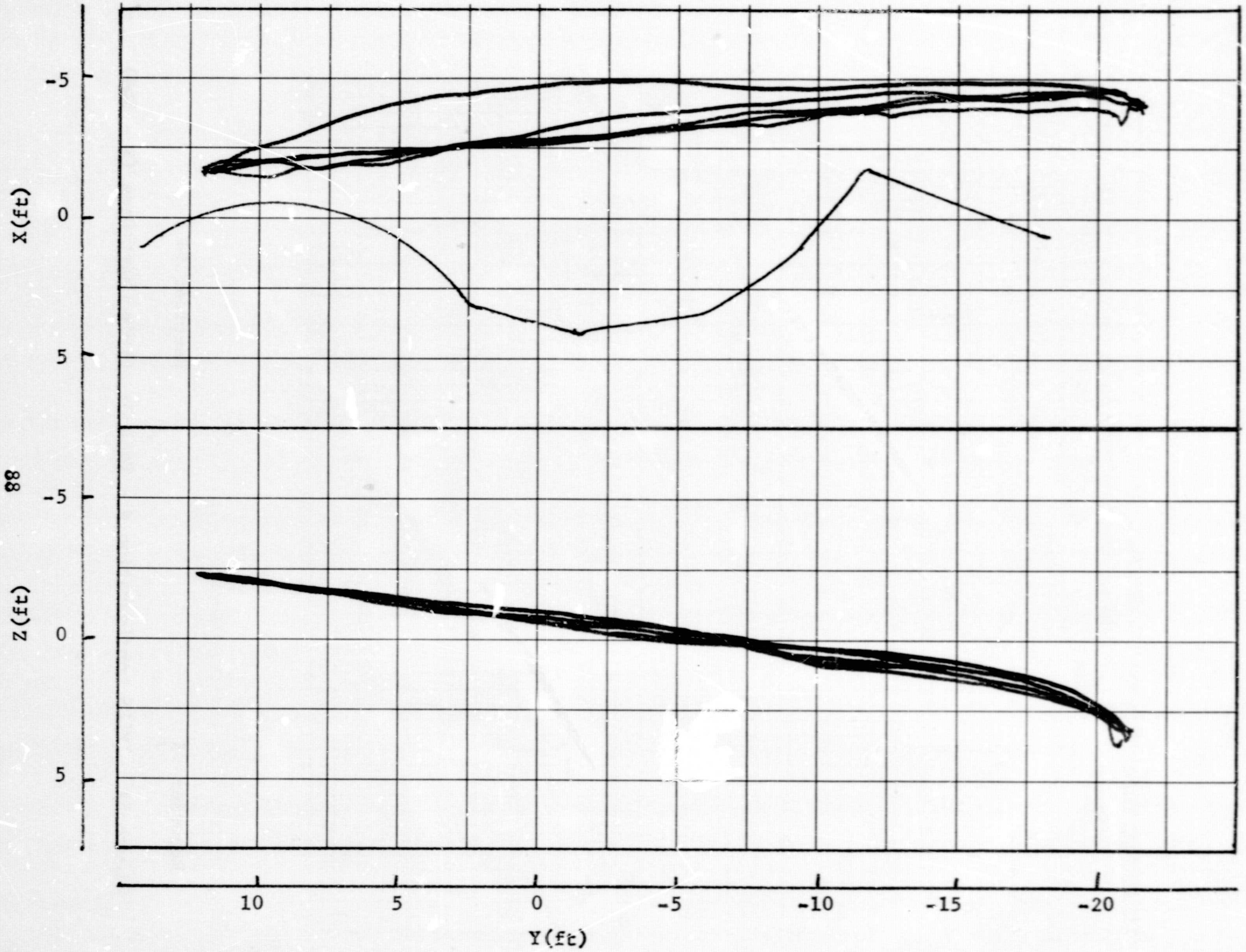


Figure 55 IMLSS Configuration 4 - Task 4: X-Y and Y-Z Motions

Table XXVI IMLSS Configuration 4 - Task 3 Data

End conditions																					
	Run	Time sec	Impulse (lb-sec)										Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			Translation			Total Trans	Rotational			Total Rot.	Total										
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	79	19.3	4.1	3.1	26.6	6.9	7.1	8.5	22.5	49.0	3886	-2.3	5.2	1.5	[illegible]	.03	-.01	-.4	-1.5	17.6
	2	78	17.3	5.9	2.0	25.3	4.2	7.9	6.4	18.4	43.7	3422	-2.6	5.0	1.9	-.01	.02	.02	.3	6.0	12.2
	3	68	20.9	7.7	2.0	30.6	3.9	5.9	5.1	14.9	45.5	3076	-2.6	4.7	1.5	.01	.06	.01	9.1	.3	16.1
	Avg	75	19.2	5.9	2.4	27.5	5.0	7.0	6.7	18.6	46.1	3421	-2.1	5.0	1.6	.01	.04	.01	3.0	2.4	15.1
	1	69	19.7	5.7	1.5	26.8	1.1	6.9	7.1	15.1	41.9	2891	-1.7	4.7	1.6	.06	.02	-.01	1.7	7.6	25.3
	2	72	21.1	5.2	1.9	28.1	5.3	5.7	5.9	16.9	45.0	3195	-2.5	5.0	1.3	-.04	.06	-.03	3.6	-8.4	13.5
	3	75	19.3	4.4	2.4	26.0	2.5	6.2	7.2	15.9	41.9	3147	-2.4	5.0	1.8	-.01	.05	.00	-1.3	-1.6	21.1
	4	77	19.9	6.7	1.2	27.8	6.8	6.3	7.8	20.8	48.6	3735	-1.9	4.7	1.5	-.04	.06	-.01	3.7	-2.8	23.4
	5	66	20.0	5.1	3.1	28.2	.7	2.6	5.7	9.0	37.2	2441	-2.3	-4.8	1.3	-.01	.06	.02	5.4	-.9	17.7
	Avg	72	20.0	5.4	2.0	26.4	3.3	5.5	6.7	15.5	42.9	3090	-2.2	2.9	1.5	-.01	.05	.00	2.6	-1.2	20.2

	Run	End conditions			Maximum rates						Average rates					
		Body rates deg/sec			ft/sec			deg/sec			ft/sec			deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	1.0	-.9	-2.8	.14	.56	.10	3.0	3.3	21.7	.00	.01	-.04	.0	.1	1.0
	2	-.7	.6	-.9	.15	.53	.12	2.7	4.0	21.2	.01	.01	-.03	.0	.2	1.1
	3	-.1	.4	-.9	.19	.60	.14	2.7	4.0	19.2	.01	.01	-.04	.1	.0	1.2
	Avg	.1	.0	-1.5	.16	.56	.12	2.8	3.8	19.7	.01	.01	-.04	.0	.1	1.1
	1	.3	.4	-.9	.17	.58	.11	1.6	4.7	20.0	.01	.01	-.04	.0	.1	1.3
	2	-1.2	-.5	-.9	.17	.64	.11	3.6	3.3	22.0	.00	.01	-.04	.0	-.1	.9
	3	.2	.8	-.9	.18	.50	.12	1.4	4.0	21.2	.00	.01	-.03	.0	.0	1.0
	4	-.4	.7	-1.0	.15	.52	.11	2.4	3.4	25.1	.01	.01	-.04	-.1	-.2	1.0
	5	-.1	.0	-.9	.13	.57	.10	1.3	4.0	20.8	.00	.01	-.05	.0	-.1	1.1
	Avg	-.2	.3	-.9	.16	.56	.11	2.1	3.9	21.8	.00	.01	-.04	.0	-.1	1.1

Table XXV[illegible] IMLSS Configuration 4 - Task 4 Data

End conditions																					
	Run	Time sec	Impulse (lb-sec) Translation			Total Trans	Impulse (lb-sec) Rotational			Total Rot.	Total	Time X Impulse	Position ft			Velocity ft/sec			Attitude deg		
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ				X	Y	Z	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	ϕ_c	θ_c	ψ_c
Practice	1	63	21.8	5.0	3.6	30.4	5.2	2.2	4.8	12.1	42.5	2695	-4.0	-21.9	3.6	.04	-.06	-.02	9.4	6.9	-93.8
	2	69	24.4	4.2	3.6	32.2	7.3	1.2	4.6	13.0	45.2	3065	-4.2	-21.6	3.4	-.10	-.00	.02	5.8	-.9	-90.5
	3	70	21.8	3.5	1.6	26.9	4.5	5.8	6.2	16.5	43.4	3051	-4.2	-21.6	3.5	.06	-.00	.05	4.3	5.2	-89.5
	Avg	67	22.7	4.2	2.9	29.8	5.7	3.1	5.2	13.9	43.7	2937	-4.1	-21.7	3.5	.00	-.02	.02	6.5	3.7	-91.3
	1	72	19.8	2.9	2.5	25.3	5.4	1.5	3.8	10.7	36.0	2592	-4.1	-21.4	3.4	.00	.01	.01	7.6	9.9	-85.5
	2	70	18.4	3.8	2.3	24.5	2.2	2.3	5.2	9.7	34.2	2394	-4.3	-21.3	3.2	.04	-.06	.04	1.2	-1.6	-88.7
	3	80	17.5	8.5	2.0	27.9	8.6	1.8	4.2	4.4	42.4	3392	-3.9	-21.6	3.7	.02	-.02	.07	10.3	1.3	-89.4
	4	86	19.5	6.4	2.5	28.4	7.6	4.4	4.1	16.1	44.6	3836	-4.2	-21.3	3.6	-.05	-.02	-.04	9.8	.3	-98.8
	5	75	19.2	2.7	1.9	23.8	2.4	1.2	4.1	7.7	31.5	2362	-3.0	-21.8	3.4	.04	-.07	.00	.1	-3.2	-94.7
	Avg	77	18.8	4.8	2.2	26.0	5.2	2.2	4.3	11.7	37.7	2888	-4.1	-21.5	3.5	.01	-.03	.02	6.0	1.1	-91.4

	Run	End conditions Body rates deg/sec			Maximum rates ft/sec			Maximum rates deg/sec			Average rates ft/sec			Average rates deg/sec		
		P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R	$\dot{X}$	$\dot{Y}$	$\dot{Z}$	P	Q	R
Practice	1	-.1	.6	-.5	.14	1.09	.22	2.7	2.8	17.5	-.04	-.54	.10	.2	.3	-2.5
	2	.2	.5	.0	.14	1.15	.22	3.6	2.2	17.3	-.04	-.50	.09	.3	.3	-2.5
	3	-.4	-.8	-.2	.21	1.05	.17	2.6	3.0	18.2	-.04	-.48	.09	.2	.3	-2.1
	Avg	-.1	.1	-.2	.16	1.10	.20	3.0	2.7	17.7	-.04	-.51	.09	.2	.3	-2.4
	1	-.4	.5	.2	.11	.95	.17	3.6	2.7	17.5	-.04	-.46	.08	.2	.3	-2.2
	2	.2	-.2	-.2	.15	.89	.19	2.6	2.2	15.5	-.04	-.47	.08	.2	.2	-2.4
	3	.8	.5	.0	.25	.86	.17	3.4	3.7	17.3	-.03	-.42	.07	.2	.3	-2.1
	4	.0	1.2	-1.2	.14	.94	.18	4.0	2.5	13.9	-.03	-.39	.07	.2	.2	-1.9
	5	.1	.2	-.2	.12	.93	.16	2.5	2.5	20.1	-.03	-.45	.10	.3	.2	-2.3
	Avg	.1	.4	-.3	.15	.91	.17	3.2	2.8	16.9	-.03	-.44	.08	.2	.2	-2.3

7. SUBJECT'S COMMENTS

The test subject felt that the 0.3 ft/sec^2 linear acceleration level for Configuration 1 gave him about the right degree of translational control authority. Therefore this level was used for Configuration 4. The 0.2 ft/sec^2 in the lateral and vertical directions for Configuration 3 was too sluggish. Also, he felt that the difference in acceleration levels between the lateral and vertical and the longitudinal (Config. 3) was a disadvantage. A balanced system in translation was preferred. In the subject's opinion the 0.44 ft/sec^2 acceleration level of the Air Force AMU (studied in the previous simulation) was a little too high. He felt that the desirable bounds on linear acceleration would be 0.3 ft/sec^2 to 0.4 ft/sec^2.

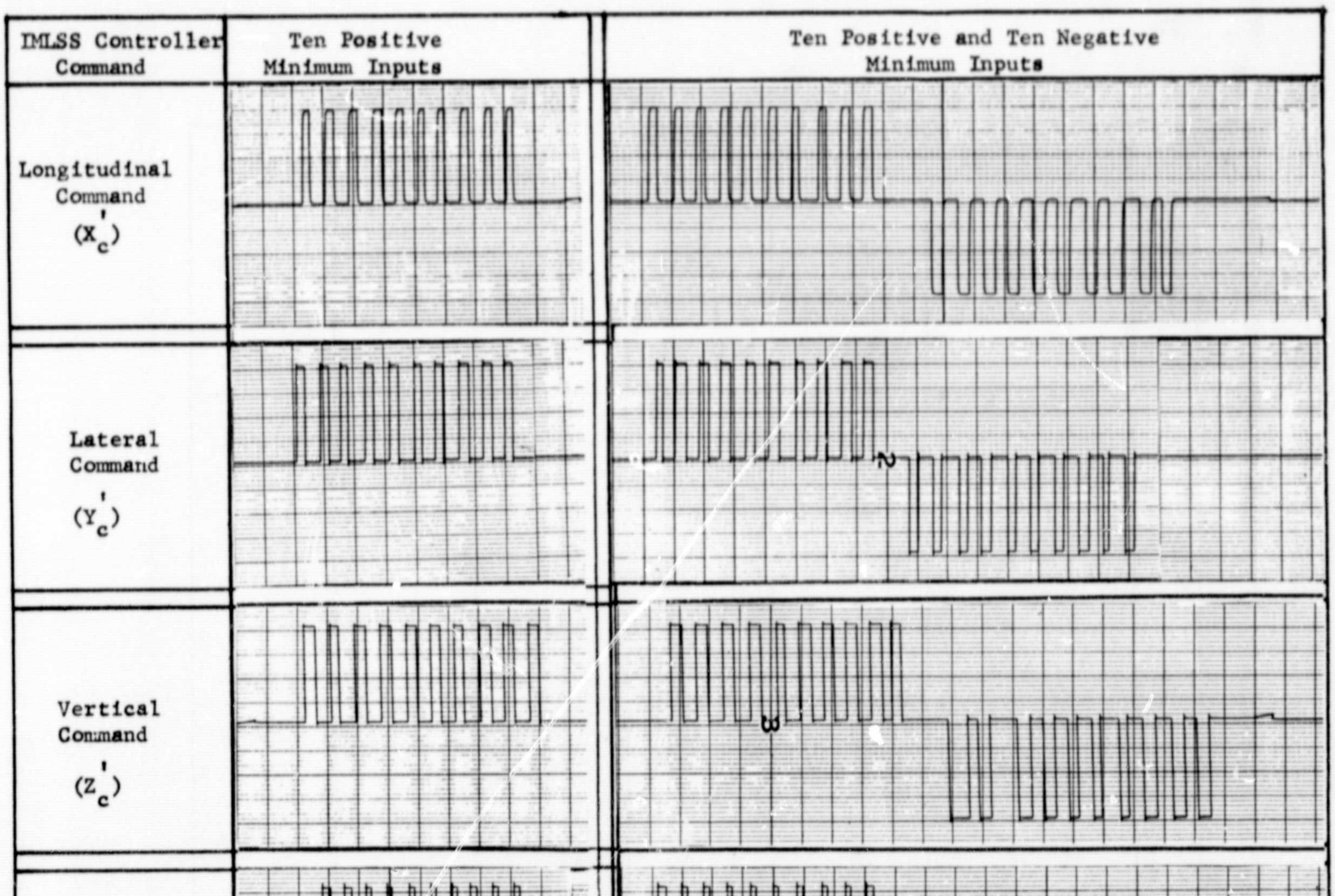
In rotational control the subject preferred the acceleration levels of Configuration 4 (yaw - 16 deg/sec^2, roll and pitch 11 deg/sec^2). He wanted the yaw acceleration level higher than the roll and pitch. Also, he wanted the roll and pitch accelerations the same. This selection of levels was based on how Configurations 1, 2, and 3 performed during the first part of the study. The subject felt that the yaw acceleration of 20 deg/sec^2 of Configuration 1 was a little too high for best performance of the selected tasks. He felt the roll and pitch acceleration levels of Configuration 1 (pitch - 10.3 deg/sec^2 and roll - 15.8 deg/sec^2). were acceptable, but it would be better if they were balanced. The pitch (5.2 deg/sec^2) and roll (7.9 deg/sec^2) accelerations of Configuration 3 were a little low. For Configuration 3 the subject felt that the yaw (13.6 deg/sec^2) and pitch (6.8 deg/sec^2) accelerations were a little low. The subject concluded that the yaw acceleration should be 20 deg/sec^2 or less, and he preferred 16 deg/sec^2. He felt that the pitch and roll accelerations should be balanced and be 15 deg/sec^2 or less. He preferred 11 deg/sec^2.

In the subject's opinion the c.g. shifts and inertia cross-product change, which were investigated, are close to an allowable maximum. Larger changes would degrade the performance of the IMLSS too significantly. For the runs involving a c.g. shift, the handling properties of the IMLSS were considerably complicated by the coupling of the translation control with the rotational control. The subject had to accelerate in a series of steps. In between each step he corrected his attitude. The subject felt that the vertical c.g. shift was easier to handle than the lateral c.g. shift. This probably was due to the lower level of rotational coupling for the vertical shift than the lateral shift. The subject rapidly learned to contend with the coupling and started to use the coupling to his advantage when possible.

For the runs where the inertia dyadic was changed by introducing an I_{XZ} term, the subject felt that the tasks were considerably more difficult to fly. He felt that this perturbation was more difficult to contend with than the c.g. shift. He stated that the physical motions resulting from the rotational coupling between axes were hard to predict. However, he could readily perform the tasks with the inertia dyadic change.

8. IMLSS HAND CONTROLLER CHARACTERISTICS

The minimum input characteristics of the IMLSS hand controller mockups were investigated. Tests were run for a series of ten positive minimum inputs in series and then ten positive and ten negative minimum inputs in series. This was performed one axis at a time. A digital print out was taken at the end of each series of inputs. The total time of the series of inputs and the average input are shown in Table XVIII. Strip chart traces of the inputs are shown in Figure 56. The average minimum input considering all six axes is 0.14 sec. This minimum input condition on linear velocity did not limit the subject's translational performance. Therefore, for a translational acceleration level of 0.3 ft/sec^2, the minimum velocity change that the subject could input was 0.042 ft/sec. This minimum input condition on linear velocity did not limit the subject's translational performance. For a rotational acceleration level of 11 deg/sec^2, the minimum velocity change that the subject could input was 1.54 deg/sec. For a yaw rotational acceleration level of 20.5 deg/sec^2 (Config. #1), the minimum velocity change that the subject could input was 2.87 deg/sec. These minimum input conditions on rotational velocity did limit the subject's rotational performance. They limit the subject's ability to arrest his low rates.



Note: Paper Speed 10 mm/sec

Figure 56 IMLSS Controller Minimum Inputs

Table XXVIII Summary of Hand Controller Minimum Input Data

IMLSS Controller Commands	Ten positive minimum inputs		Ten pos. & ten neg. min. inputs	
	Total Time (sec)	Avg. Min. input (sec)	Total time (sec)	Avg.min.input (sec)
Longitudinal (X_c')	1.3	0.13	3.3	0.16
Lateral (Y_c')	1.4	0.14	3.0	0.15
Vertical (Z_c')	1.7	0.17	3.8	0.19
Roll (ϕ_c')	1.0	0.10	2.2	0.11
Pitch (θ_c')	1.4	0.14	2.3	0.11
Yaw (Ψ_c')	1.3	0.13	2.7	0.13

SECTION VI

CONCLUSIONS

The most important conclusions of the study are based on the subject's opinions of the flying quality of the IMLSS configurations. Based on the experience gained during this simulation and the previous simulation involving the Air Force AMU (Reference 2), the subject concluded that acceptable linear acceleration bounds are 0.3 to 0.4 ft/sec^2. Major C. E. Whitsett, Jr. preferred 0.3 ft/sec^2 for linear acceleration. Also, the system should be balanced in translation. This means that all the translational directions should have the same acceleration level.

In rotational control the subject preferred the acceleration levels of Configuration 4 (yaw-16 deg/sec^2, roll and pitch-11 deg/sec^2). He wanted the yaw acceleration higher than the pitch and roll accelerations. He concluded that the bounds on the yaw acceleration should be 20 deg/sec^2 or less. He felt that the pitch and roll accelerations should be balanced and be 15 deg/sec^2 or less. It is of interest to note that the subject preferred a higher acceleration level in yaw than in pitch or roll. It appears that this results from the physical angular rate conditions the human body is accustomed to. In daily operations a person uses considerably higher yaw rates than pitch and roll.

In the subject's opinion the c.g. shifts and inertia cross-product change, which were investigated, are close to an allowable maximum. The lateral total system c.g. shift investigated was 0.25 ft, and the vertical c.g. shift was 0.5 ft. The cross-product change consisted of introducing an I_{xz} term of a negative 4 slug-ft^2. It was felt that larger changes would degrade the IMLSS's performance and control qualities too significantly. The subject learned to contend with the c.g. shift perturbations more readily than the inertia cross-product change perturbations. This would be expected because in terms of physical motions the former is more easily understood than the later.

Table XXIX is a summary of tasks 1 and 2 end conditions, maximum rates, and average rates for IMLSS configurations 1, 2, and 3. Table XXX is a summary of tasks 3 and 4 end conditions, maximum rates, and average rates for IMLSS configurations 1, 2, 3 and 4. The values shown in the Tables are the five run averages as listed on the data sheets of Section V. The summary tables show that the subject flew the four tasks consistently for all four of the configurations. This can be concluded by observing any of the data. The data for task 4 is taken as an example. The average flight times for the runs varied from 72 sec to 77 sec. This is within the individual run variation. The subject's end potition (X, Y, and Z) varied by 0.4 ft in the worst case. His final attitude (ϕ, θ, and Ψ) varied by 7 deg in the worst case. His translational velocities (X, Y and Z) varied by 0.17 ft/sec. This same

Table XXIX IMLSS Summary of Data Averages - Configurations 1,2 and 3 - Tasks 1 and 2

TASK 1 — End conditions

Config.	Time Sec	Impulse (lb-sec) Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot.	Total	Time X Impulse	Position ft X	Y	Z	Velocity ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg ϕ_c	θ_c	ψ_c
1	74	10.1	2.4	1.7	14.3	3.2	1.6	2.3	7.2	21.5	1566	-3.3	-12.3	1.0	-.28	-.27	-.01	-.1	3.1	-67.6
2	70	12.2	1.4	2.0	15.1	3.6	.9	5.8	10.3	25.4	1766	-3.5	-12.3	.9	-.32	-.31	-.01	3.1	4.4	-67.4
3	70	12.1	3.3	2.7	18.1	4.0	1.3	6.4	11.8	29.8	2067	-3.5	-12.5	1.9	-.37	-.20	.00	3.9	3.4	-59.8

Config.	End conditions Body rates deg/sec P	Q	R	Maximum rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R	Average rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R
1	-.5	.3	-1.0	.26	.46	.06	1.5	1.0	5.1	-.02	-.37	.02	-.1	-.1	.3
2	-.6	.0	.4	.33	.50	.06	2.1	1.5	10.6	-.02	-.39	.04	-.2	.0	.3
3	-.5	.2	1.9	.32	.50	.09	1.9	.9	9.3	-.02	-.40	.03	-.1	.0	.5

TASK 2 — End conditions

Config.	Time Sec	Impulse (lb-sec) Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot.	Total	Time X Impulse	Position ft X	Y	Z	Velocity ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg ϕ_c	θ_c	ψ_c
1	84	8.1	8.9	1.4	18.4	5.6	4.6	3.5	13.6	32.0	2701	-2.2	-19.4	1.1	.00	.04	-.01	-2.7	-1.2	25.1
2	81	8.3	10.2	2.9	22.4	2.1	1.2	4.1	7.4	29.8	2469	-2.3	-19.1	1.1	-.02	.00	.00	1.4	- .12	25.8
3	86	11.1	10.5	2.3	23.9	3.8	.5	6.4	10.9	34.9	2652	-2.5	19.0	1.2	.00	.00	-.01	-.4	.8	26.6

Config.	End conditions Body rates deg/sec P	Q	R	Maximum rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R	Average rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R
1	-.2	.4	.9	.23	.35	.05	2.4	1.5	7.0	-.03	-.13	.01	-.2	-.1	1.8
2	.0	-.2	.0	.22	.40	.07	1.5	.7	8.0	-.03	-.10	.01	-.2	.0	2.0
3	-.5	-.2	-.2	.23	.42	.08	2.3	.9	13.0	-.04	-.20	.02	-.2	.0	2.0

Table XXX IMLSS Summary of Data Averages - Configurations 1,2,3 and 4 - Tasks 3 and 4

Config.	End conditions: Time sec	Impulse (lb-sec): Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot	Total	Time X Impulse	Position ft: X	Y	Z	Velocity ft/sec: $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg: ϕ_c	θ_c	ψ_c
Task 3: Workshop Excursion																				
1	9[illegible]	20.3	7.4	1.5	29.2	7.4	5.3	12.1	25.9	55.1	5417	-2.2	4.8	1.5	.04	.01	.02	-1.2	-3.0	23.9
2	108	18.1	6.3	1.8	26.2	5.0	5.0	12.0	22.0	48.3	5230	-2.1	5.0	1.6	.04	.00	.03	.5	1.1	16.2
3	94	21.5	4.3	2.1	27.9	7.5	10.6	10.5	28.6	56.5	5311	-2.4	4.8	1.1	.03	.04	.01	.7	-1.3	22.2
4	72	20.0	5.4	2.0	26.4	3.3	5.5	6.7	15.5	42.9	3090	-2.2	2.9	1.5	-.03	.05	.00	2.6	-1.2	20.2
Task 4: LM to CM Transfer																				
1	73	22.7	4.4	3.8	30.8	6.9	5.5	7.8	20.3	51.1	3757	-3.9	-21.6	3.8	.03	-.05	.02	5.0	5.4	-96.1
2	72	22.4	4.2	4.2	29.6	4.0	1.6	9.6	15.0	49.9	3322	-4.3	-21.5	3.8	.01	-.03	.05	5.2	2.7	-91.9
3	76	20.6	3.6	1.9	25.7	5.4	2.8	7.0	15.1	41.3	3157	-4.1	-21.3	3.7	.03	.00	.03	-.6	4.4	-92.7
4	77	18.8	4.8	2.2	26.0	5.2	2.2	4.3	11.7	37.7	2888	-4.1	-21.5	3.5	.00	-.03	.02	6.0	1.1	-91.4

Config.	End conditions: Body rates deg/sec P	Q	R	Maximum rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R	Average rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R
Task 3: Workshop Excursion															
1	.1	.6	-.8	.18	.57	.13	2.2	2.6	25.3	.00	.01	-.03	-.1	.0	1.2
2	.1	.0	-.3	.16	.52	.11	1.6	1.9	24.4	.00	.01	-.03	.0	.0	.8
3	-.2	.2	-.4	.16	.51	.13	3.0	3.1	20.6	.00	.01	-.04	-.1	.0	1.0
4	-.2	.3	-.9	.16	.56	.11	2.1	3.9	21.8	.00	.00	-.03	-.1	-.1	-.1
Task 4: LM to CM Transfer															
1	-.3	.0	-.5	.15	1.08	.22	3.5	2.5	16.8	-.03	-.47	.10	.2	.3	-2.3
2	-.5	.3	.4	.16	1.07	.24	2.7	1.6	17.3	-.03	-.47	.09	.2	.2	-2.4
3	-.7	.1	.3	.14	.95	.18	2.6	1.4	14.7	-.03	-.44	.08	.2	.1	-2.2
4	.0	.0	-.3	.14	.91	.17	3.2	2.8	16.9	-.03	-.50	.08	.2	.2	- .2

degree of variation of the data between configurations can be observed in the translational plots of Section V. The conclusion drawn from this data is that all the acceleration levels investigated were acceptable. This agrees with the test subject's opinion on acceptable acceleration bounds. He found all of the acceleration levels investigated acceptable, but he did prefer certain levels.

For most parameters the data for IMLSS configuration 4 is not significantly different from the other configuration data to conclude that the subject performed better using configuration 4. However, a trend can be seen in the total rotational impulse data. The rotational impulse used for tasks 3 and 4, flying configuration 4, is lower than that used for any other configuration. This trend would be more noticeable if tasks 3 and 4 contained more attitude maneuvering. It is interesting to note that in many of the parameters the variation of the averages between configurations is lower than the run to run maximum deviations.

Table XXXI summarizes this point for translational impulse, rotational impulse, flight time and the product of time and impulse. The table lists the maximum deviation for the five run series for each configuration. The averages of these maximum deviations is also indicated. The maximum deviations between the averages (for each configuration) of Tables XXIX and XXX are shown. For example, the data for task 4 shows the translational impulse has a 6.2 lb-sec average, run to run, maximum deviation. The maximum, configuration to configuration, deviation (from Table XXX) is 5.1 lb-sec. Thus the variation in data due to the IMLSS configuration changes is comparable to the run to run variations.

Table XXXII summarizes the impulse data for tasks 1, 2, 3 and 4 for configurations 1, 2 and 3. The total impulse required to perform the four tasks for each configuration is shown. Then this comparison is based on data from four tasks. The total flight times (sec) for configurations 1, 2, and 3 are 330, 331 and 316, respectively. The total impulses (lb-sec) for configurations 1, 2 and 3 are 159.7, 153.4 and 162.5, respectively. Again the variations between configurations are small.

The overall conclusion drawn from examining and reviewing the data is that the acceleration levels investigated are acceptable. Differences in performance data would appear if 1) larger acceleration level changes were introduced or 2) more restricted tasks were flown. The latter refers to the possibility of flying from instruments over longer periods of time. For example, the subject could fly a station keeping task for ten minutes from instruments.

Tables XXXIII and XXXIV summarize all of the data for task 3 and 4, respectively. The five run averages are the values listed. The

Table XXXI IMLSS Maximum Deviation (Δ) Comparison

Configuration	Impulse (lb-sec) Trans		Impulse (lb-sec) Rot		Time		Time X Impulse	
	Trans		Rot					
Task #1								
1	3.3		4.0		9.0		443	
2	2.5	Avg	3.7	Avg	12.0	Avg	278	Avg
3	3.6	3.1	12.1	6.6	15.0	9.0	1235	952
Summary Δ's	3.8		4.6		4.0		501	
Task #2								
1	3.5		5.5		15.0		801	
2	2.6	Avg	5.4	Avg	12.0		937	Avg
3	3.9	3.3	7.4	6.1	12.0	13.0	1045	1928
Summary Δ's	5.5		6.2		8.0		232	
Task #3								
1	3.7		7.2		16.0		907	
2	10.2		4.5		17.0		969	
3	8.4	Avg.	18.1	Avg	14.0	Avg	2095	Avg
4	2.2	6.1	11.8	10.4	11.0	14.5	1294	1318
Summary Δ's	3.2		13.1		36.0		2327	
Task #4								
1	5.8		12.0		21.0		2005	
2	9.0		5.2		22.0		1023	
3	5.3	Avg	10.4	Avg	5.0	Avg	908	Avg
4	4.6	6.2	8.4	9.0	16.0	16.0	1442	1345
Summary Δ's	5.1		8.6		5.0		869	

Table XXXII Impulse Comparison Summary For All Four Tasks

	Task No.	Time Sec	Impulse (lb-sec)								
			Translation			Total Trans	Rotational			Total Rot.	Total
			I_x	I_y	I_z		I_ϕ	I_θ	I_ψ		
Configuration 1	1	74	10.1	2.4	1.7	14.3	3.2	1.6	2.3	7.2	21.5
	2	84	8.1	8.9	1.4	18.4	5.6	4.6	3.5	13.6	32.0
	3	99	20.3	7.4	1.5	29.2	7.4	5.3	12.1	25.9	55.1
	4	73	22.7	4.4	3.8	30.8	6.9	5.5	7.8	20.3	51.1
	Total	330	61.2	23.1	8.4	92.7	23.1	17.0	25.7	67.0	159.1
Configuration 2	1	70	12.2	1.4	2.0	15.1	3.6	.9	5.8	10.3	25.4
	2	81	8.3	11.2	2.9	22.4	2.1	1.2	4.1	7.4	29.8
	3	108	18.1	6.3	1.8	26.2	5.0	5.0	12.0	22.0	48.3
	4	72	22.4	4.2	4.2	29.6	4.0	1.6	9.6	15.0	29.9
	Total	331	61.0	23.1	10.9	93.3	14.7	8.7	31.5	54.7	153.4
Configuration 3	1	70	12.1	3.3	2.7	18.1	4.0	1.3	6.4	11.8	29.8
	2	76	11.1	10.5	2.3	23.9	3.8	.5	6.4	10.9	34.9
	3	94	21.5	4.3	2.1	27.9	7.5	10.6	10.5	28.6	56.5
	4	76	20.6	3.6	1.9	25.7	5.4	2.8	7.0	15.1	41.3
	Total	316	65.3	21.7	9.0	95.0	20.7	15.2	30.3	66.4	162.5

Table XXXIII JMLSS Summary of Data Averages - Task 3

Config.	Time Sec	End conditions: Impulse (lb-sec): Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot	Total	Time X Impulse	Position ft: X	Y	Z	Velocity ft/sec: $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg: ϕ_c	θ_c	ψ_c
1	99	20.3	7.4	1.5	29.2	7.4	5.3	12.1	25.9	55.1	5417	-2.2	4.8	1.5	.04	.01	.02	4.2	-3.0	23.9
2	108	18.1	6.3	1.8	26.2	5.0	5.0	12.0	22.0	48.3	5230	-2.1	5.0	1.6	.04	.00	.03	.5	1.1	16.2
3	94	21.5	4.3	2.1	27.9	7.5	10.6	10.6	28.6	56.5	5311	-2.4	4.8	1.1	.03	.04	.01	.7	-1.3	22.2
Shift#1	98	22.8	4.9	2.5	30.3	14.2	9.7	24.2	48.1	78.4	7750	- .2	4.6	1.8	.00	.03	.00	.4	-1.6	21.1
Shift#2	111	18.3	4.9	2.2	25.4	17.0	30.3	12.6	59.9	85.2	9493	-2.1	4.7	1.0	-.01	.05	.00	1.9	.7	23.9
Inertia Change	98	22.1	6.7	2.9	32.6	15.8	13.4	19.6	48.9	80.8	7886	-2.3	4.8	1.3	.02	.02	.00	4.2	-2.5	20.3
4	72	20.0	5.4	2.6	26.4	3.3	5.5	6.7	15.5	42.9	3090	-2.2	2.9	1.5	-.03	.05	.00	2.6	-1.2	20.2

Config.	End conditions: Body rates deg/sec: P	Q	R	Maximum rates ft/sec: $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec: P	Q	R	Average rates ft/sec: $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec: P	Q	R
1	.1	.6	-.8	.18	.57	.13	7.2	2.6	25.3	.00	.01	-.03	-.1	.0	1.2
2	.1	.0	-.3	.16	.52	.11	1.6	1.9	24.4	.00	.01	-.03	.0	.0	.8
3	-.2	.2	-.4	.16	.51	.13	3.0	3.1	20.1	.00	.01	-.04	-.1	.0	1.0
Shift#1	-.1	.3	-.7	.16	.59	.14	3.7	2.8	21.4	.00	.00	.03	.1	.1	1.0
Shift#2	-.1	.8	.0	.13	.47	.12	4.1	4.0	23.8	.00	.00	-.04	-.1	.1	.9
Inertia Change	-.1	-.4	.2	.19	.64	.14	6.4	3.4	24.9	.00	.01	-.04	.0	.2	1.0
4	-.2	.3	-.9	.16	.56	.11	2.1	3.9	21.8	.00	.00	-.03	-.1	-.1	-.1

Table XXXIV IMLSS Summary of Data Averages - Task 4

Config.	Time Sec	Impulse (lb-sec) Translation I_x	I_y	I_z	Total Trans	Rotational I_ϕ	I_θ	I_ψ	Total Rot.	Total	Time X Impulse	Position ft X	Y	Z	Velocity ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	Attitude deg ϕ_c	θ_c	ψ_c
1	73	22.7	4.4	3.8	30.8	6.9	5.5	7.8	20.3	51.1	3757	-3.9	-21.6	3.8	.03	-.05	.02	5.0	5.4	-96.1
2	72	22.4	4.2	4.2	29.6	4.0	1.6	9.6	15.0	49.9	3322	-4.3	-21.5	3.8		-.03	.03	5.2	2.7	-91.9
3	76	20.6	3.6	1.9	25.7	5.4	2.8	7.0	15.1	41.3	3157	-4.1	-21.3	3.7	.03	.00	.03	-.6	4.4	-92.7
Shift#1	8[illegible]	[illegible]	4.6	2.6	26.3	13.8	6.5	18.2	38.5	64.8	5400	-4.5	-21.5	3.6	.00	-.05	.01	4.7	2.1	-90.5
Shift#2	88	19.8	4.1	2.5	26.4	15.8	29.4	7.8	52.9	78.6	6885	-4.2	-21.4	2.4	.03	-.02	.00	4.8	3.5	-90.9
Inertia Change	88	20.7	3.5	4.1	27.1	14.7	9.9	14.3	27.0	66.2	4912	-4.3	-21.4	2.4	.03	-.86	.02	1.8	2.9	-86.2
4	77	18.8	4.8	2.2	26.0	5.2	2.2	4.3	11.7	37.7	2888	-4.1	-21.5	3.5	.00	-.03	.02	6.0	1.1	-91.4

Config.	End conditions Body rates deg/sec P	Q	R	Maximum rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R	Average rates ft/sec $\dot{X}$	$\dot{Y}$	$\dot{Z}$	deg/sec P	Q	R
1	-.3	.0	-.5	.15	1.03	.22	3.5	2.5	16.8	-.03	-.47	.10	.2	.3	-2.3
2	-.5	.3	.4	.16	1.07	.24	2.7	1.6	17.3	-.03	-.47	.09	.2	.2	-2.4
3	-.7	-.1	.3	.14	.95	.18	2.6	1.4	14.7	-.03	-.44	.08	.2	.1	-2.2
Shift #1	.0	-.4	.6	.13	.93	.18	4.7	1.8	15.6	-.04	-.40	.08	.2	.2	-2.0
Shift #2	0.1	-.4	.3	.15	.90	.16	4.0	4.8	17.0	-.03	-.38	.06	.2	.2	-2.2
Inertia Change	-.2	.0	.6	.17	.97	.22	5.1	3.0	14.8	-.03	-.38	.07	.2	.1	-2.0
4	.0	.0	-.3	.14	.91	.17	3.2	2.8	16.9	-0.3	-.50	.08	.2	.2	-.2

data includes the runs where c.g. shifts and inertia cross-product changes (perturbations) were investigated. The main objective of this summary is for comparison of the IMLSS performance with and without perturbation effects. A comparison of the position and velocity end conditions shows that the subject controlled his final conditions as well with the perturbations as without. In order to do this, the subject had to concentrate more on his flying during the runs with the perturbations in. The flight time for task 4 went up when the perturbations were introduced. A trend in the flight time for task 3 cannot be drawn because of the overall variations. The increases in impulses that would be expected due to perturbations can be observed. The lateral c.g. shift (#1) introduces couplings of longitudinal control to yaw control and vertical control to roll control. The data shows an increase in both yaw and roll impulses to perform tasks 3 and 4 for c.g. shift #1. A vertical c.g. shift(#2) introduces couplings of longitudinal control to pitch control and lateral control to yaw control. The data shows an increase in both pitch and roll impulses to perform tasks 3 and 4 for c.g. shift #2. A rotational coupling between roll and yaw is introduced by the inertia cross-product change. In the data summary it can be seen that all three rotational impulses increased for both tasks 3 and 4. Apparently, the subject taxed his pitch control more because of the difficulty in controlling roll and yaw. The subject felt that flying with the inertia cross-product perturbation was considerably more difficult than with the c.g. shift perturbation.

APPENDIX I

MODEL MAN

The following equations express the segment masses, moments of inertia, centers of gravity and pivot points for the nine segment model man as a function of the man's weight.

1. SEGMENT MASSES (SLUGS)

$$m_1 = K_m \ (0.47W + 12.0) \tag{28}$$

$$m_2 = m_3 = K_m \ (0.04W - 1.45) \tag{29}$$

$$m_4 = m_5 = K_m \ (0.025W + 0.1) \tag{30}$$

$$m_6 = m_7 = K_m \ (0.09W + 1.6) \tag{31}$$

$$m_8 = m_9 = K_m \ (0.065W - 0.2) \tag{32}$$

where W is the man's weight in pounds and K_m is given by

$$K_m = \frac{W}{29.3W + 389} \tag{33}$$

2. SEGMENT MASS CENTERS AND PIVOT POINTS (FT)

With reference to Figure 57, the segment mass and pivot point dimensions are

$$S_1 = 0.00196W + 0.388 \tag{34}$$

$$S_2 = 0.00135W + 0.916 \tag{35}$$

$$S_3 = 0.000422W + 0.208 \tag{36}$$

$$L_1 = 0.0038W + 2.117 \tag{37}$$

$$L_2 = L_3 = 0.00132W + 0.768 \tag{38}$$

$$L_6 = L_7 = 0.000729W + 1.324 \quad (39)$$

$$\ell_1 = 0.00145W + 1.55 \quad (40)$$

$$\ell_2 = \ell_3 = 0.000145W + 0.355 \quad (41)$$

$$\ell_4 = \ell_5 = 0.000658W + 0.456 \quad (42)$$

$$\ell_6 = \ell_7 = -0.0004W + 0.828 \quad (43)$$

$$\ell_8 = \ell_9 = 0.00106W + 0.597 \quad (44)$$

3. SEGMENT INERTIAS, SLUG-FEET^2

$$_1I_{1xx} = 0.0146W - 0.576 \quad (45)$$

$$_1I_{1yy} = 0.0137W - 0.536 \quad (46)$$

$$_1I_{1zz} = 0.00331W - 0.243 \quad (47)$$

$$_2I_{2xx} = {_2I_{2yy}} = {_3I_{3xx}} = {_3I_{3yy}} = 0.00022W - 0.0127 \quad (48)$$

$$_2I_{2zz} = {_3I_{3zz}} = 0.0000268W - 0.00243 \quad (49)$$

$$_4I_{4xx} = {_4I_{4yy}} = {_5I_{5xx}} = {_5I_{5yy}} = 0.000159W - 0.00781 \quad (50)$$

$$_4I_{4zz} = {_5I_{5zz}} = 0.0000112W - 0.000768 \quad (51)$$

$$_6I_{6xx} = {_6I_{6yy}} = {_7I_{7yy}} = 0.000656W - 0.0373 \quad (52)$$

$$_6I_{6zz} = {_7I_{7zz}} = 0.00019W - 0.0142 \quad (53)$$

$$_8I_{8xx} = {_9I_{9xx}} = 0.000892W - 0.0544 \quad (54)$$

$$_8I_{8yy} = {_9I_{9yy}} = 0.000859W - 0.0534 \quad (55)$$

$$_8I_{8zz} = {_9I_{9zz}} = 0.0000797W - 0.00463 \quad (56)$$

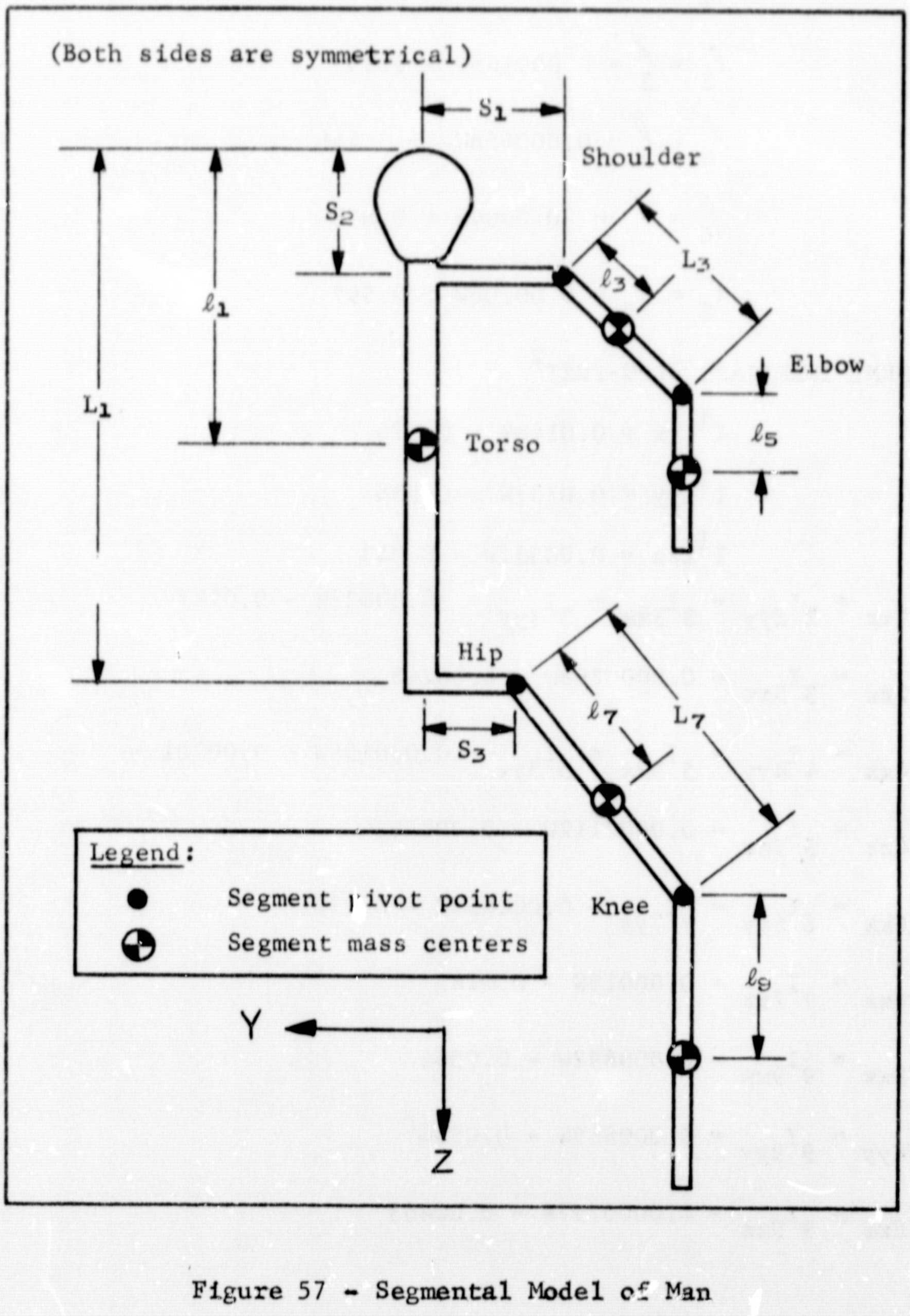


Figure 57 - Segmental Model of Man

APPENDIX II

NON-DIAGONAL INERTIA

DYADIC

The following equations express the rotation of the principal axis due to a non-diagonal inertia dyadic term (I_{xz}).

1. TRANSFORMATION

With reference to Figure 58 consider the transformation from the unprimed system to the primed system by an angle A.

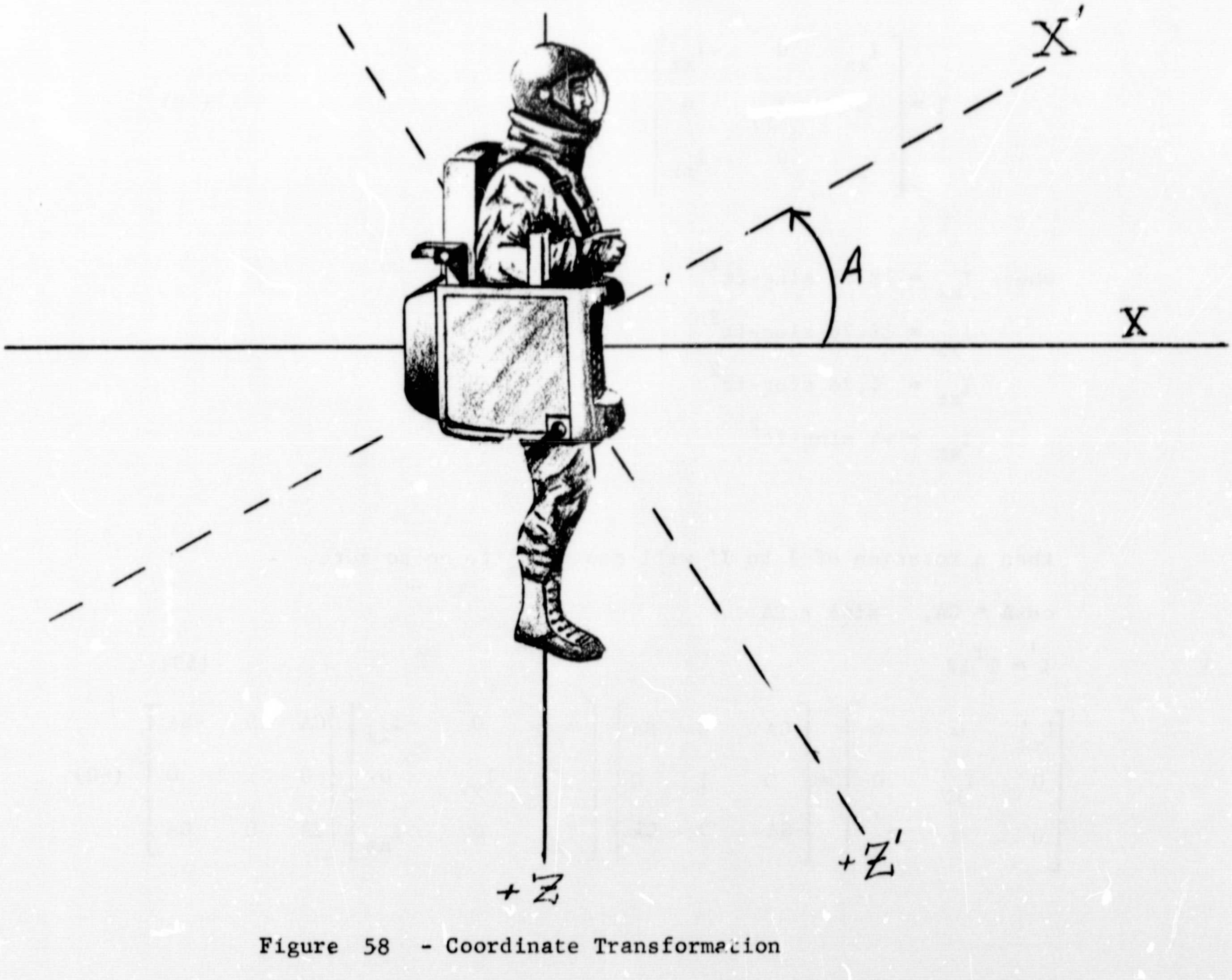


Figure 58 - Coordinate Transformation

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} \cos A & 0 & -\sin A \\ 0 & 1 & 0 \\ \sin A & 0 & \cos A \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \qquad (57)$$

2. CALCULATIONS

Then when operating on the inertia dyadic in the unprimed system, the orthogonal transformation (T) produces the primed inertia dyadic.

$$I = \begin{bmatrix} I_{xx} & 0 & -I_{xz} \\ 0 & I_{yy} & 0 \\ -I_{zx} & 0 & I_{zz} \end{bmatrix} \qquad (58)$$

where $I_{xx} = 18.76$ slug-ft^2

$I_{yy} = 18.76$ slug-ft^2

$I_{zz} = 4.78$ slug-ft^2

$I_{xz} = -4$ slug-ft^2

then a rotation of I to I' will cause I_{xz}' to go to zero.

$\cos A = CA, \quad \sin A = SA$

$$I' = T^T I T \qquad (59)$$

$$\begin{bmatrix} I_{xx}' & 0 & 0 \\ 0 & I_{yy}' & 0 \\ 0 & 0 & I_{zz}' \end{bmatrix} = \begin{bmatrix} CA & 0 & SA \\ 0 & 1 & 0 \\ -SA & 0 & CA \end{bmatrix} \begin{bmatrix} I_{xx} & 0 & -I_{xz} \\ 0 & I_{yy} & 0 \\ -I_{zx} & 0 & I_{zz} \end{bmatrix} \begin{bmatrix} CA & 0 & -SA \\ 0 & 1 & 0 \\ SA & 0 & CA \end{bmatrix} \qquad (60)$$

multiplication produces

$$I' = \begin{bmatrix} I_{xx}CA - I_{xz}SA, & 0 & , & -I_{xz}CA + I_{zz}SA \\ 0 & , I_{yy} & , & 0 \\ -I_{xx}SA + I_{xz}CA, & 0 & , & I_{xz}SA + I_{zz}CA \end{bmatrix} \begin{bmatrix} CA & 0 & -SA \\ 0 & 1 & 0 \\ SA & 0 & CA \end{bmatrix} \quad (61)$$

$$\begin{bmatrix} I'_{xx} & 0 & 0 \\ 0 & I'_{yy} & 0 \\ 0 & 0 & I'_{zz} \end{bmatrix} = \begin{bmatrix} I_{xx}C^2A - 2I_{xz}SACA + I_{zz}S^2A, & 0 , & I_{xz}(S^2A - C^2A) + (I_{zz} - I_{xx})SACA \\ 0 & I_{yy}, & 0 \\ I_{xz}(S^2A - C^2A) + (I_{zz} - I_{xx})SACA, & 0 , & I_{xx}S^2A + 2I_{xz}SACA + I_{zz}C^2A \end{bmatrix} \quad (62)$$

then

$$I'_{xz} = 0 = I_{xz}(S^2A - C^2A) + (I_{zz} - I_{xx})SACA \quad (63)$$

and

$$\left[SA - \left(\frac{-K \pm (K^2 + 4)^{\frac{1}{2}}}{2} \right) CA \right] \left[SA + \left(\frac{2}{-K \pm (K^2 + 4)^{\frac{1}{2}}} \right) CA \right] = 0 \quad (64)$$

where, $K = \dfrac{I_{zz} - I_{xx}}{I_{xz}}$

$$SA = -\frac{K \pm (K^2 + 4)^{\frac{1}{2}}}{2} CA$$

or,

$$SA = -\frac{2}{-K \pm (K^2 + 4)^{\frac{1}{2}}} CA$$

then,

$$\tan A = \frac{-K \pm (K^2 + 4)^{\frac{1}{2}}}{2} \quad \text{or} \quad \frac{-2}{(-K \pm (K^2 + 4)^{\frac{1}{2}})}$$

$K = 3.50$

$\tan A = .27$ or -3.77

$A \approx 15^{o}$ or $\approx 75^{o}$ (Compliment of A)

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