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NASA
Technical
Paper
3140

November 1991

The Microgravity Environment of the Space Shuttle Columbia Middeck During STS-32

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CONTENTS

TABLES

FIGURES

ABSTRACT

Four hours of three-axis microgravity accelerometer data were successfully measured at the MA9F locker location in the Orbiter middeck of Columbia as part of the Microgravity Disturbances Experiment (MDE) on STS-32. The data were measured using the Honeywell In-Space Accelerometer (HISA), a small three-axis accelerometer that was hard-mounted onto the Fluids Experiment Apparatus (FEA), to record the microgravity environment at the exact location of the MDE. Data were recorded during specific mission events such as Orbiter quiescent periods, crew exercise on the treadmill, and numerous Orbiter engine burns. Orbiter background levels were measured to be in the 3×10^{-5} to 2×10^{-4}g range, treadmill operations in the 6×10^{-4} to 5×10^{-3}g range, and Orbiter engine burns from 4×10^{-3} to in excess of 1.0×10^{-2}g. These data represent some of the first microgravity accelerometer data ever recorded in the middeck area of the Orbiter.

INTRODUCTION

It is well known among microgravity scientists that the magnitude of residual acceleration aboard an orbiting spacecraft is a critical parameter in conducting materials processing experiments in the reduced gravity environment of space.[1,2,3,4] The terms *weightlessness* and *zero-gravity* are frequently used to describe the space environment but are misnomers and are technically incorrect. Although many orders of magnitude lower than the gravity level experienced on Earth (1-g), the gravity level aboard a spacecraft in low Earth orbit is more accurately described as *microgravity* or *micro-g*, which is technically one millionth the gravity level of Earth (10^{-6}g) and more widely used to describe the extremely low residual gravity levels experienced aboard an orbiting spacecraft.

In spite of its recognition as a critical parameter in processing materials in space, very little information on gravity level has been made available to microgravity scientists conducting experiments aboard the Space Shuttle. While previous shuttle missions have collected accelerometer data elsewhere in the Orbiter[5,6] (mainly near the Orbiter center of gravity in the aft payload bay), three-axis microgravity accelerometer data have not been available for the Orbiter middeck area where many microgravity experiments are performed during typical shuttle missions.

This report provides the first data characterizing the microgravity level of the Orbiter middeck as measured during the STS-32 mission of Space Shuttle Columbia in January 1990. While these data were taken at a single location within the middeck and may not be representative of microgravity levels elsewhere in the middeck area, it nonetheless represents the first such data collected in this part of the Orbiter. (The HISA was first flown as part of the 3M Polymer Morphology Experiment in the middeck of Discovery on STS-34 in October, 1989; but hardware anomalies limited the amount of useful three-axis accelerometer data collected.)

The data presented were collected as part of the Microgravity Disturbances Experiment (MDE), a middeck experiment designed to investigate the effects of crew and Orbiter induced disturbances in the microgravity environment on the growth of single crystals of metallic indium using the Rockwell Fluids Experiment Apparatus (FEA). Figure 1 shows one of the authors performing the experiment during the STS-32 mission. To quantify the microgravity environment of the growing crystals, a small three-axis accelerometer called the Honeywell In-Space Accelerometer (HISA) was hard-mounted onto the FEA to record data directly at the site of the experiment.

This was an ideal mission on which to have a middeck accelerometer. Besides being the longest shuttle mission yet flown, it also provided detailed and frequent exercise protocols on the treadmill to support long duration life science experiments and numerous engine burns that resulted from the SYNCOM satellite deploy and Long Duration Exposure Facility (LDEF) retrieval. These mission events provided a unique opportunity for valuable data to be collected that would characterize one location of the Orbiter middeck during these known disturbances.

Additional accelerometer data were collected at a second location within the Orbiter (below the aft payload bay) using the High Resolution Accelerometer Package (HIRAP) and the Aerodynamic Coefficient Identification Package (ACIP). These two accelerometer data sets, recorded simultaneously but at widely different locations within the Orbiter (see figure 2), will permit studies to be performed on how disturbances are transmitted through the Orbiter structure and will be a starting point for mapping out the microgravity environment throughout the Orbiter. The results of these studies will be reported as data analyses progress.

This report summarizes the 4 hours of middeck accelerometer data recorded with the HISA. A second report will be issued providing more detailed analyses of this data such as shock spectrum and power spectral density analyses.

HARDWARE DESCRIPTION

The middeck accelerometer used in this experiment was the HISA shown in figure 3. This small three-axis microgravity accelerometer was developed by Honeywell Incorporated to monitor oscillatory and transient accelerations onboard spacecraft and was designed to be located with materials processing equipment flown on the Orbiter. Its small size (8" × 4" × 2"), low weight (4 pounds), and low power requirements (5.6 watts of Orbiter power @ 28 volts) make it a versatile unit ideal for many applications in the Orbiter middeck. Other specifications for the HISA are listed in table 1.

The HISA data were recorded on 3-1/2" floppy disks using an MDE dedicated Payload General Support Computer (PGSC). (The PGSC used to record the HISA accelerometer data has a hard disk capable of recording 20 megabytes of data. Current National Space Transportation System policy prohibits the use of the hard disk for experiment data recording. All data must be recorded on 1.4 megabyte floppy disks or separate data recorders, which take up additional space and payload weight, both critical resources on the Space Shuttle.) A total of eight disks were flown to support MDE, with each 1.2

Table 1. Honeywell In-Space Accelerometer Specifications

PARAMETER	PERFORMANCE
ORIENTATION	Three-axis orthogonal
RANGE	10^{-6} to 10^{-2}g at 1 Hz 10^{-5} to 10^{-2}g at 50 Hz
ACCURACY	$\pm$(1% |reading| + 0.00002)g
RESOLUTION	1.0×10^{-6}g at 1 Hz 8.7×10^{-6}g at 50 Hz
FREQUENCY RESPONSE ($\pm$5%)	0.025 to 19.500 Hz
DC BIAS	None (ac output)
SAMPLE DATA RATE	50 Hz, 1 Hz
COMMUNICATIONS	RS-422/ASCI II format

megabyte disk capable of recording 40 minutes of 1 Hz and 50 Hz accelerometer data. As data recording capability was limited due to the number of floppies available, only specific mission events were targeted for data recording. The recorded data generally involved 2-minute segments centered around Orbiter engine burns, or 30- to 40-minute segments focusing on crew exercise periods on the treadmill, or Orbiter background accelerations.

The HISA was stowed in a middeck locker for ascent and descent and was attached to the FEA by the crew during orbital operations as shown in figure 4. The FEA was mounted in locker location MA9F in the aft middeck as shown in figure 5, at Orbiter coordinates $x_0 = 514"$, $y_0 = 70"$, $z_0 = 384"$.

DETAILS OF HISA OPERATION

The sensing of acceleration is accomplished using a set of three Sunstrand Qflex QA-2000 pendulous mass, force-balanced accelerometers oriented in coordinates X, Y, and Z. The operating principle of each sensor is based on the movement of a proof mass due to external disturbance forces. The position of the proof mass is sensed by a servo amplifier as a change in capacitance and output as current proportional to the acceleration. The current output is also used in a closed-loop manner to rebalance the proof mass to its neutral position.

The electrical design of the HISA consists of three individual microgravity data acquisition system (DAS) circuits interfaced with each of the accelerometers, a measurement and control computer, and an RS-422 computer interface. The microgravity DAS circuit was created to detect large transient and oscillatory acceleration events. The key features of the DAS circuit design include (1) the elimination of the accelerometer bias to maximize accelerometer dynamic response, (2) a high amplifier gain of 695 volts/g to achieve resolution less than 1 micro-g, and (3) conversion of accelerometer data from raw acceleration to delta velocity impulses to enhance interpretation of the accelerometer data. The elimination of DC bias allowed the HISA to operate at a high gain without overloading to achieve the 1 micro-g resolution.

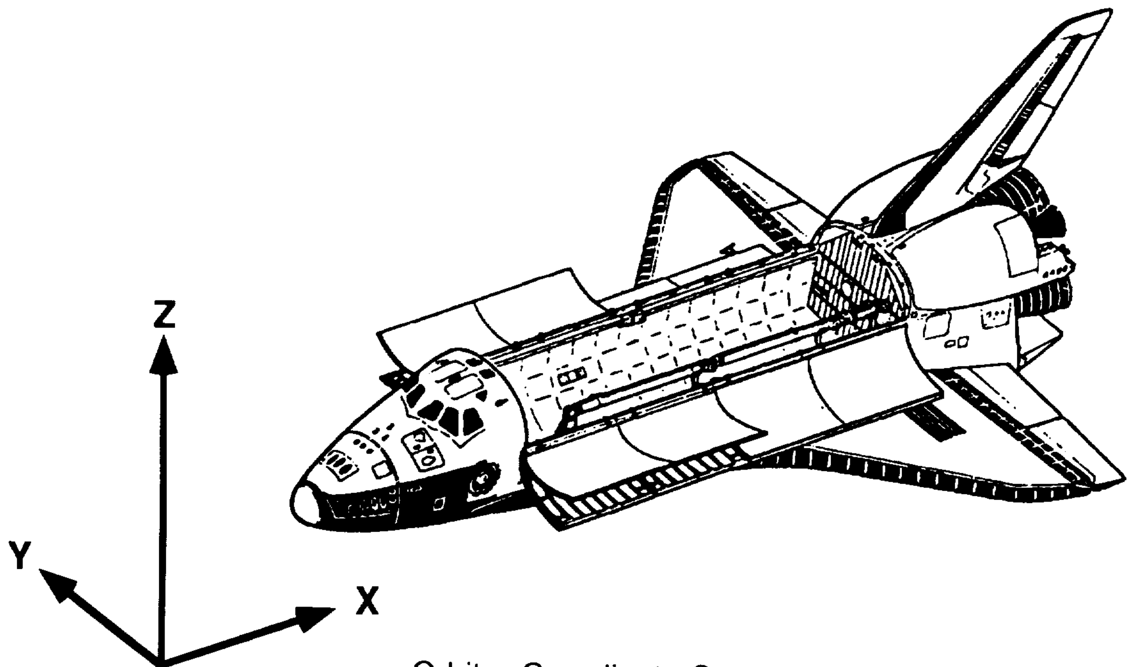
The accelerometer interface electronics block receives an accelerometer input signal A(t) from the accelerometer sensor whose output voltage is proportional to sensed acceleration in one axis of motion (X, Y, or Z). This signal is fed to the DC bias attenuator and anti-alias filter block. This block contains a single-pole (-3db corner frequency of 19.5 Hz) low-pass filter amplifier with gain KA which is served by a loop integrator A1. The output of the loop integrator is subtracted from the accelerometer input signal A(t) to cancel any accelerometer DC biased voltage. The integrator A1 is set up with a long time constant of 40 seconds to integrate the accelerometer DC bias voltage passed by the low-pass filter, not any transient acceleration voltage information. The DB bias attenuator block is cascaded with a second-order shunt filter block to create a three-pole characteristic with a rolloff attenuation factor of 18 db/octave to remove any potential alias frequencies that may exist in the accelerometer data. The high gain of 695 volts/g is achieved by selecting an appropriate scaling resistor which converts the accelerometer output current to an equivalent voltage.

Further technical details on the operation of the HISA can be found in reference 7.

The accelerometer data as recorded by the HISA does not represent instantaneous measurements of acceleration at a given point in time. Instead, the recorded data are averages of acceleration impulses between two 50 Hz sample periods. Furthermore, the HISA records data in pairs (positive axis value and negative axis value) because there are two A/D converters for each axis of acceleration. One converter averages positive axis data and the other negative axis data. As a result, there are two data plots on the same timeline with one curve representing positive axis data and the other negative axis data (see appendix A, plot 8, for example).

REVIEW OF ACCELEROMETER DATA

All accelerometer data presented in this report are reported in terms of the Orbiter body axis coordinate system shown on page 5.



Orbiter Coordinate System

HISA middeck accelerometer data were recorded during the following STS-32 mission events.

- Orbiter quiescent periods
- Crew exercise activity on treadmill
  - Commander
  - Pilot
  - Mission Specialist #3
- Orbiter engine burns
  - Vernier Reaction Control System (VRCS)
  - Primary Reaction Control System (PRCS)
  - Orbiter Maneuvering System (OMS)

Summary data plots characterizing the three-axis accelerometer levels for each of the above listed events are given in appendix A (plots 1 through 29). The accelerometer data is further summarized in table 2, which provides a quick reference of the typical acceleration levels recorded for each of the above mission events. As there is large scatter in the peak accelerations (see the time-history plots in appendix A), only typical or average peak acceleration levels are reported here. A more detailed analysis of the data focusing on peak accelerations and averages at various frequencies is in progress.

ORBITER BACKGROUND LEVELS

Plots 1 through 4 of appendix A illustrate the background microgravity levels recorded in the Orbiter middeck during normal shuttle operations on STS-32. The background levels

Table 2. Summary of Middeck Accelerations
(all data reported in units of 1g, normal Earth gravity)

	X-axis	Y-axis	Z-axis
Orbiter Background			
Quiescent Period	3.0×10^{-5}	2.5×10^{-5}	4.5×10^{-5}
Normal Operations	2.1×10^{-4}	2.0×10^{-4}	2.4×10^{-4}
Treadmill Operations			
Walking			
Commander	5.0×10^{-4}	7.0×10^{-4}	1.2×10^{-3}
Pilot (5.5 mph)	9.0×10^{-4}	8.5×10^{-4}	1.8×10^{-3}
Pilot (2.5 mph)	7.0×10^{-4}	5.0×10^{-4}	8.8×10^{-4}
Pilot (1.5 mph)	1.8×10^{-4}	1.4×10^{-4}	1.5×10^{-4}
Mission Specialist #3	6.0×10^{-4}	5.0×10^{-4}	1.2×10^{-3}
Running			
Commander	6.5×10^{-4}	8.5×10^{-4}	3.0×10^{-3}
Pilot	1.3×10^{-3}	1.3×10^{-3}	4.0×10^{-3}
Mission Specialist #3	2.5×10^{-3}	1.8×10^{-3}	5.0×10^{-3}
Orbiter Engine Burns			
VRCS	(3.0×10^{-4} to 7.5×10^{-4} along axis of engine fired; near background levels along other axes)		
PRCS			
NCC	5.0×10^{-3}	4.0×10^{-3}	7.5×10^{-3}
TI	1.0×10^{-2}*	6.0×10^{-3}	1.0×10^{-2}*
MC3	9.0×10^{-3}	8.0×10^{-3}	9.0×10^{-3}
MC4	8.0×10^{-3}	1.0×10^{-2}	1.0×10^{-2}*
OMS			
NH1	1.0×10^{-2}*	1.0×10^{-2}*	1.0×10^{-2}*
NSR	1.0×10^{-2}*	1.0×10^{-2}*	1.0×10^{-2}*
Miscellaneous Events	(up to 6×10^{-3} depending on event)		

* 1.0×10^{-2}g represents the upper limit detection capability of the HISA. Many of the Orbiter engine burns produced accelerations greater than this level, but the HISA was not able to determine the upper limit accelerations for these events.

were typically in the 2.0×10^{-4} to 2.5×10^{-4}g range along each axis as shown in plots 1 and 2. During two special time periods of relative quiescence, lasting roughly 1 and 5 minutes each, the background level dropped suddenly by a factor of 4-5 to the 2.5×10^{-5} to 4.5×10^{-5}g range as shown in plots 3 and 4. This sudden drop in acceleration appeared to be related to the turning off of some Orbiter equipment or system that is unidentified at this time and still under investigation. A clue to identifying the source of these additional background accelerations may be that they are found to modulate the basic background signal at a frequency of approximately 1.1 Hz.

Further examination of the frequency content indicates that 17 Hz is the dominant frequency of the Orbiter background acceleration levels (see plots 2 and 4). Previous studies[8] have identified the source of this 17 Hz vibration of the Orbiter to be dither in the Ku band antenna.

In general, the Orbiter Z-axis had the highest background acceleration levels--roughly 40 percent greater than levels along the X and Y axes. The Y-axis had slightly (10 to 20 percent) lower background acceleration levels than the X-axis.

CREW TREADMILL ACTIVITY

Plots 5 through 13 of appendix A illustrate in varying degrees of detail the microgravity levels induced at the FEA during crew activity on the exercise treadmill. As shown in figure 6, the treadmill was mounted to the floor of the Orbiter middeck in front of the airlock, a position roughly 7 feet from the HISA. Accelerometer data were collected on all three crewmembers (commander, pilot, and mission specialist #3) who performed treadmill exercise on STS-32.

Crewmembers are held in place on the treadmill with the harness and elastic cord arrangement shown in figure 6 that provides the necessary restraint to permit running under reduced gravity conditions.

While similar in appearance, each crewmember had a different and distinct induced acceleration pattern for both walking and running which can be seen by comparing plots 5 through 7. Plot 8 compares the characteristic Z-axis pattern of each crewmember running and is expanded in greater detail. By far the greatest induced accelerations for all crewmembers in all cases are along the Orbiter Z-axis, which is perpendicular to the plane of the treadmill. Induced accelerations along the X and Y axes are roughly 2 to 4 times lower in magnitude than along the Z-axis.

From the frequency content of this data, it is also possible to determine the pace of activity on the treadmill. All three crewmembers had similar natural paces of approximately 1 step/second when walking and 2.5 steps/second when running.

Because of the unique exercise protocol of the pilot, it was possible to compare the induced disturbances at walking speeds of 5.5, 2.5, and 1.5 mph which are shown in plot 9. (Walking speeds are estimated based on heart rate and preflight training.) The HISA easily distinguished the different acceleration levels induced at these three walking speeds, which were found to have typical Z-axis components of 1.8×10^{-3}, 8.8×10^{-4}, and 1.5×10^{-4}g, respectively.

(NOTE: Because of the wide range in the acceleration levels measured during treadmill operations, only estimated average acceleration levels representative of most of the data collected are reported here. Maximum and minimum acceleration levels recorded during these events can be obtained by further examination of the data plots presented in appendix A. Detailed stochastic analyses, including frequency spectrum analysis, will follow in future studies.)

Plot 10 was recorded during initial preparation and startup of treadmill activity as the commander was preparing for his exercise protocol. Short duration peaks of 6×10^{-3} to 8×10^{-3}g were recorded during this period. This initial warmup period of walking, which starts the commander's exercise protocol, begins at approximately the 46 seconds mark on the X, Y, and Z axes plots.

Plots 11 and 12 illustrate the induced accelerations when transitioning from walking-to-running and from running-to-walking, respectively. Plot 13 shows these transition events along the Z-axis in expanded detail. The transitions are fairly rapid and occur over a time scale generally less than 1 second.

ORBITER ENGINE BURNS

During the STS-32 mission, the acceleration levels induced in the middeck from at least 12 Orbiter engine burns were successfully recorded with the HISA. The six VRCS engine burns, four PRCS burns, and two OMS burns are listed in table 3 along with their resulting changes in Orbiter velocity v_x, v_y, and v_z. Further details of the OMS and RCS engine systems along with a description of the burns listed in table 3 are provided in appendix B.

Vernier RCS

Plots 14 and 15 illustrate the induced accelerations resulting from single-axis vernier jet firings which produce approximately 25 pounds of thrust. Both of these burns occurred during the LDEF rendezvous sequence when the Orbiter was in its lightest configuration (post-SYNCOM deploy, pre-LDEF retrieval). The resulting induced accelerations are principally along the single axis of the burn, with the other axes relatively unaffected. Both of these burns represent about a 2-second engine firing which produced approximately a 7.5×10^{-4}g acceleration for the duration of the burn. Very few transients appear to be associated with these burns. The induced accelerations dropped rapidly at the conclusion of each burn.

Table 3. STS-32 Orbiter Engine Burn Parameters

Burn type	Change in velocity (feet per second)		
	ΔV_x	ΔV_y	ΔV_z
<u>VRCS</u>	(typically less than 0.01)		
<u>PRCS</u>			
NCC	0.6	-0.3	0.8
TI	-0.2	0.1	-3.4
MC3	-0.2	0.0	1.2
MC4	-0.1	0.1	0.3
<u>OMS</u>			
NH1	-7.2	0.1	0.0
NSR	9.4	-0.1	0.0

Plots 16 and 17 illustrate the induced accelerations resulting from multi-axis vernier burns. Plot 16 represents a 5- to 6-second burn and plot 17 a 1-second burn which yielded middeck accelerations in the 3×10^{-4}g range along two Orbiter axes (Y and Z). As with the single-axis burns discussed previously, very few transients appear to be associated with these burns.

One effect that is observed, but is as yet unexplainable, is a slight change in the frequency content in the background level at the conclusion of each burn. This is most clearly demonstrated in plot 17. The reason for this change is still under investigation.

Primary RCS

Plots 18 through 22 are of the induced accelerations in the Orbiter middeck resulting from the firing of PRCS engines, which produce approximately 870 pounds of thrust. All four of the burns were associated with the LDEF rendezvous sequence and occurred on mission day 4. Plot 18 represents a relatively simple single-pulse PRCS firing during the NCC burn and illustrates the short duration of these burns and the resulting "ringing" and transient exponential decay in acceleration experienced in the Orbiter structure. Following the burn, there is about a 15-second decay time until the accelerations approach background levels once again. Plot 19 shows this same NCC burn in expanded detail. The 3.5 Hz frequency observed in these plots is one of the primary modes of vibration for the Orbiter structure (first torsional mode) which is evidently excited during the PRCS firings. The resulting maximum induced accelerations along the X, Y, and Z axes were 5×10^{-3}, 4×10^{-3}, and 8×10^{-3}g, respectively, for the NCC burn.

Plot 20 illustrates the complexities associated with multiple engine firings during the TI burn. This was the largest magnitude PRCS burn for which accelerometer data were recorded (Δv_z = -3.4 fps) and clearly demonstrates the long duration (almost 2 minutes) and complexity of this Orbiter engine burn maneuver. Individual engine pulse firings can be seen in the data, and many of the induced accelerations are greater than the 10^{-2}g upper limit detection capability of the HISA (see the X and Z axes).

Plots 21 and 22 are of the MC3 and MC4 PRCS burns which were the final PRCS burns of the LDEF rendezvous sequence. Once again, the complexities of multiple firings are evident along with the transient exponential decay at the conclusion of each firing. On numerous occasions during these two burns, the induced accelerations exceeded the 10^{-2}g upper limit of the HISA.

OMS

Some rather complex acceleration patterns were recorded during the NH1 and NSR OMS engine burns shown in plots 23 and 24 which were part of the LDEF rendezvous sequence. OMS burns are typically a few seconds in duration and are constant thrust (each OMS engine produces approximately 6,000 pounds of thrust). From these characteristics, a "square wave" type acceleration pattern might be expected as the engine is ignited, burns at constant thrust for a fixed duration (up to a few seconds producing a DC acceleration condition), then abruptly cuts off. This is indeed the acceleration pattern that has been recorded by the HIRAP and ACIP accelerometers located near the Orbiter center of gravity[9] (and relatively close to the OMS engines).

The initial acceleration response recorded by the HISA in the middeck is also a "square wave" function, which is modulated into an exponential decay by the electronics of the HISA as it attempts to eliminate the DC component of acceleration. (Remember, the HISA is designed to measure oscillatory and transient accelerations only, not DC conditions.) This is best illustrated between 5 and 15 seconds on the Y-axis data presented in plot 24.

By the time the OMS engines are shut down, the induced acceleration levels measured during these DC conditions have been reduced substantially as the accelerometer readjusts its zero-point to eliminate the DC component. As a result of this new zero-point at the conclusion of the OMS firing, the sudden change in acceleration (going from the engine burn acceleration level to zero as the burn is concluded) registers as an acceleration of opposite polarity from the original signal. As before, this signal exponentially decays to zero as the accelerometer signal processing eliminates the DC component.

The magnitude of the OMS burns along the X and Z axes was generally greater than the 10^{-2}g upper limit capability of the HISA.

MISCELLANEOUS AND UNIDENTIFIED EVENTS

Plots 25 through 27 are acceleration patterns that were recorded during events or activities not yet identified. These events are probably related to either crew activity (push-off, closing of locker door, etc.) or the operation of Orbiter equipment or systems (fans or pump operations). The sharp peaks of some of these events are in the 6×10^{-3}g range.

Plot 28 is another example of a "modulation frequency" phenomenon that results from a low frequency pattern modulating the higher frequency background levels. The low frequency component observed here is approximately 1.1 Hz and may be related to the pace of walking on the treadmill. The higher frequency component is approximately 17 Hz, which is probably related to the Orbiter Ku band antenna dither mentioned previously.

Plot 29 is an example of a "beat frequency" phenomenon. This results when two individual frequencies interfere constructively and destructively and produce the observed modulated pattern of maximums and minimums in the induced accelerations.

CONCLUSIONS

Four hours of three-axis microgravity accelerometer data were successfully measured at the MA9F locker location in the Orbiter middeck as part of the MDE on STS-32. Orbiter background levels were measured to be in the 3×10^{-5} to 2×10^{-4}g range, treadmill operations typically in the 6.5×10^{-4} to 5×10^{-3}g range, and Orbiter engine burns from 4×10^{-3}g to in excess of 1.0×10^{-2}g (the upper limit capability of the HISA). Further analysis of the data is in progress and will be reported at a future date.

FUTURE DIRECTIONS

As mentioned previously, three-axis accelerometer data were measured simultaneously with the HISA using the HIRAP and the ACIP which are located on the Orbiter keel in the aft payload bay (near the Orbiter center of gravity). An additional report[9] is being prepared that summarizes the microgravity at this location in the Orbiter payload bay. Further reports will be issued that will compare the accelerometer measurements made from these widely separated Orbiter locations to investigate how disturbances are transmitted through the Orbiter structure; this is a necessary starting point in mapping out the microgravity environment throughout the Orbiter.

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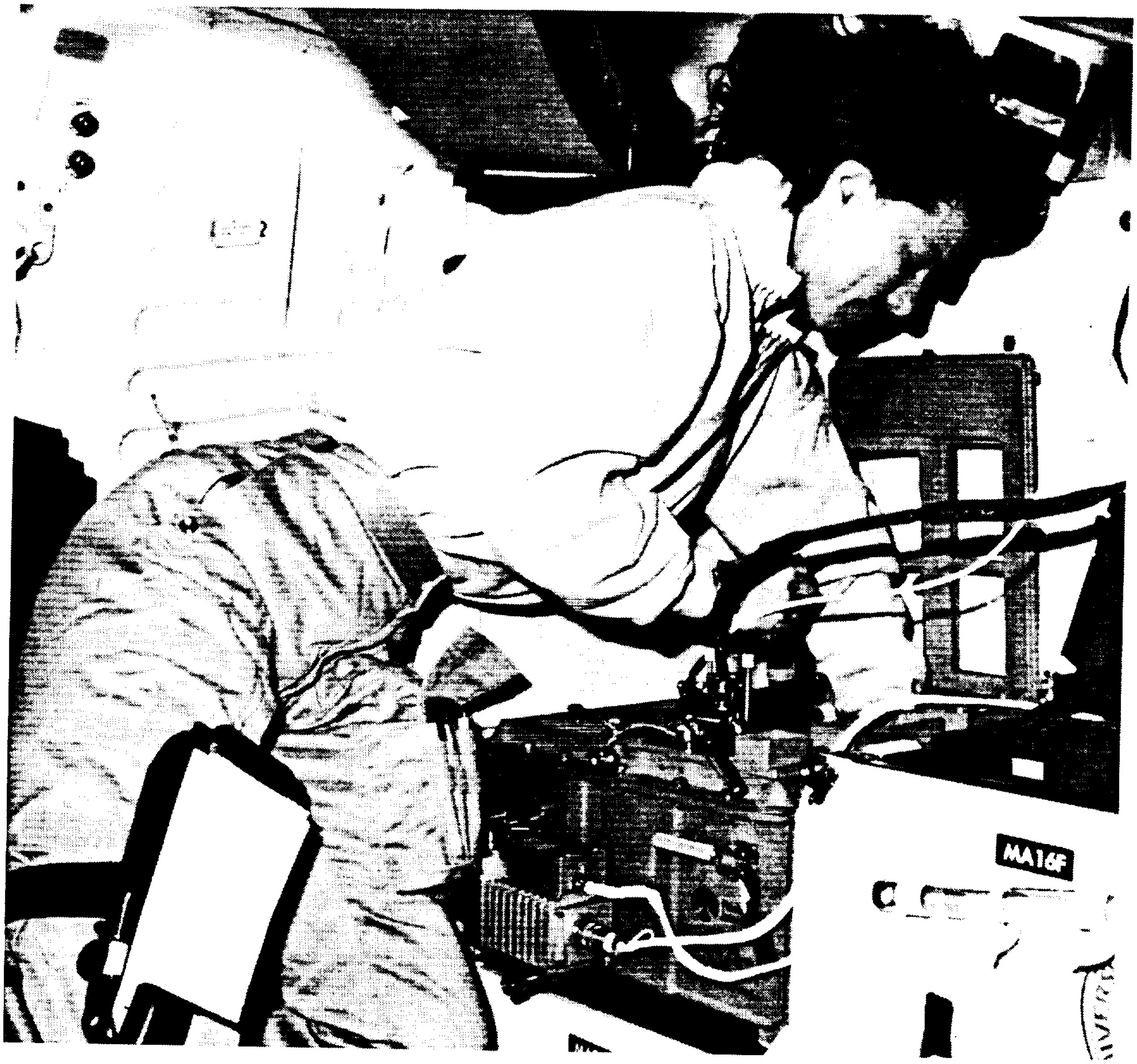

Figure 1. Mission Specialist and Principal Investigator Bonnie Dunbar is exchanging samples in the Fluids Experiment Apparatus (FEA) for the Microgravity Disturbances Experiment on STS-32. The HISA is visible as the small box attached to the front of the FEA.

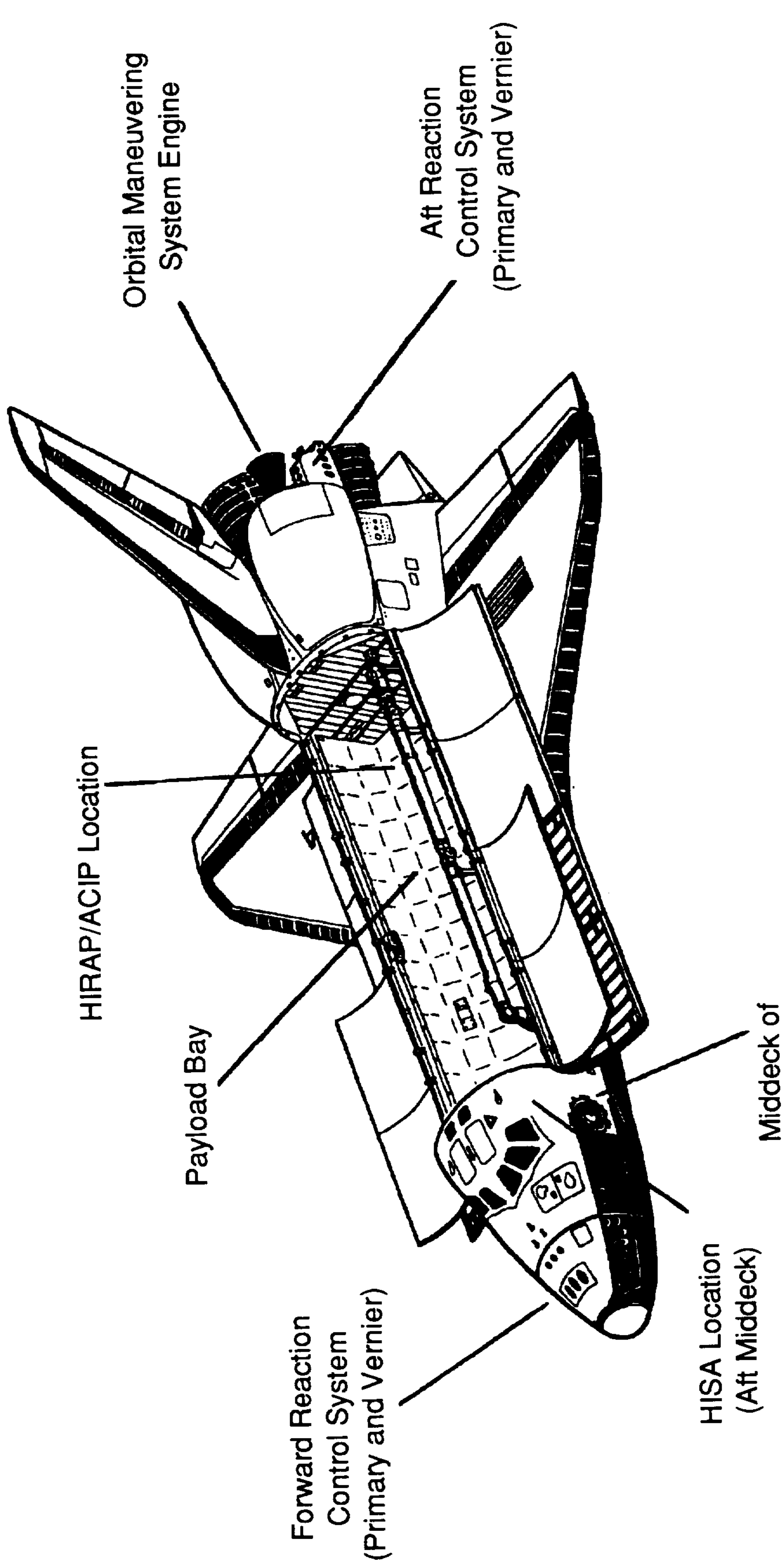

Figure 2. Overview of the Orbiter showing locations of middeck and payload bay

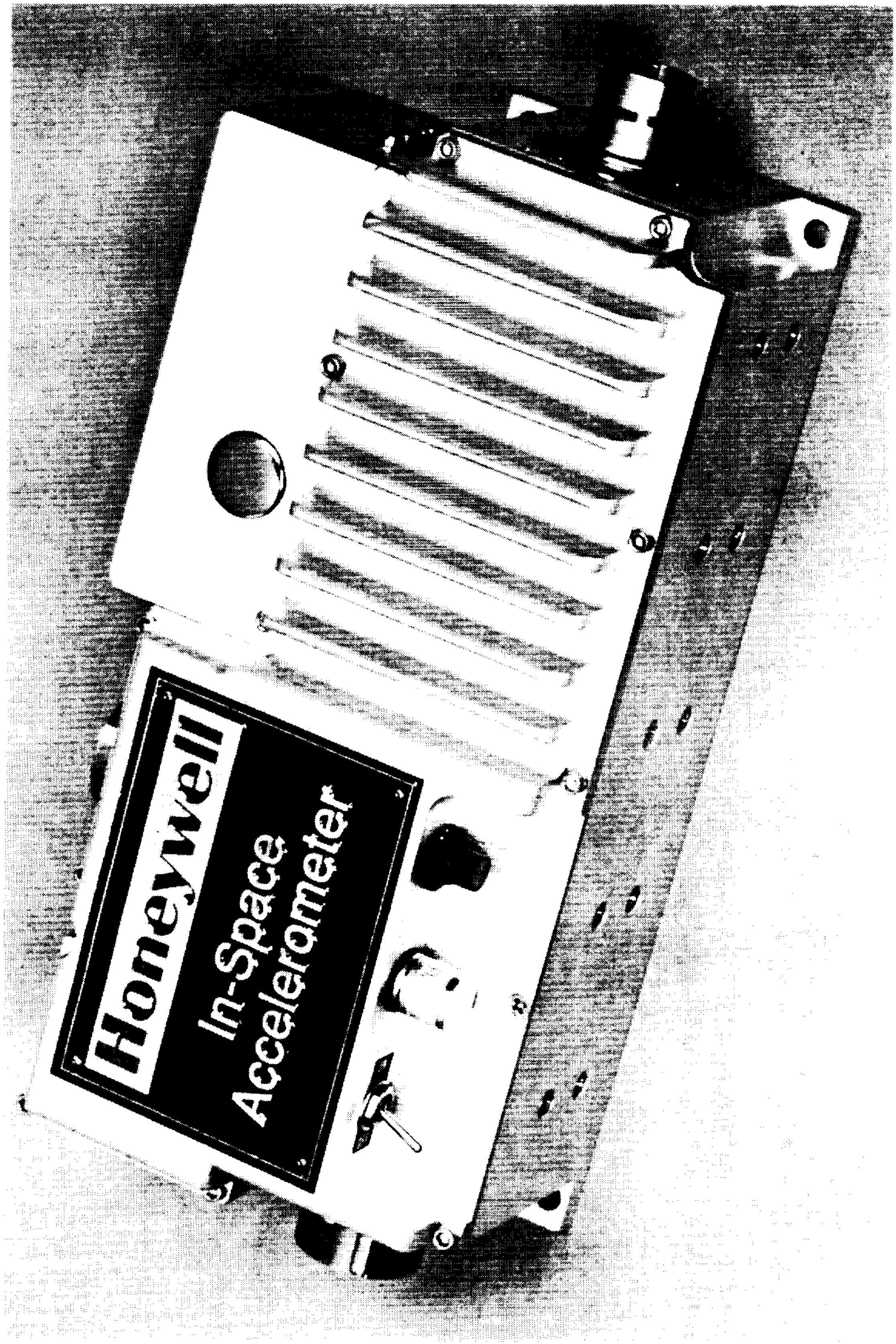

Figure 3. The Honeywell In-Space Accelerometer

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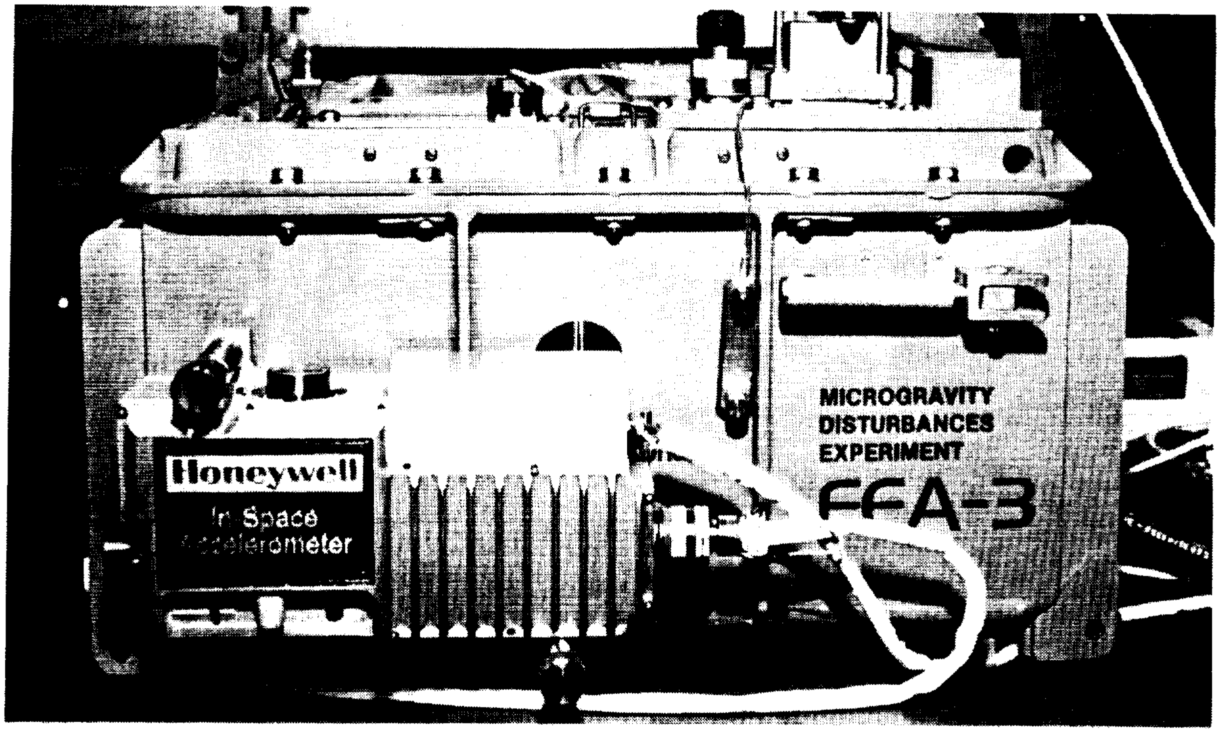

Figure 4. The HISA mounting location on the FEA

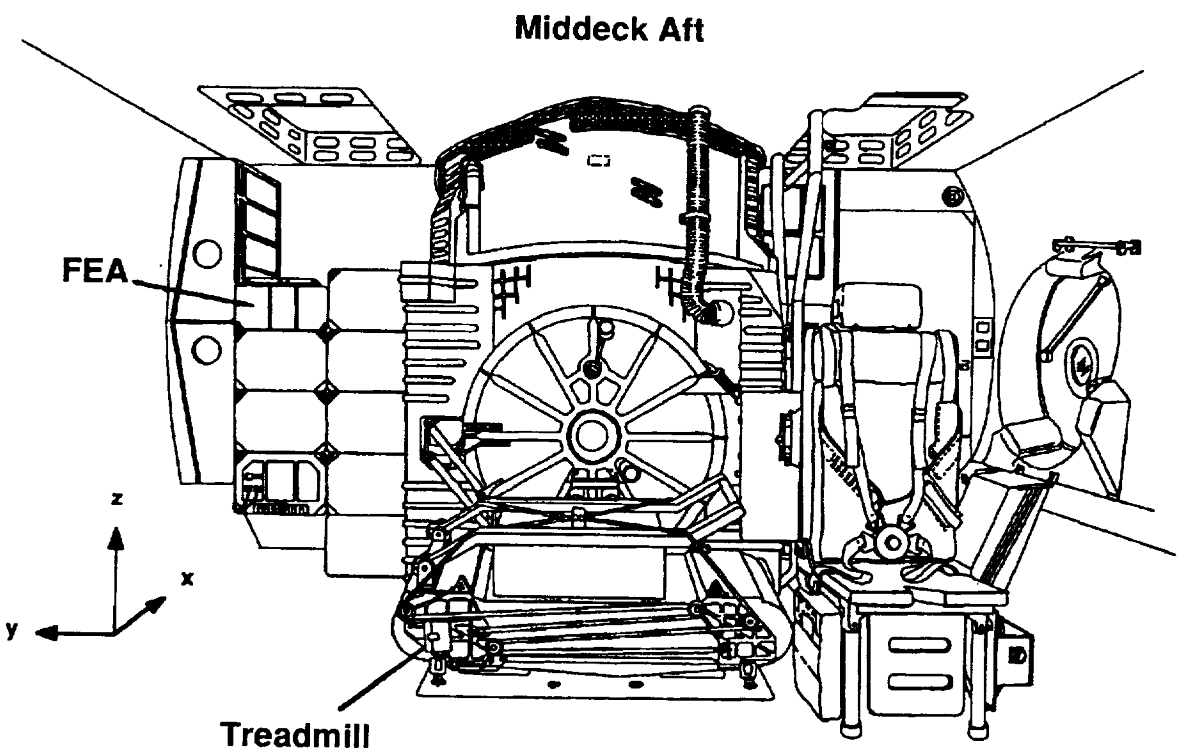

Figure 5. The FEA location in the aft Orbiter middeck on STS-32

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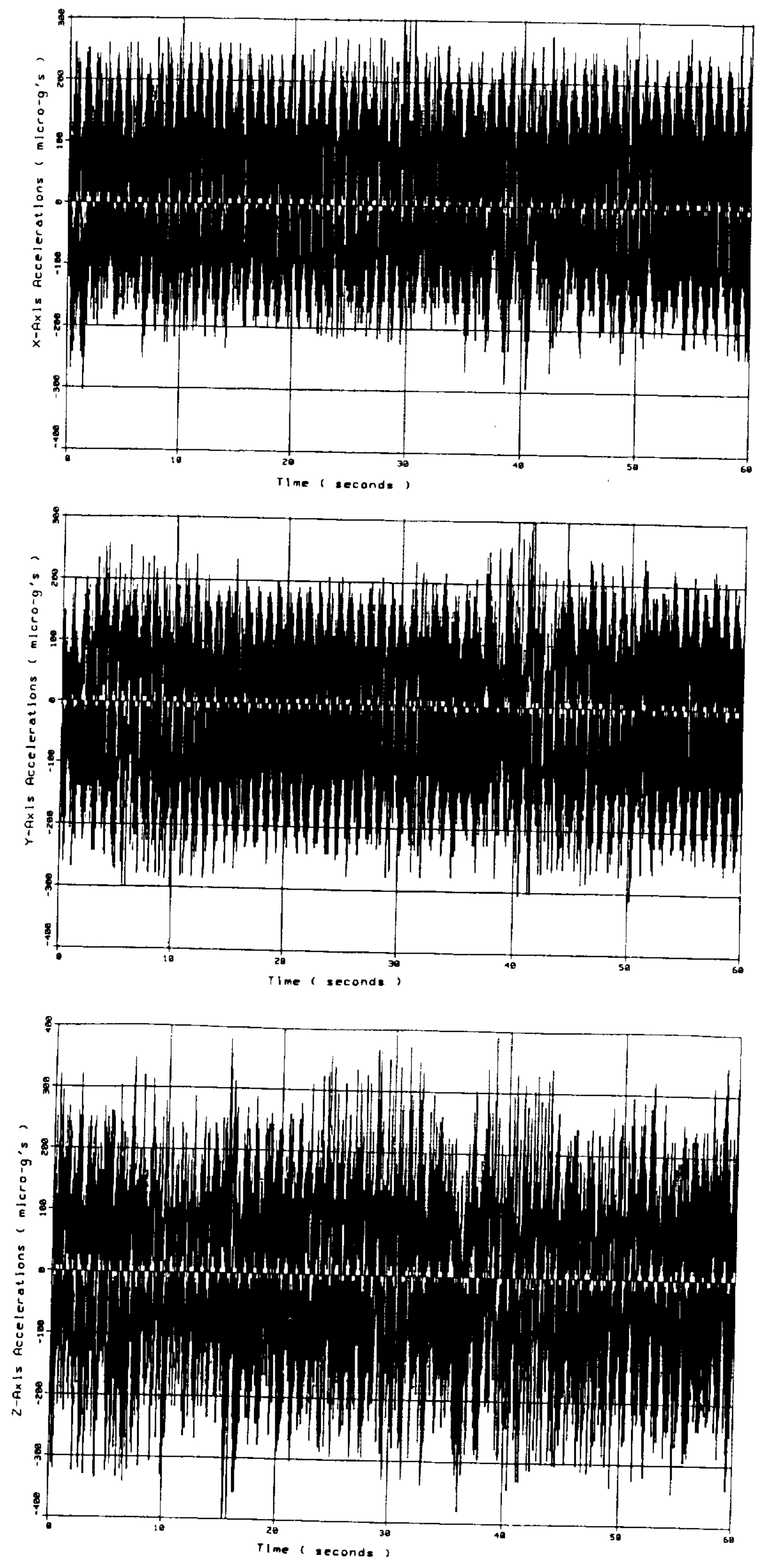
Figure 6. The crew exercise treadmill mounted on the floor of the Orbiter middeck

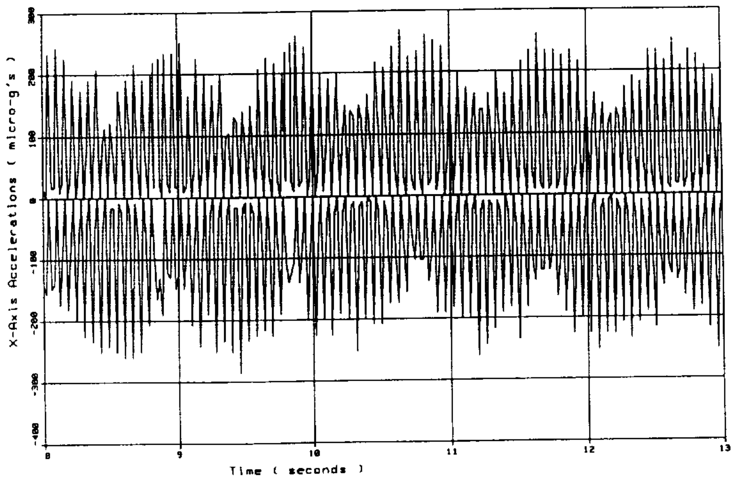
APPENDIX A

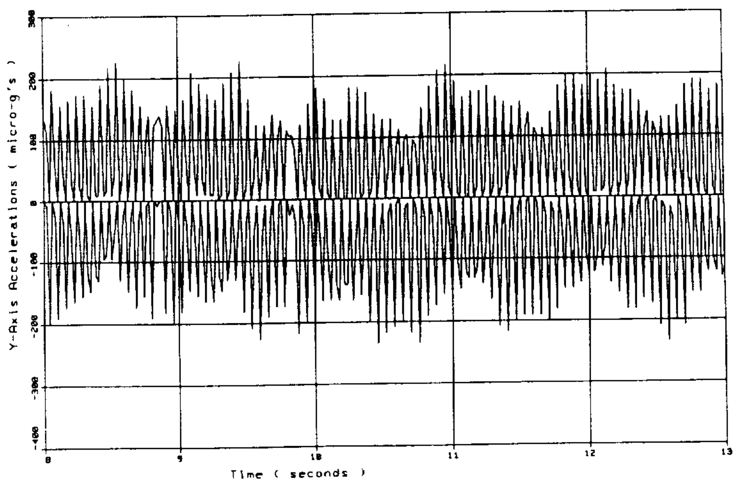
HISA Accelerometer Data Plots

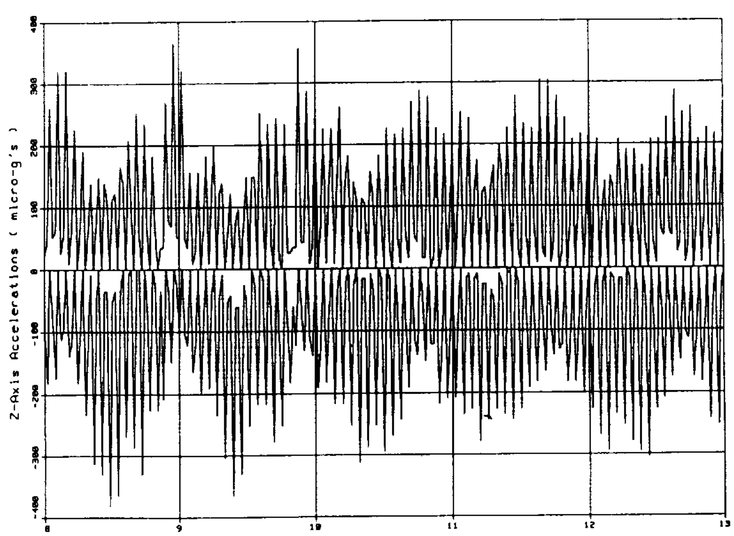
1. Orbiter Background - normal operations
2. Orbiter Background - expanded detail
3. Orbiter Background - quiescent period
4. Orbiter Background - expanded detail
5. Treadmill Activity - Commander
6. Treadmill Activity - Pilot
7. Treadmill Activity - Mission Specialist #3
8. Treadmill Profiles
9. Treadmill Activity - Pilot
10. Treadmill Activity - Commander, startup
11. Treadmill Activity - walking-to-running transition
12. Treadmill Activity - running-to-walking transition
13. Treadmill - details of walking/running transitions
14. Vernier Engine Burn - single-axis
15. Vernier Engine Burn - single-axis
16. Vernier Engine Burn - multi-axis
17. Vernier Engine Burn - multi-axis
18. PRCS Burn - NCC
19. PRCS Burn - NCC expanded detail
20. PRCS Burn - TI
21. PRCS Burn - MC3
22. PRCS Burn - MC4
23. OMS Burn - NH1
24. OMS Burn - NSR
25. Unidentified Event
26. Unidentified Event
27. Unidentified Event
28. Beat Frequency - treadmill walking
29. Beat Frequency - post MC4 burn



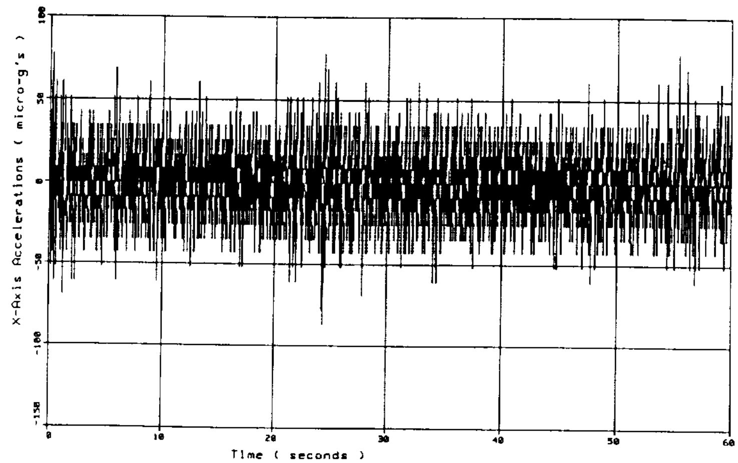
Orbiter Background - normal operations

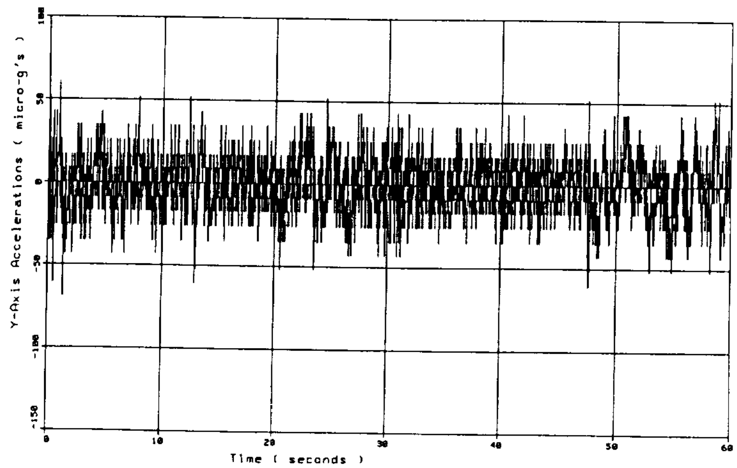


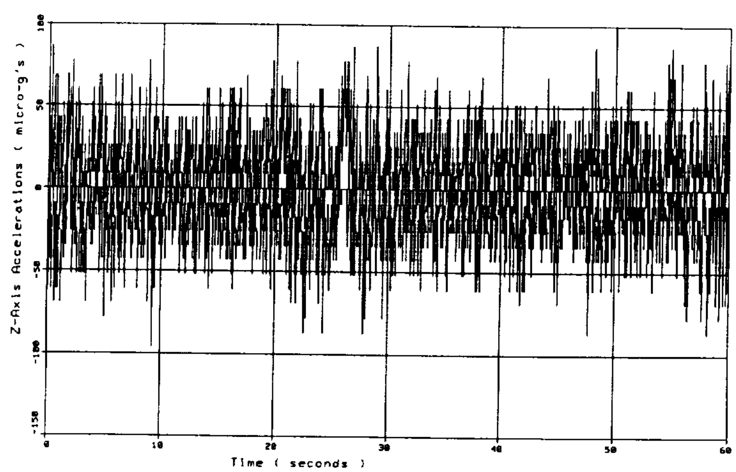




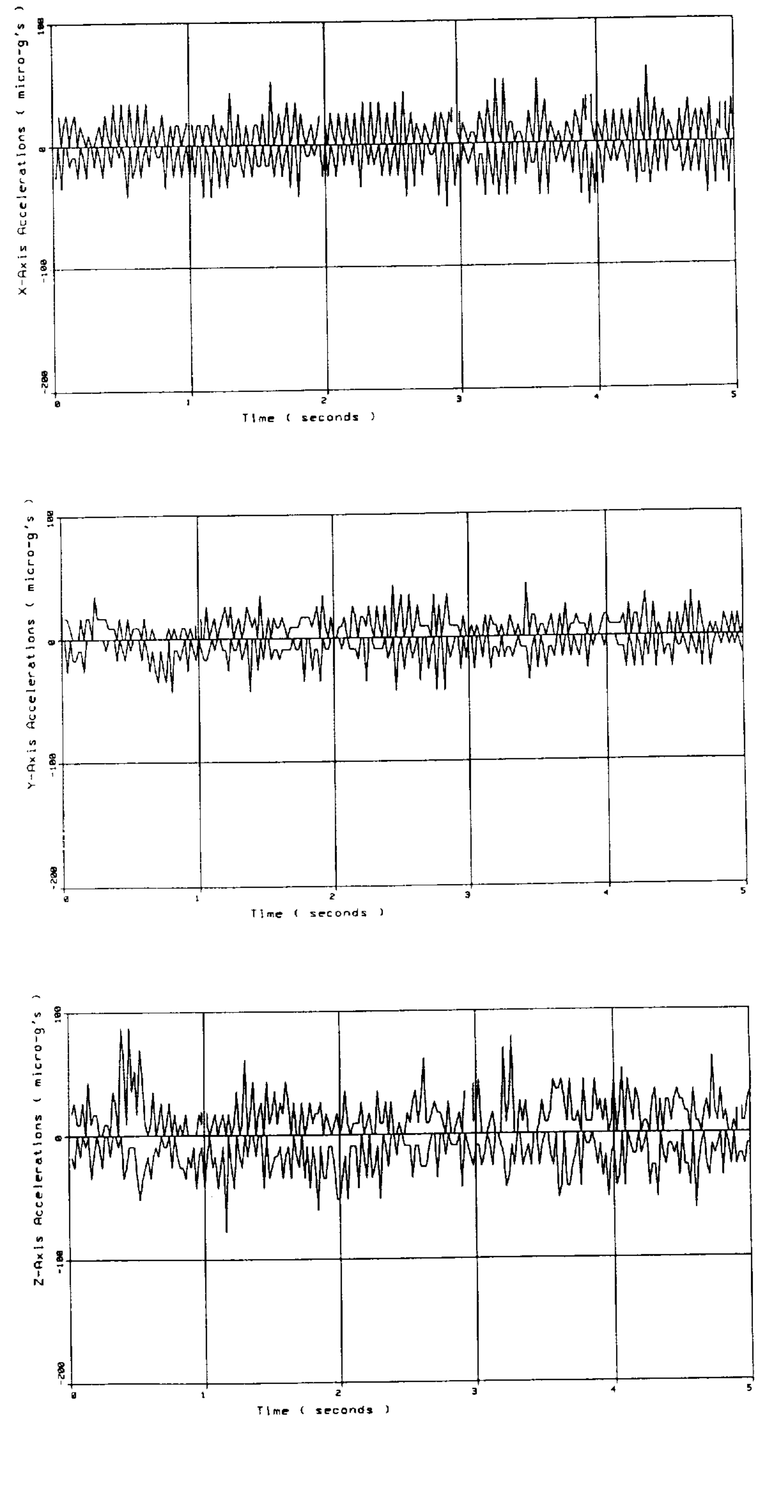
Orbiter Background - expanded detail



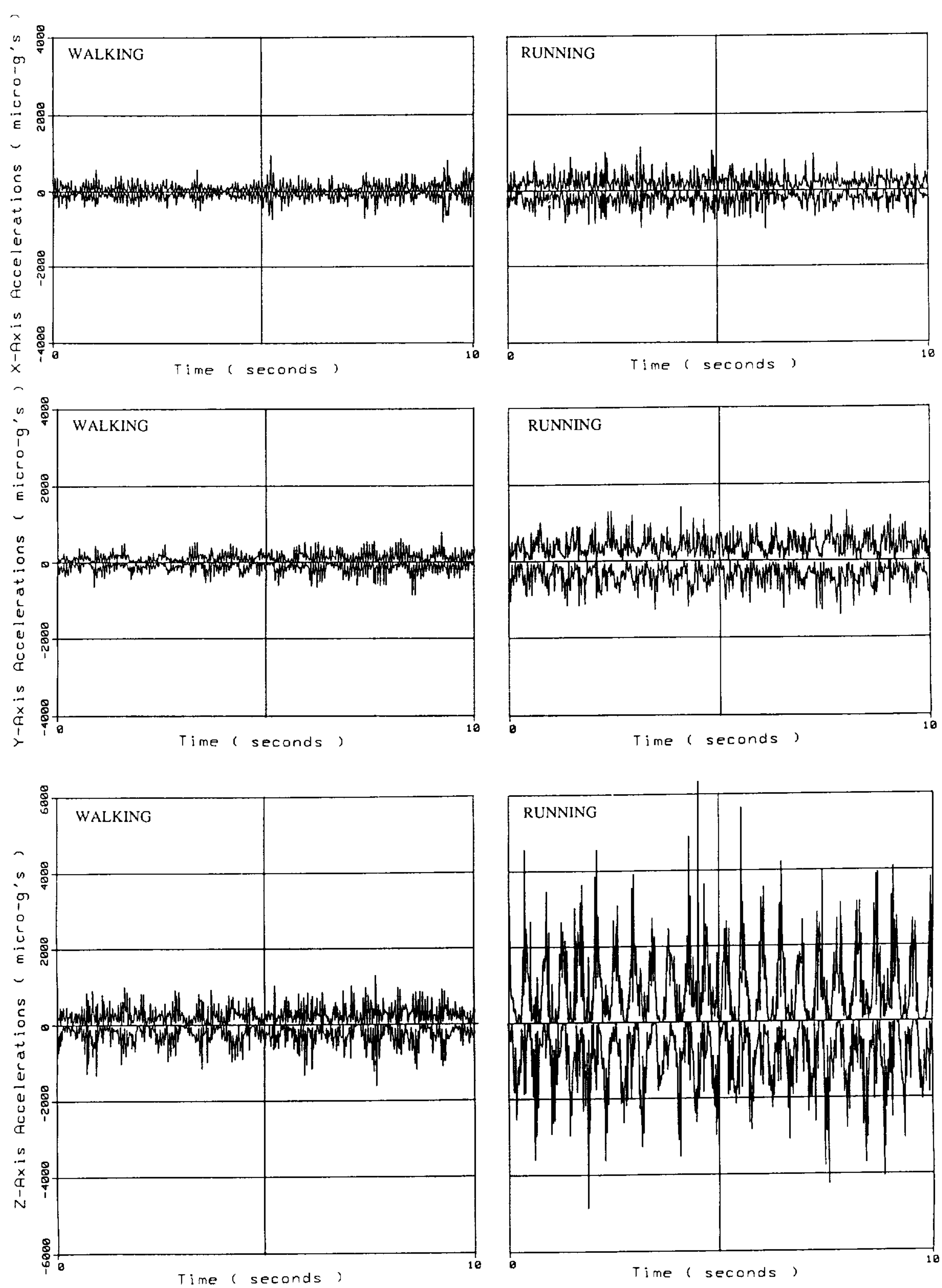




Orbiter Background - quiescent period



Orbiter Background - expanded detail



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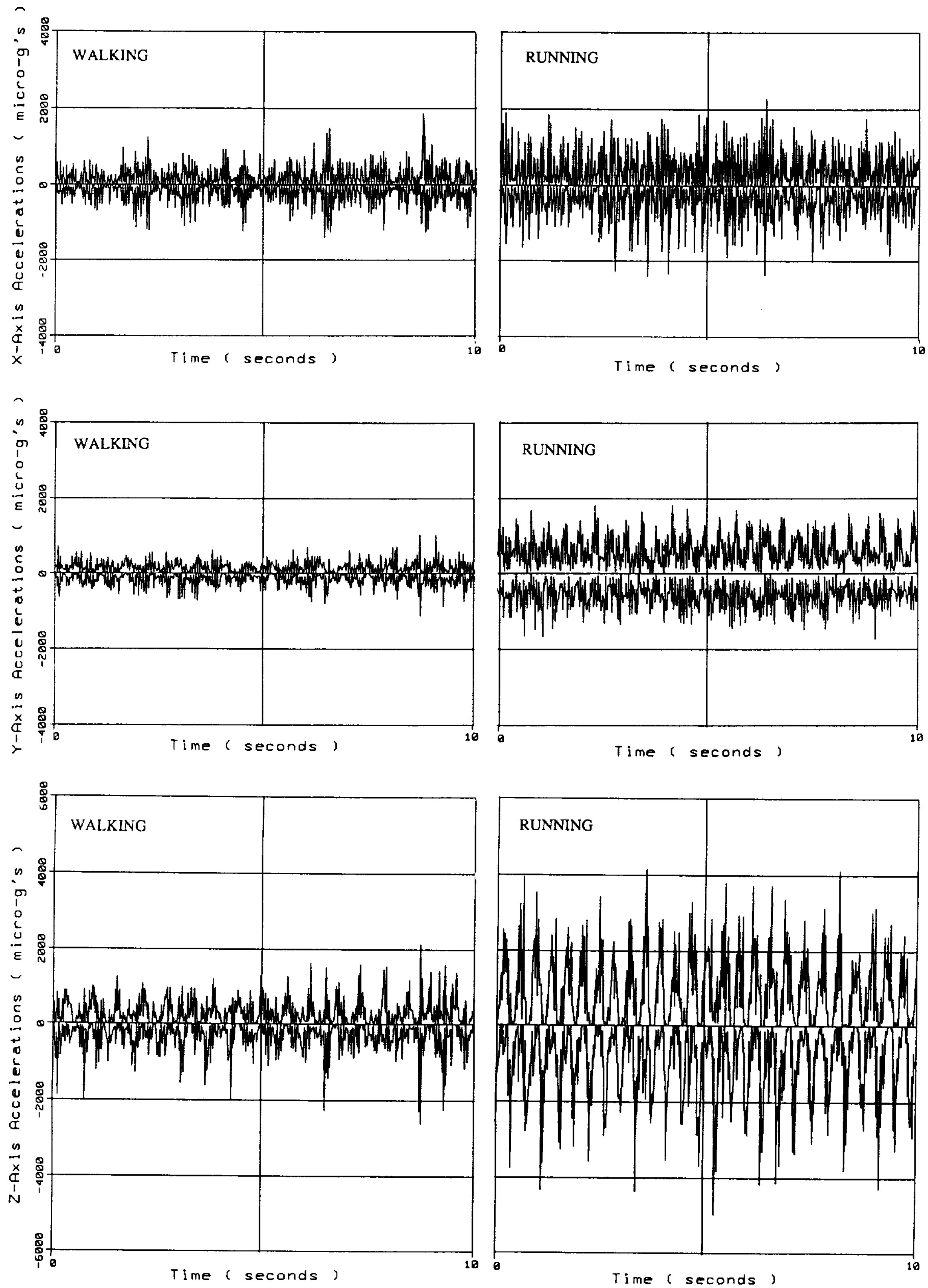
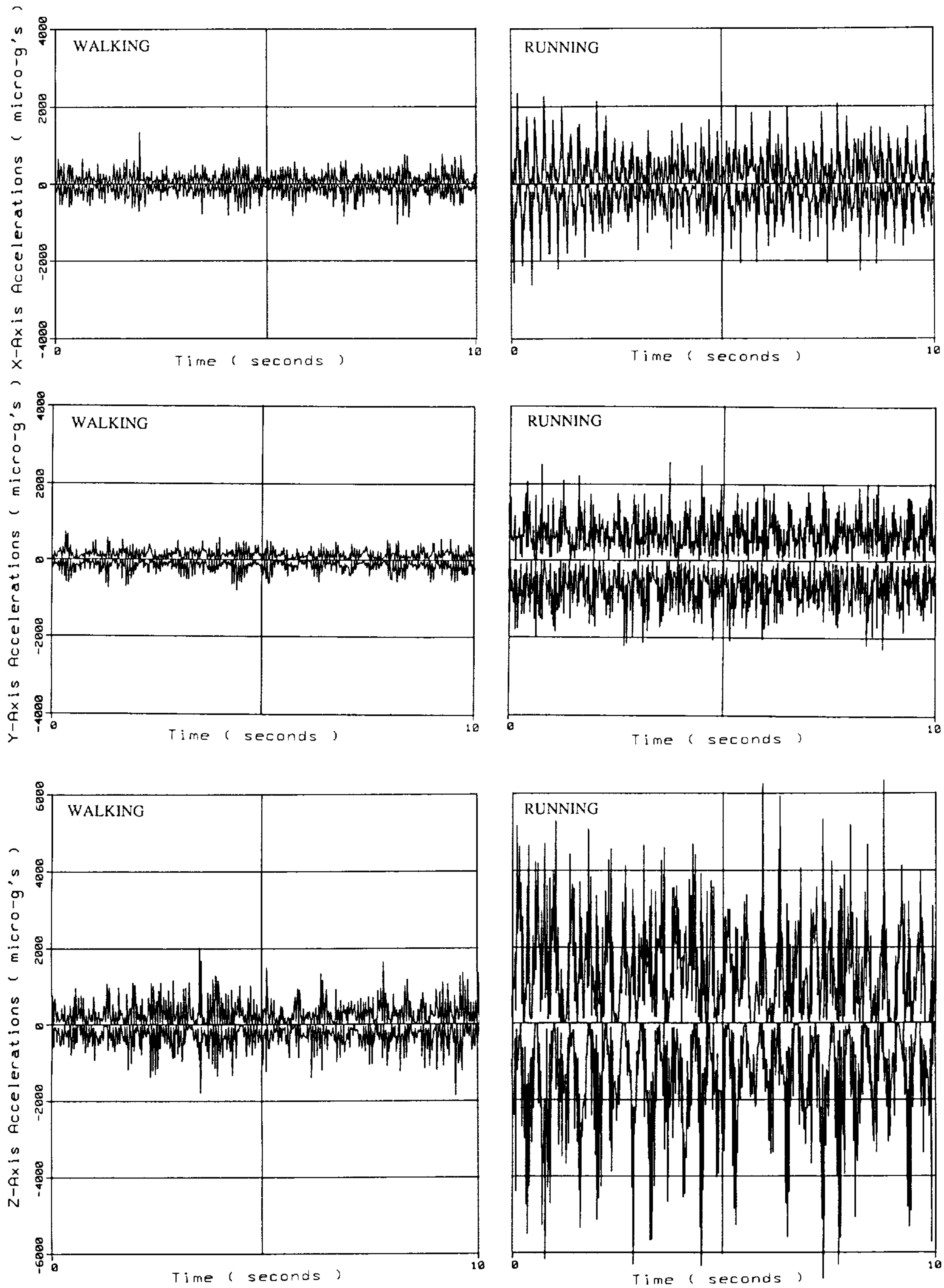
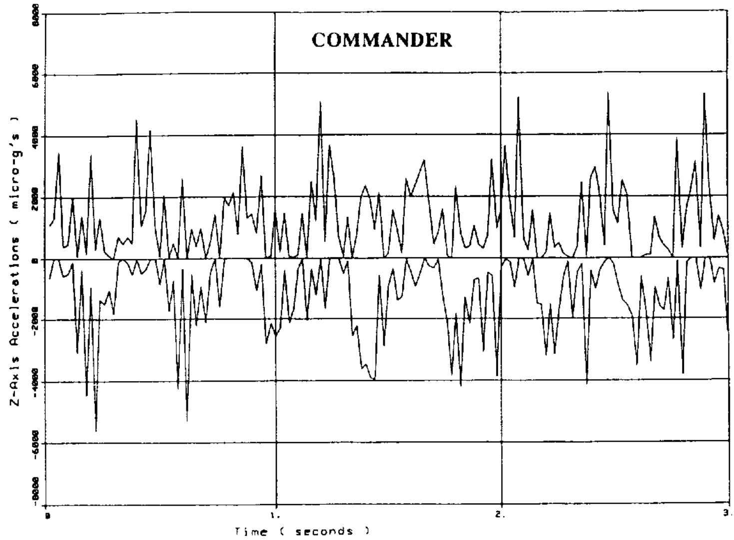
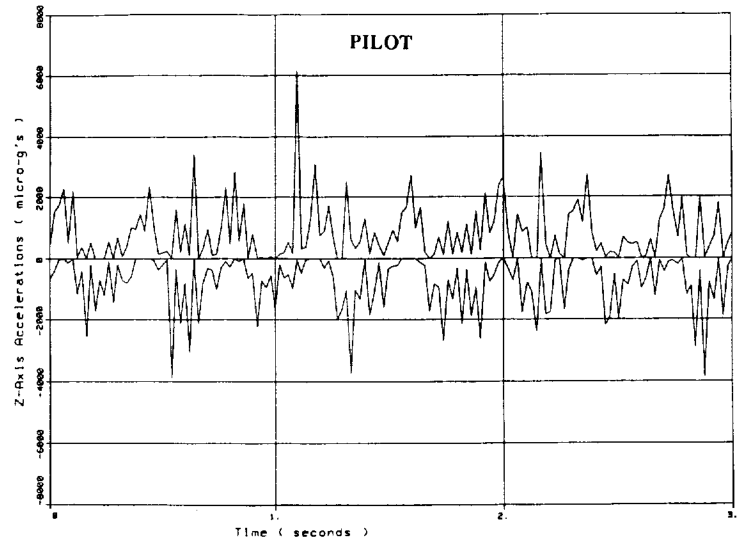


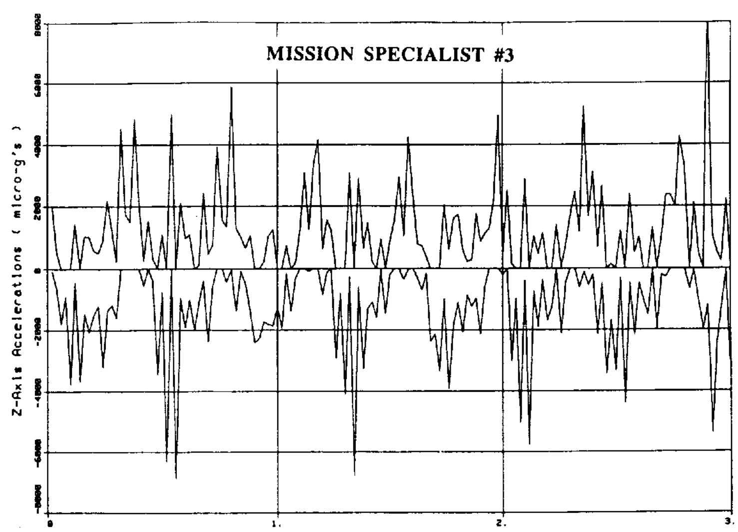
Treadmill Activity - Pilot



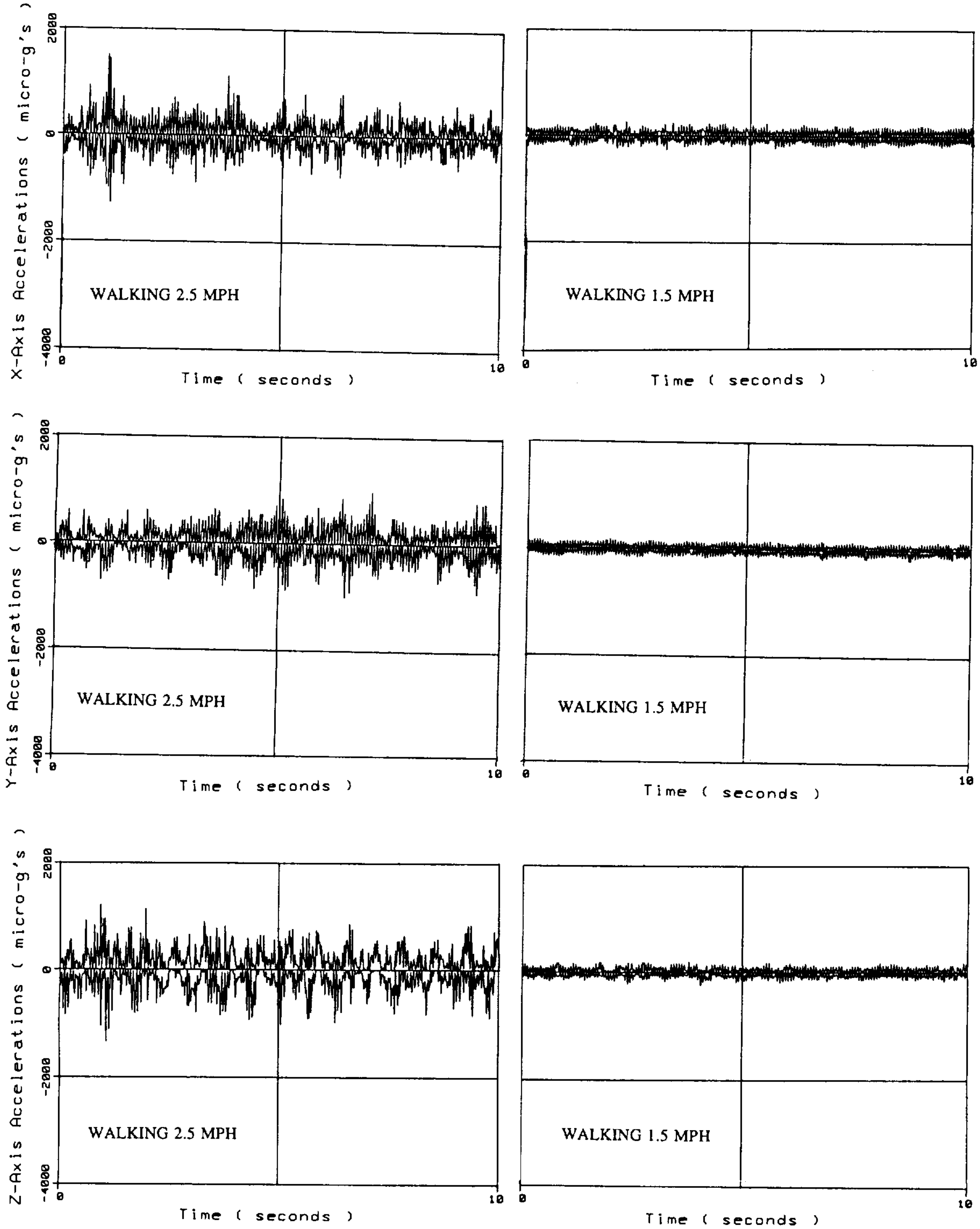
Treadmill Activity - Mission Specialist #3



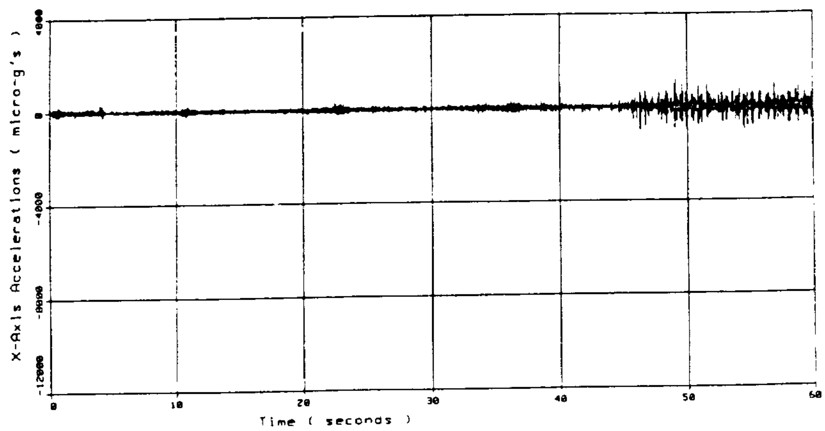


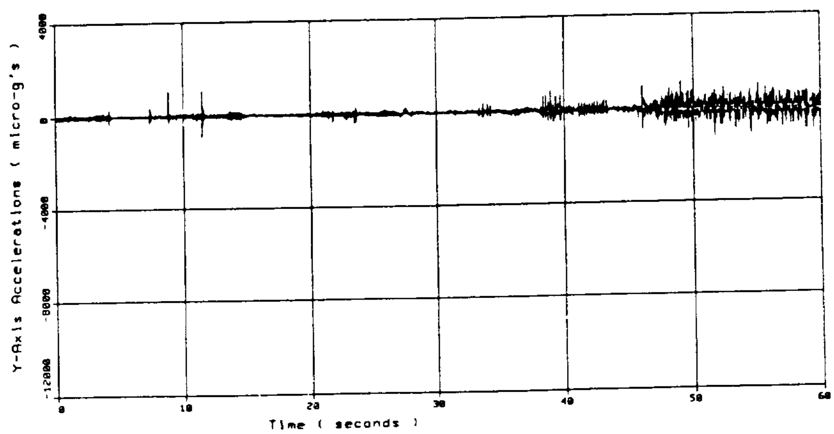


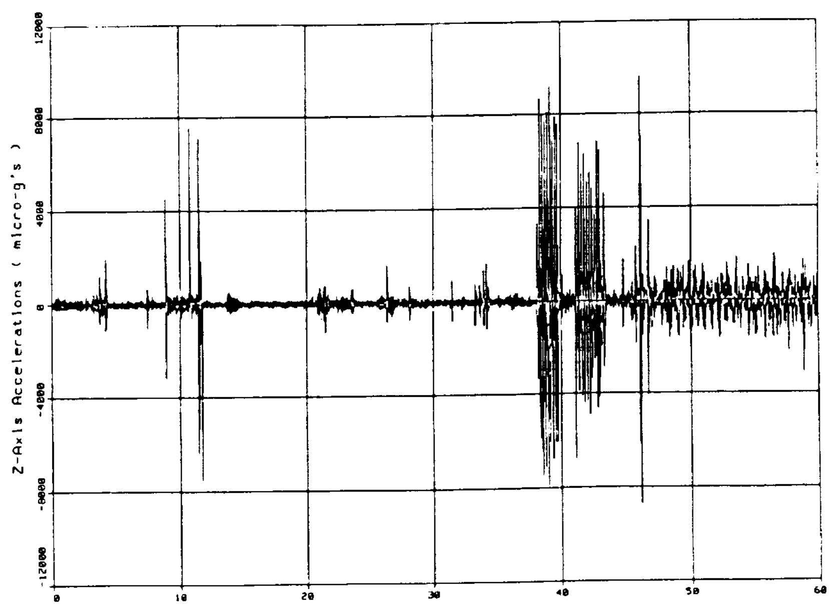
Treadmill Profiles



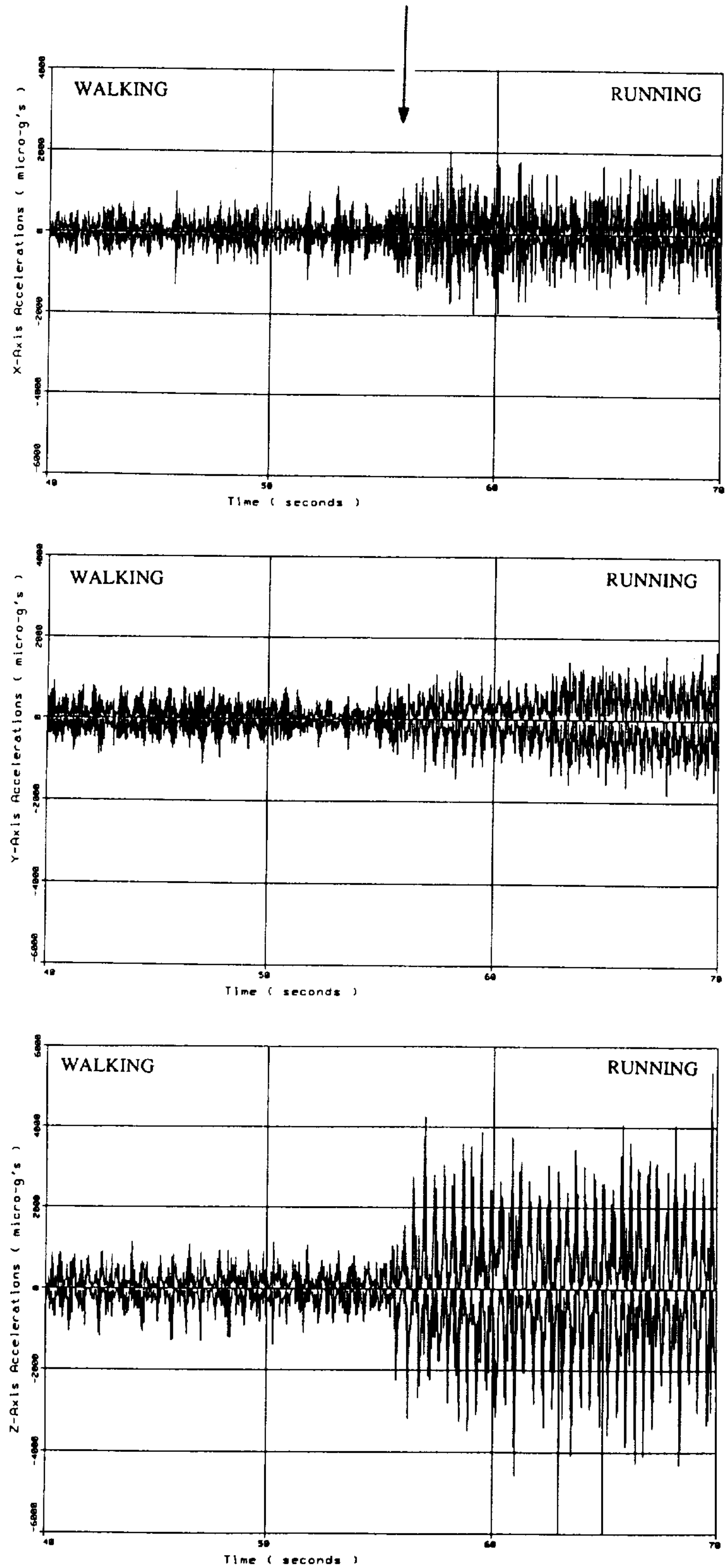
Treadmill Activity - Pilot



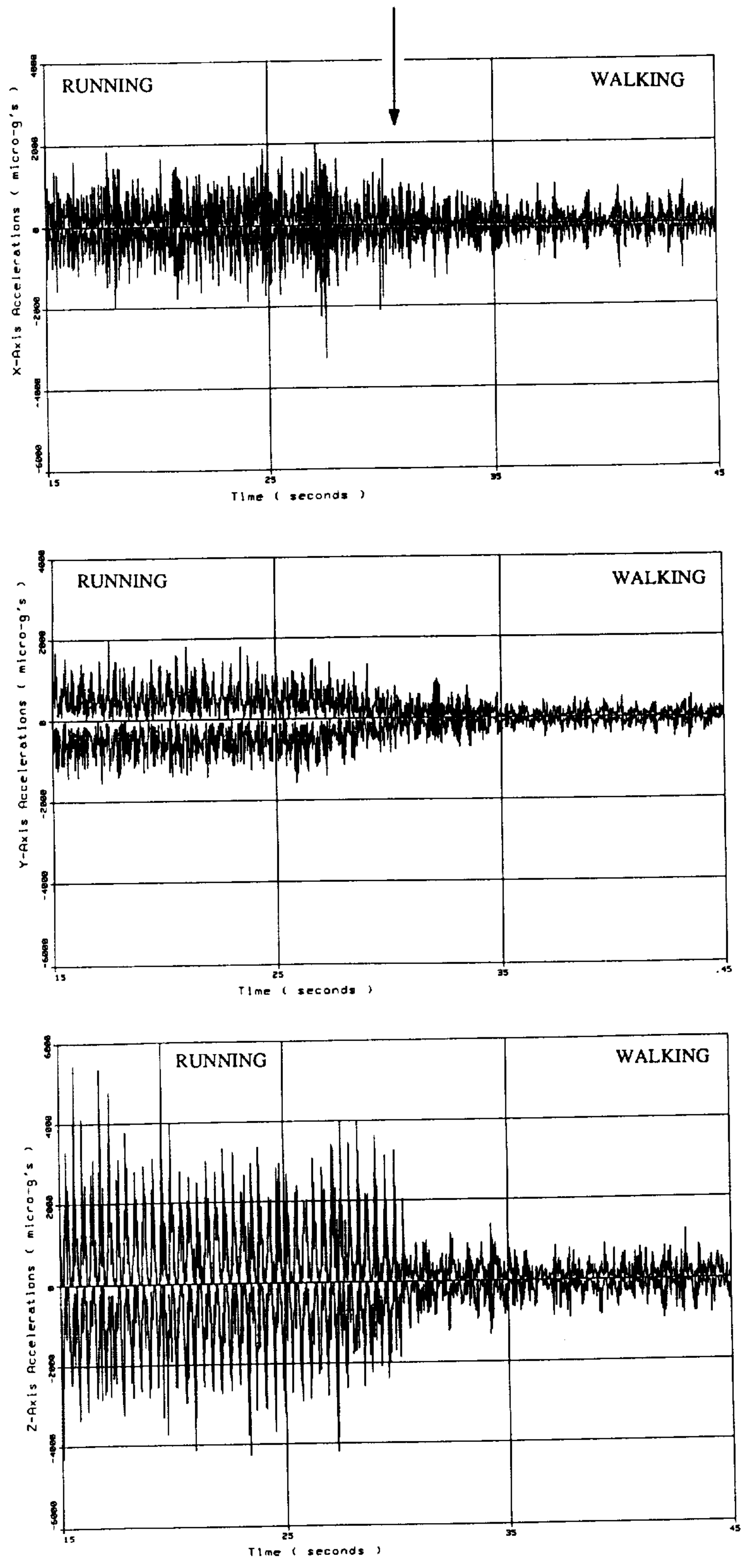




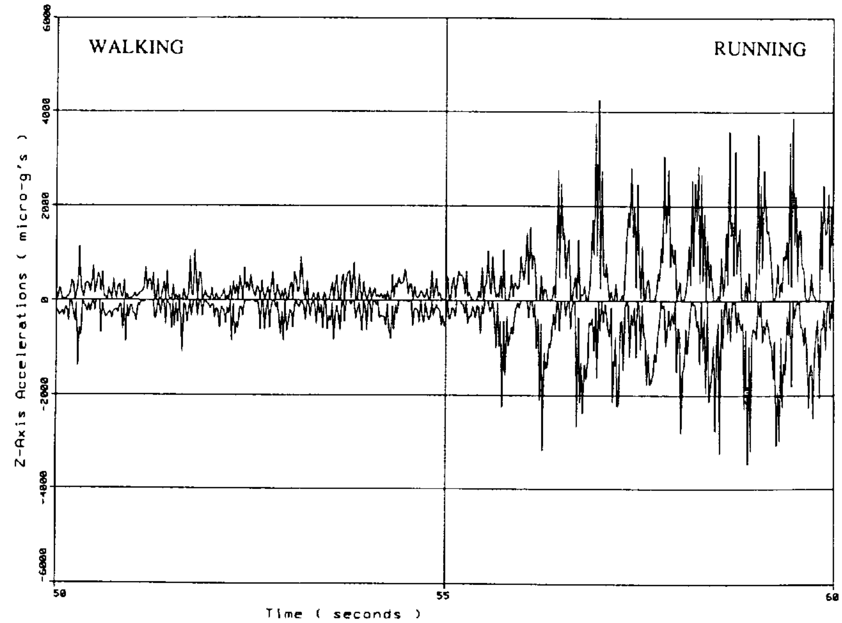
Treadmill Activity - Commander, startup

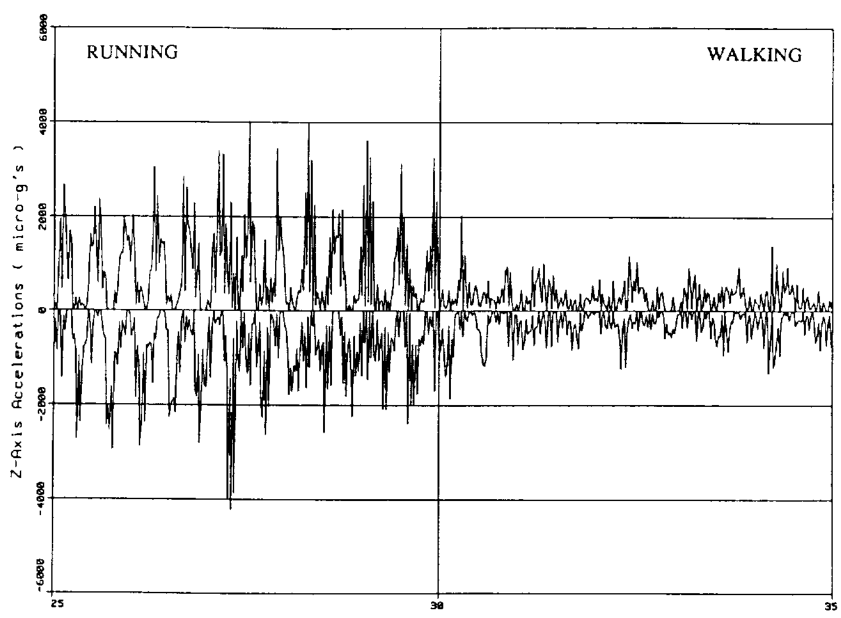


Treadmill Activity - walking-to-running transition

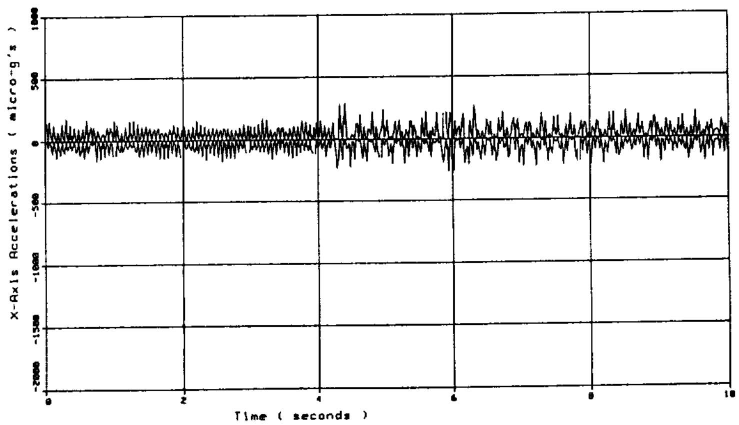


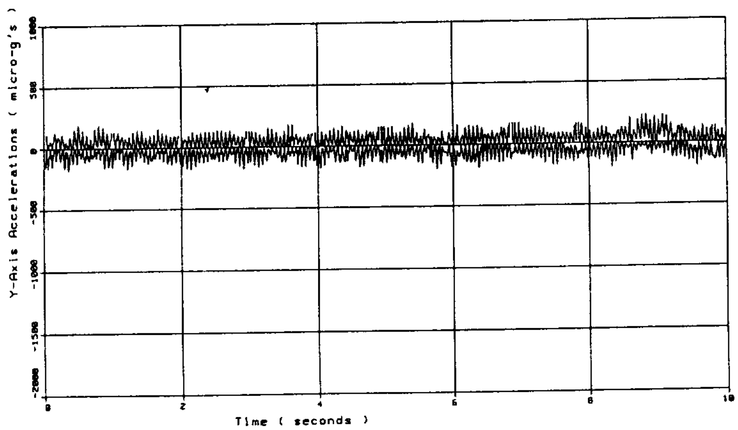
Treadmill Activity - running-to-walking transition

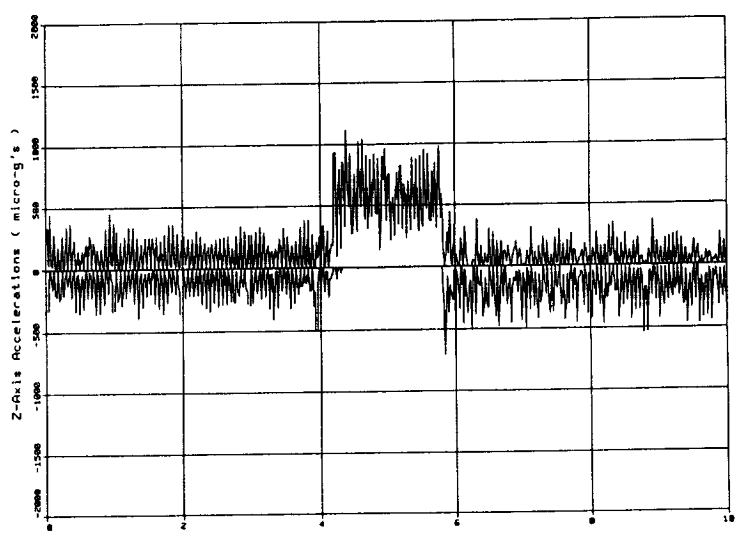




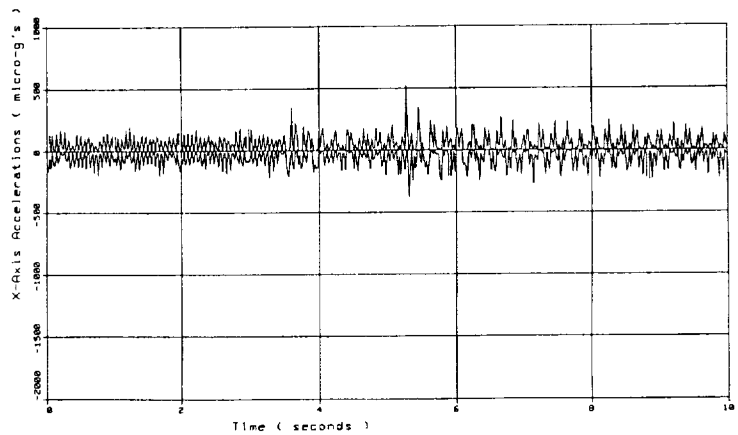
Treadmill - details of walking/running transitions

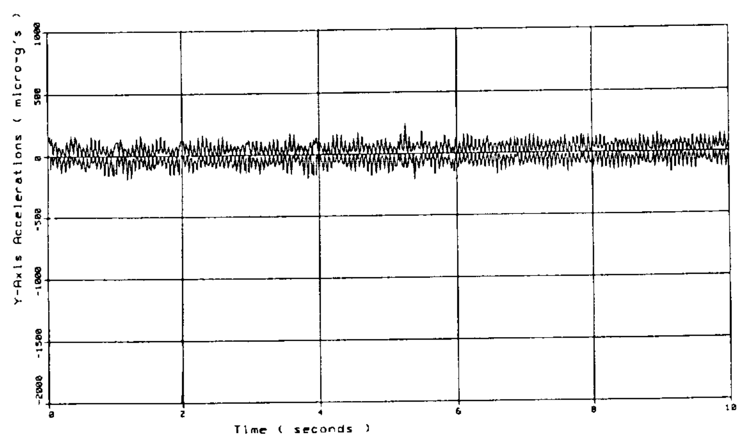


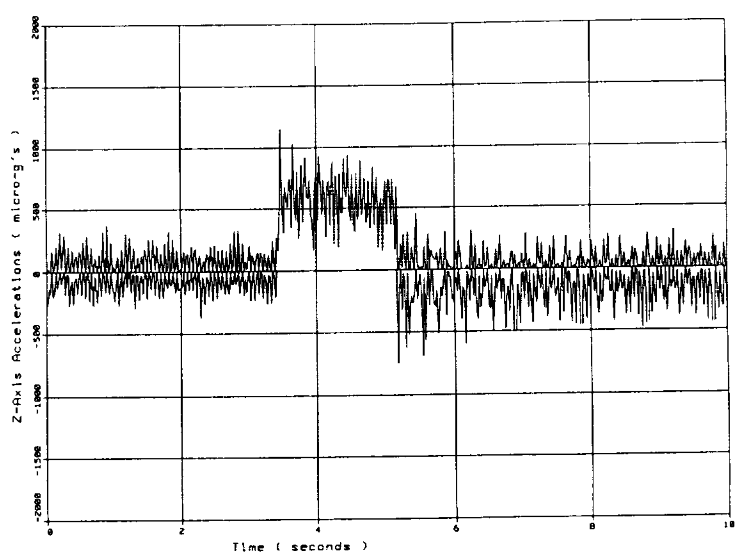




Vernier Engine Burn - single-axis







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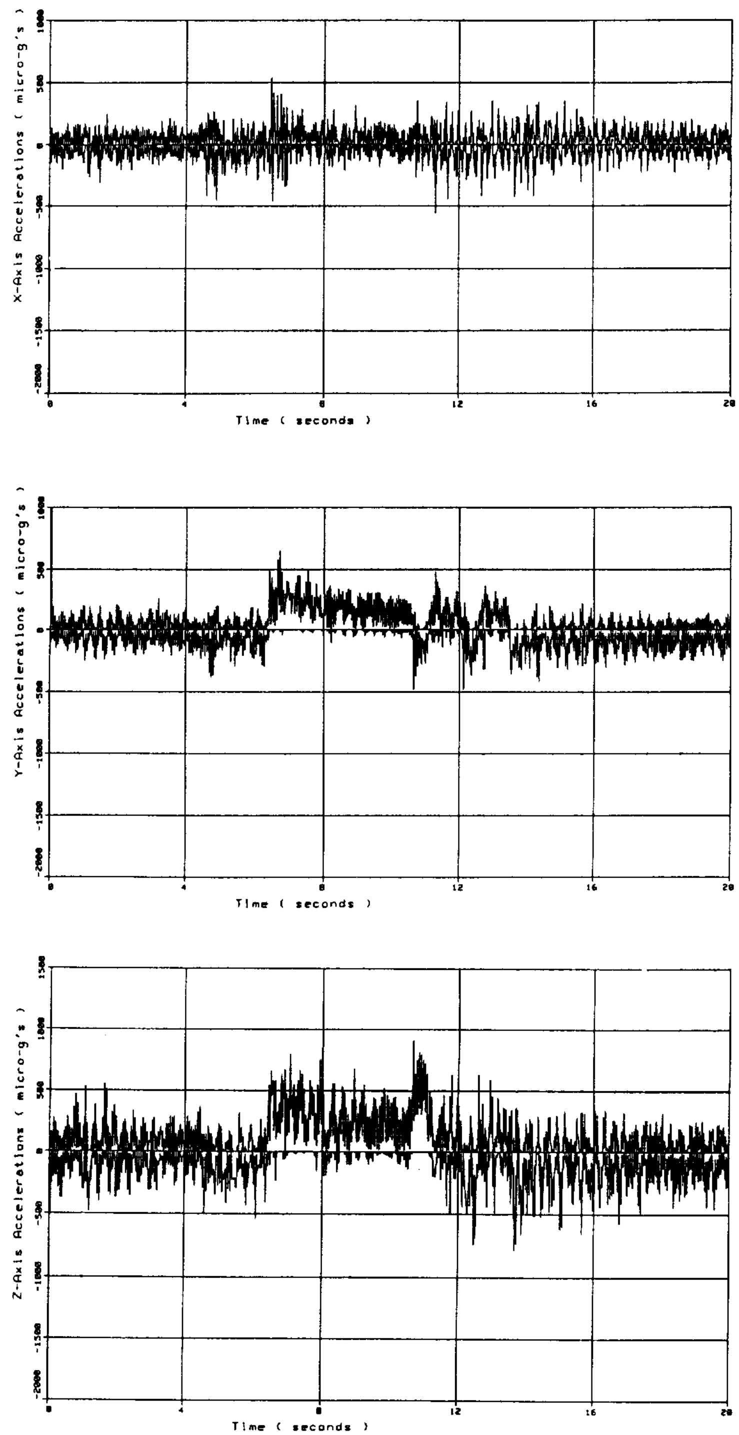

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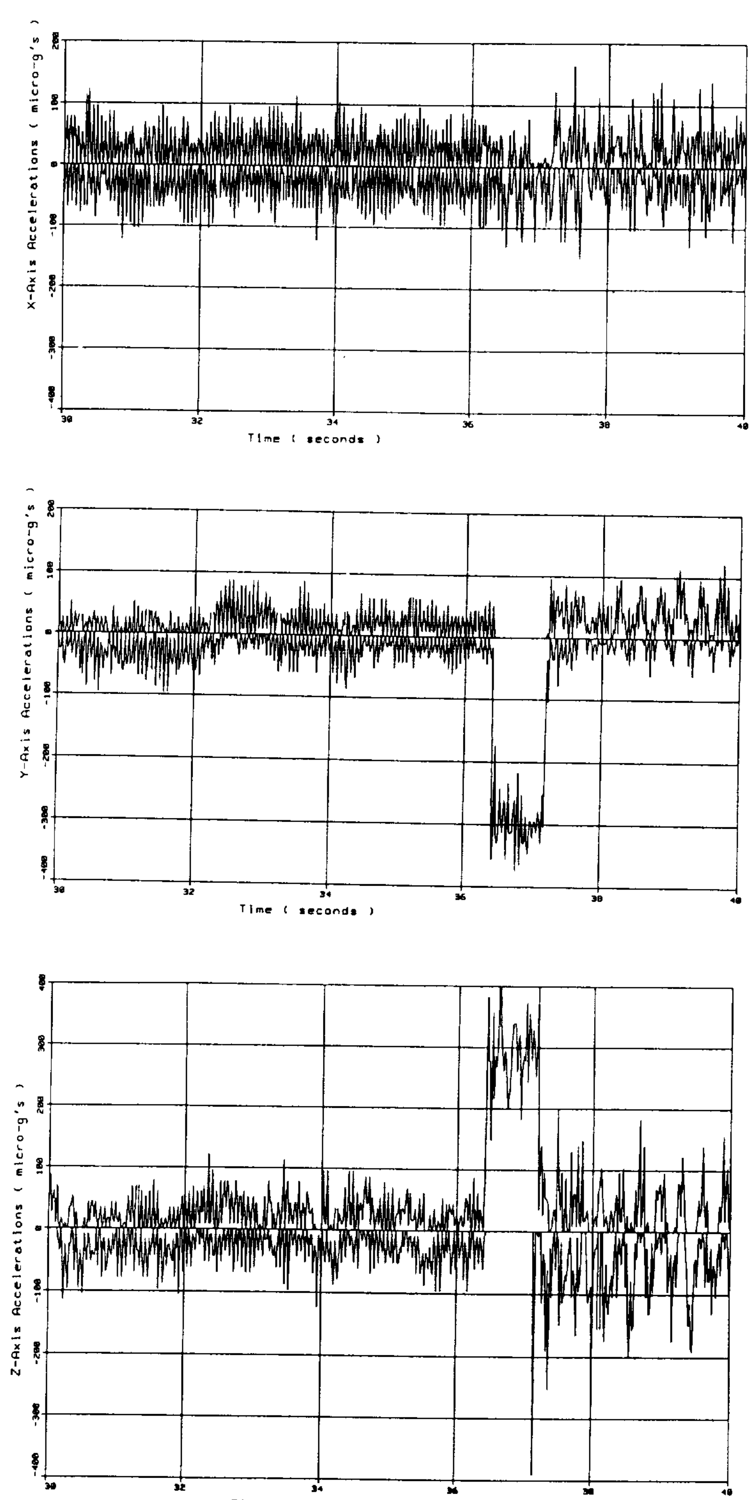

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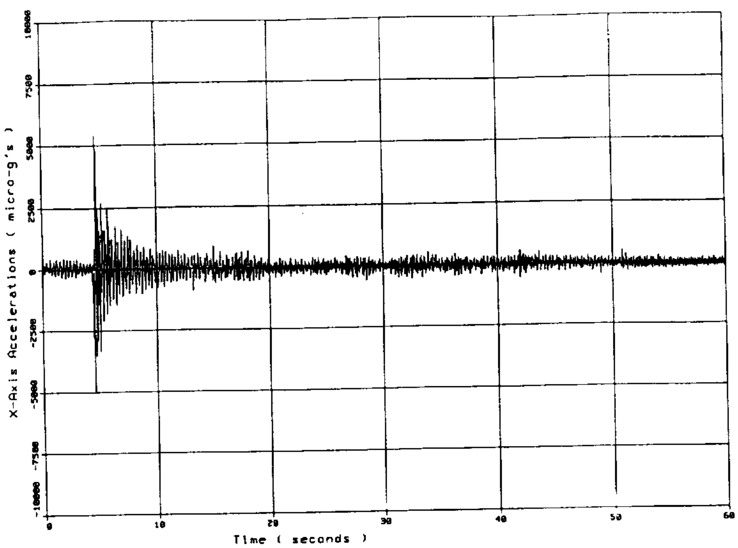
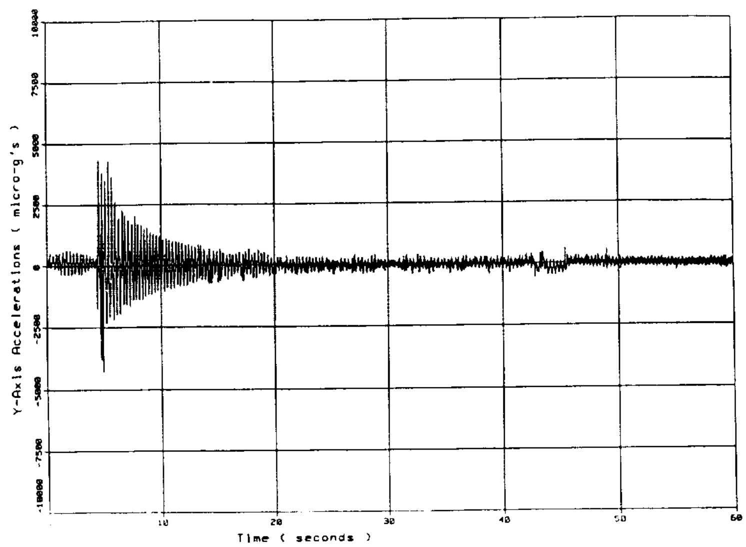
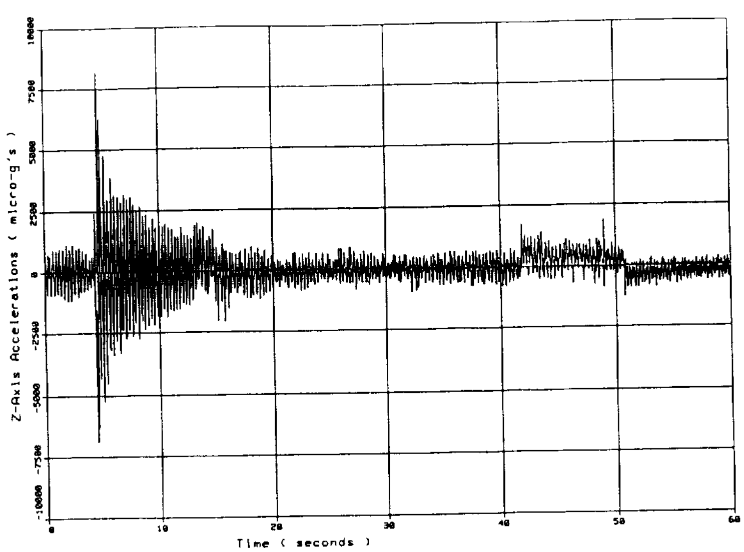
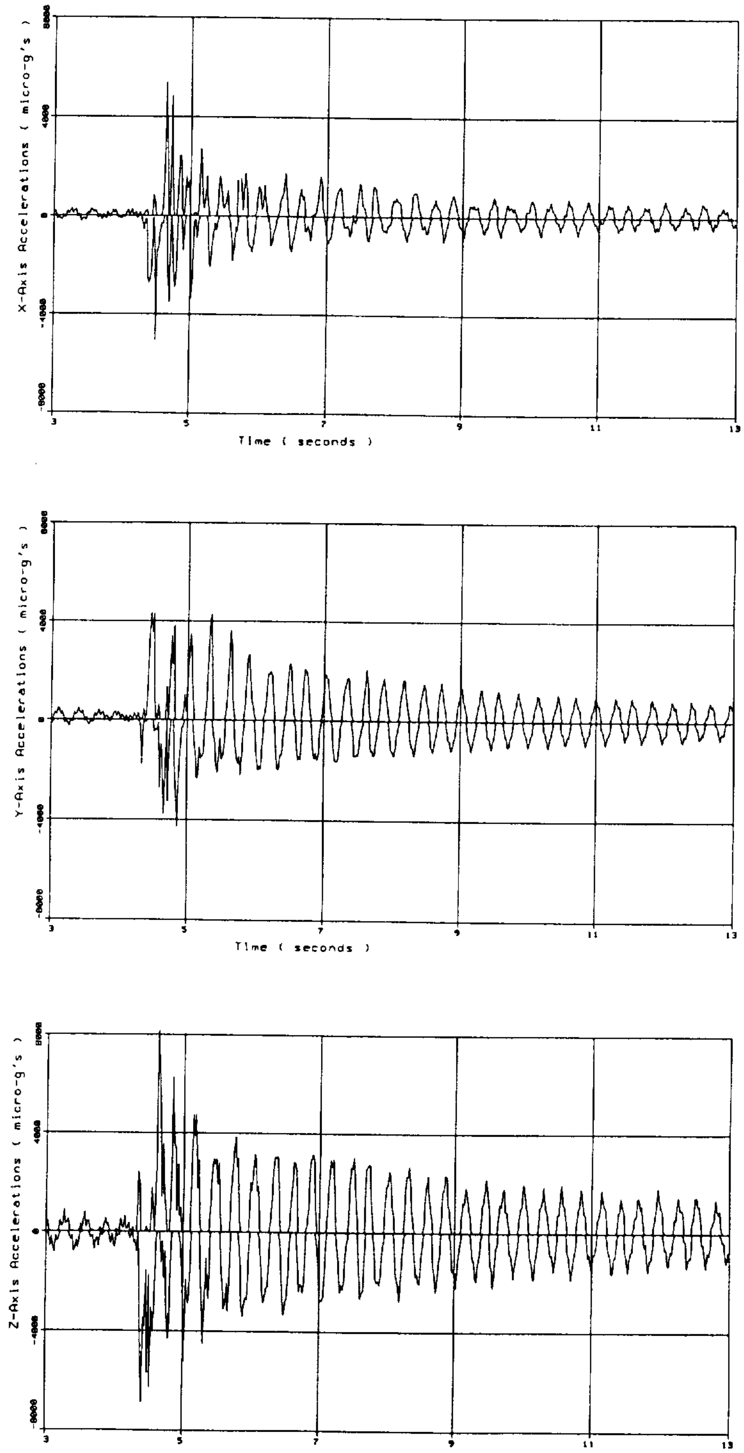


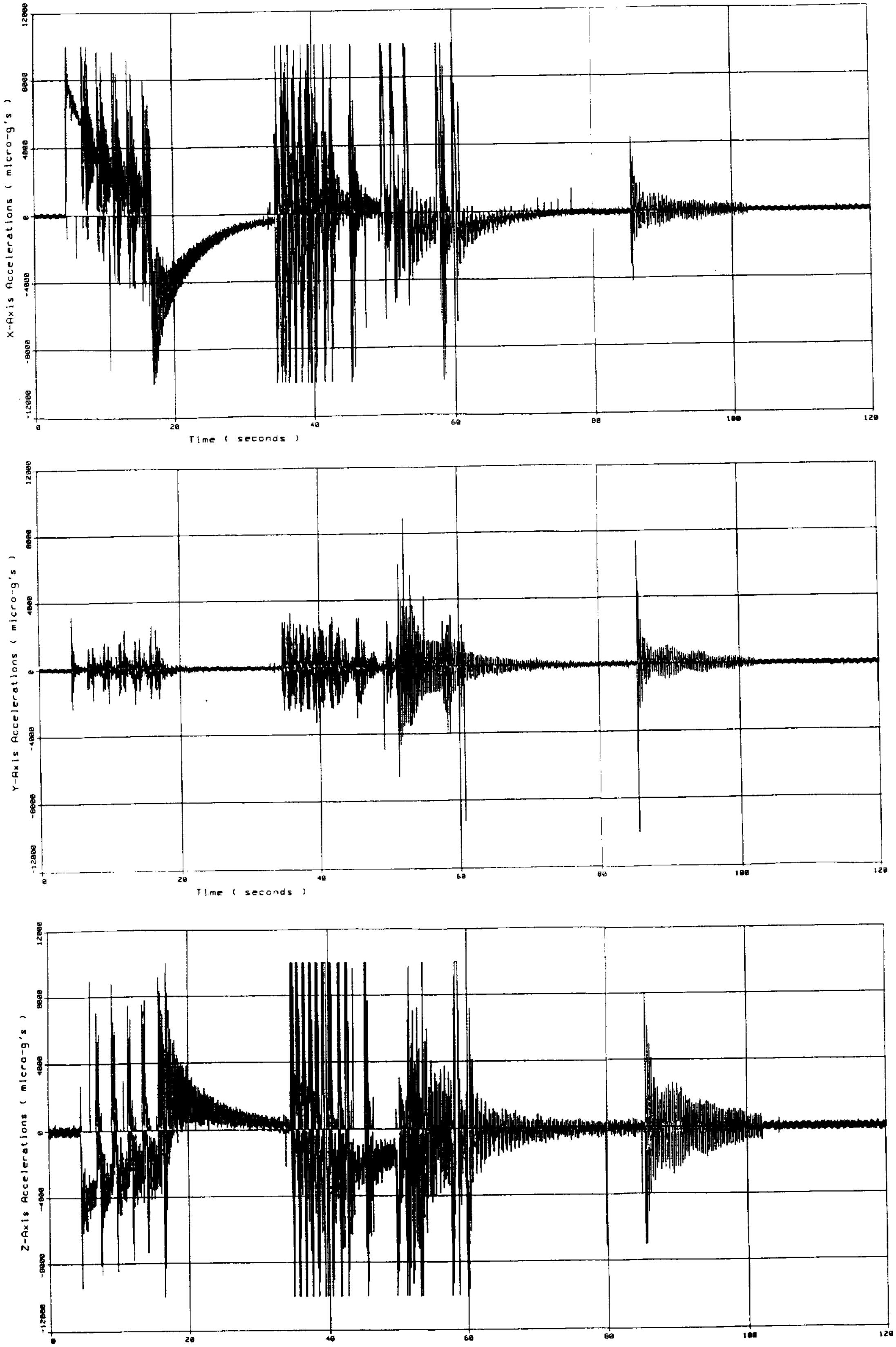




PRCS Burn - NCC



PRCS Burn - NCC expanded detail


X-Axis Accelerations (micro-g's)
12000
8000
4000
0
-4000
-8000
-12000
0
20
40
60
80
100
120
Time (seconds)
Y-Axis Accelerations (micro-g's)
12000
8000
4000
0
-4000
-8000
-12000
0
20
40
60
80
100
120
Time (seconds)
Z-Axis Accelerations (micro-g's)
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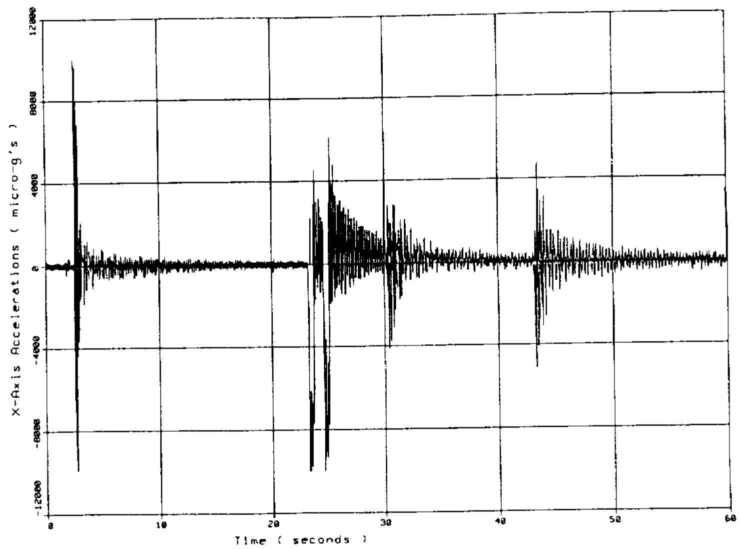
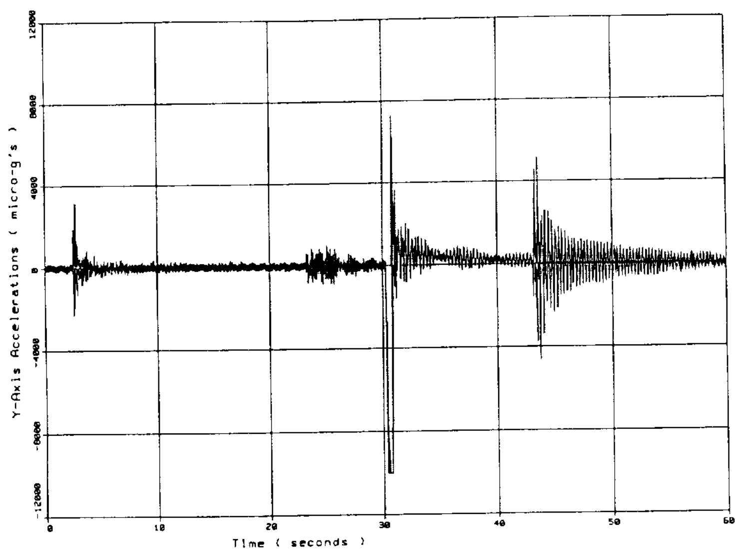
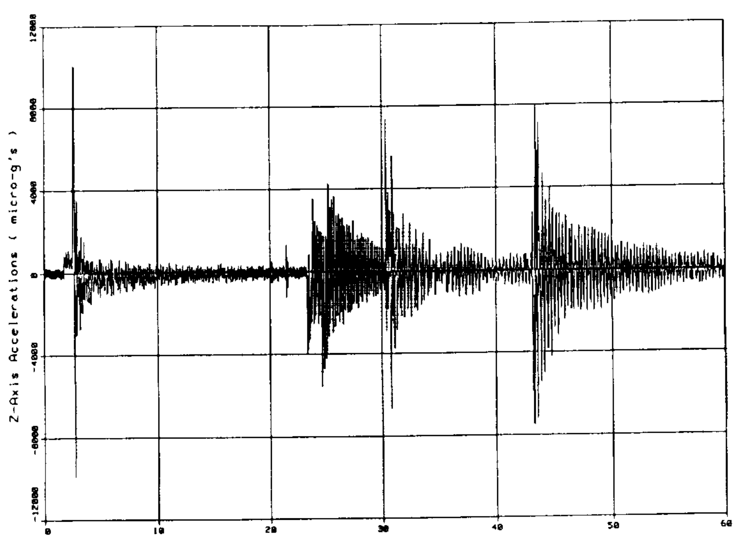
0
-4000
-8000
-12000
0
20
40
60
80
100
120
Time (seconds)

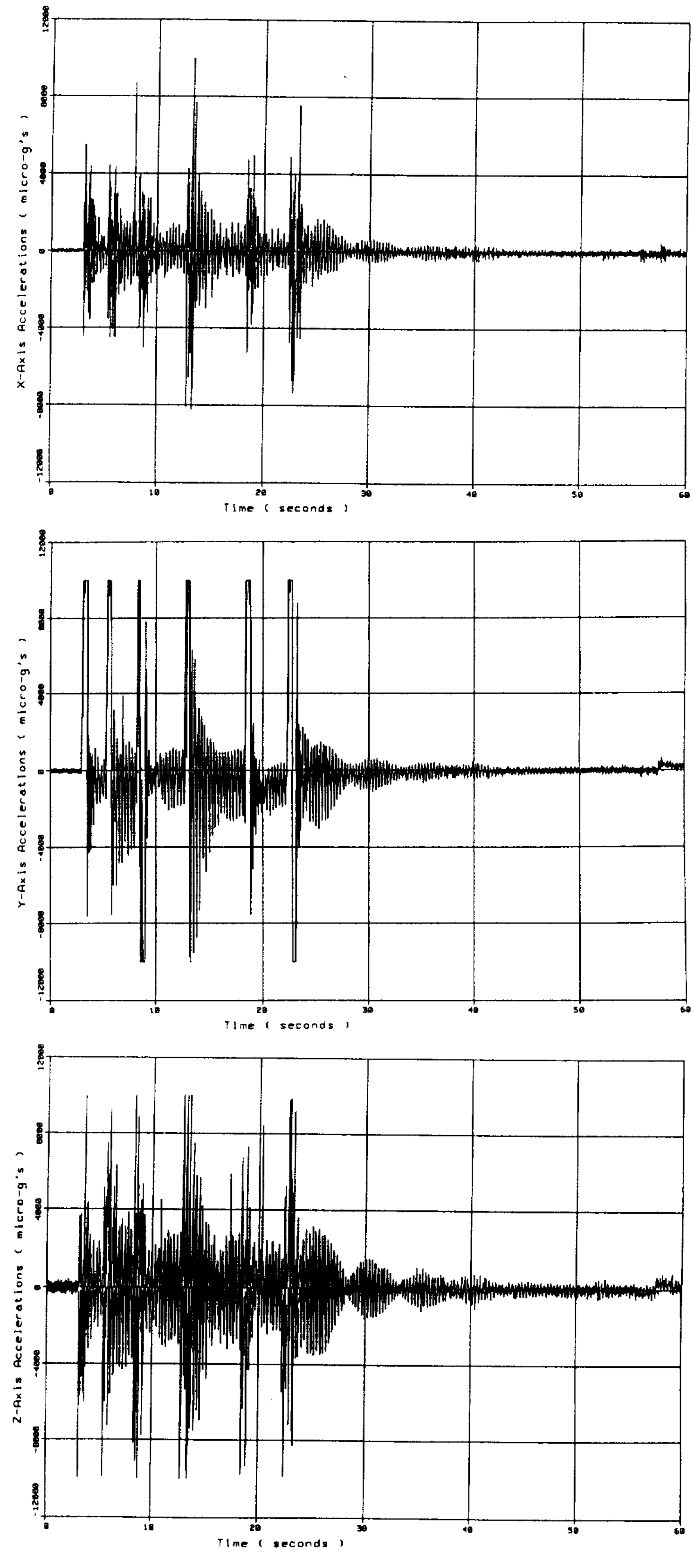
PRCS Burn - TI







PRCS Burn - MC3



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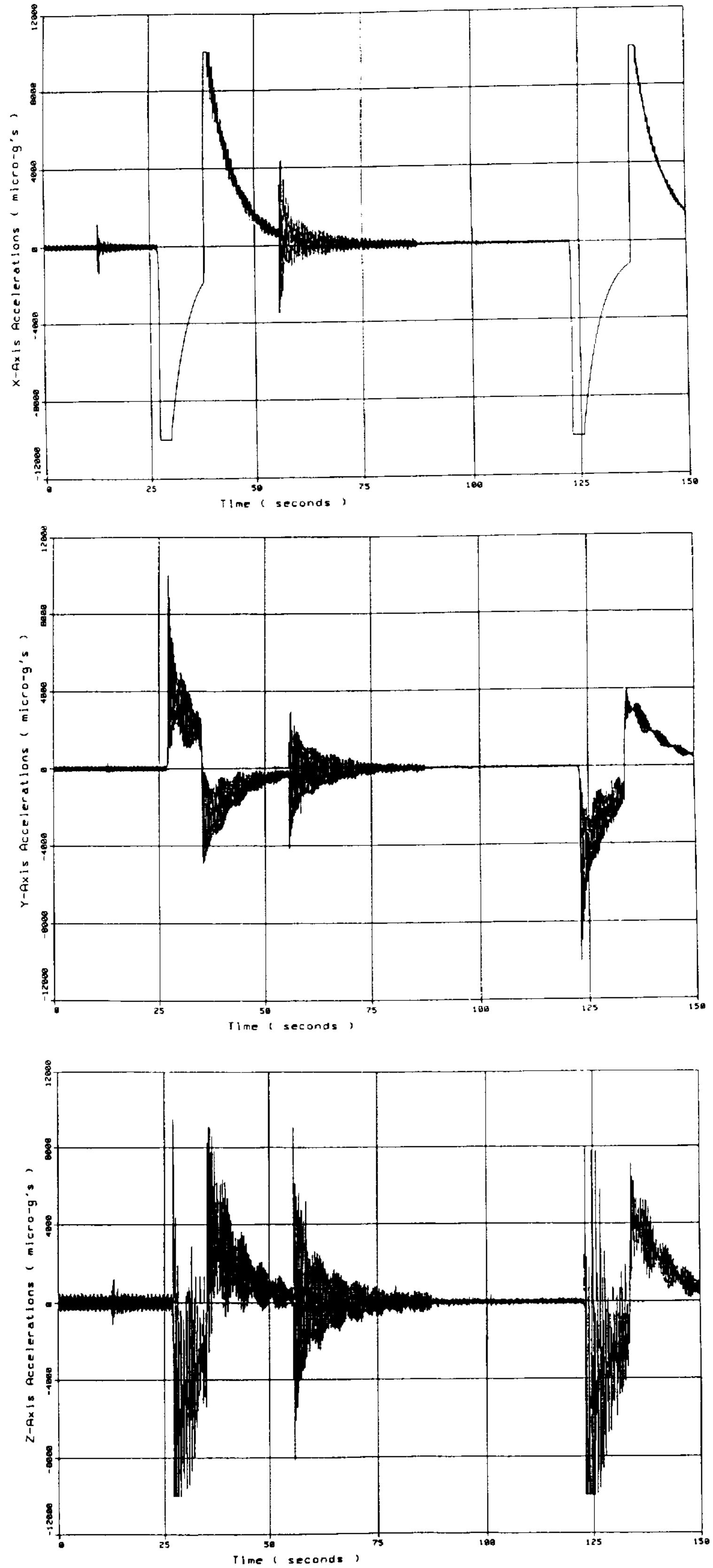
X-Axis Accelerations (micro-g's)
Time (seconds)
Y-Axis Accelerations (micro-g's)
Time (seconds)
Z-Axis Accelerations (micro-g's)
Time (seconds)
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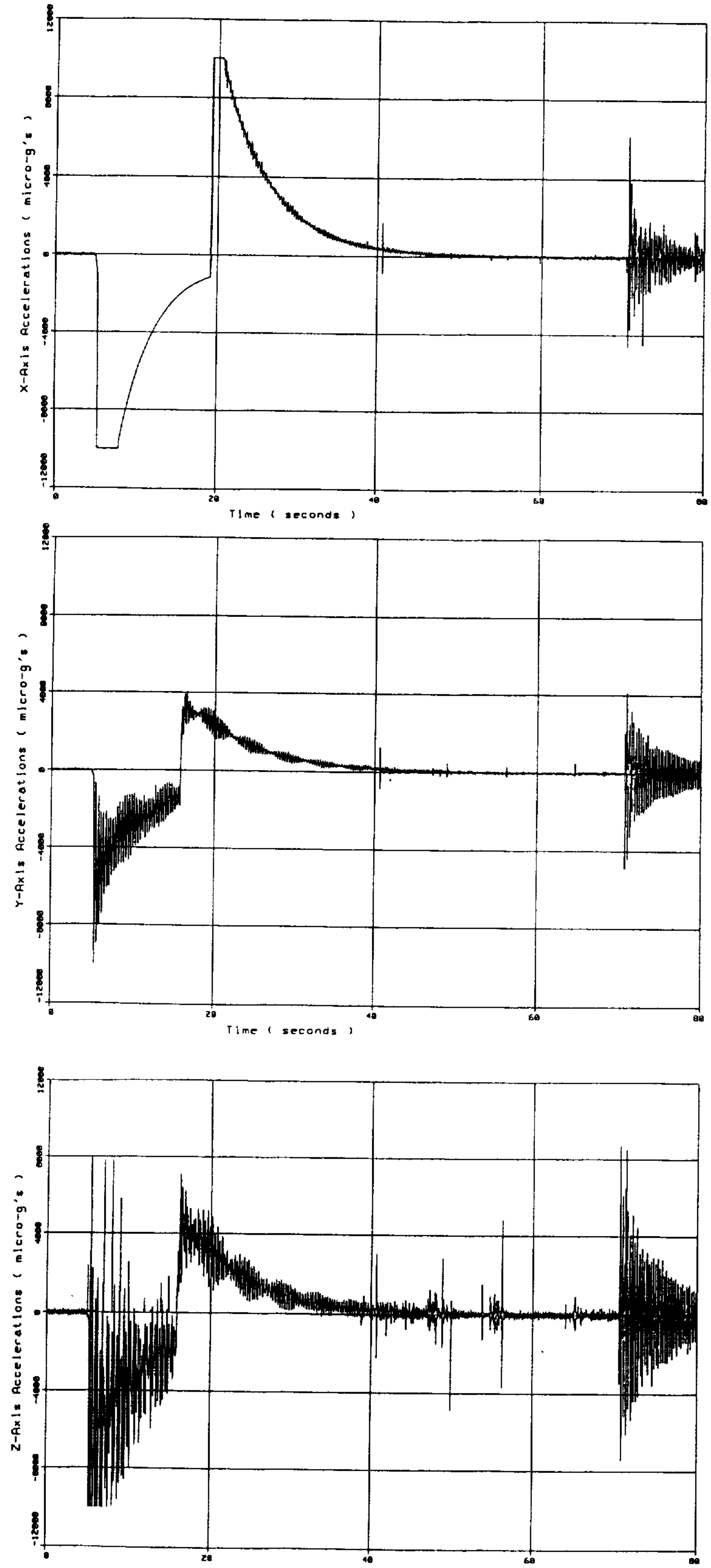
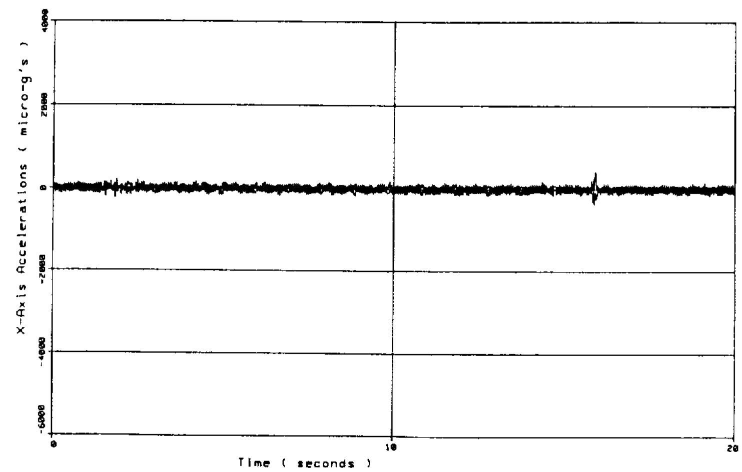
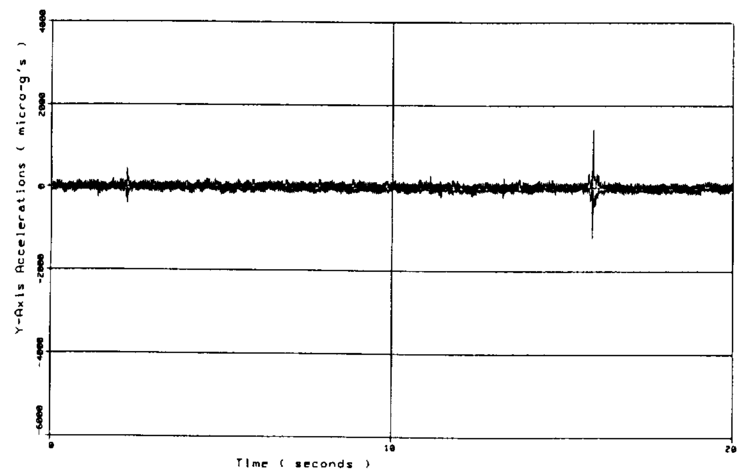
-8000
-4000
0
4000
8000
12000
0
25
50
75
100
125
150

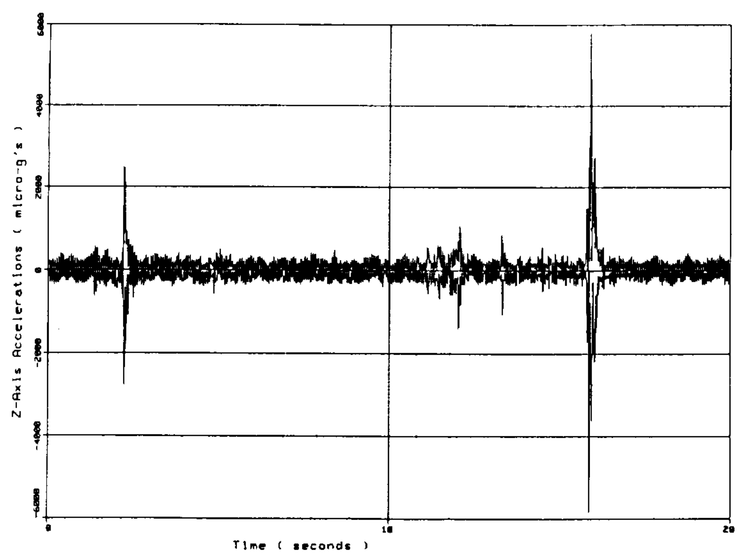
OMS Burn - NH1


X-Axis Accelerations (micro-g's)
Y-Axis Accelerations (micro-g's)
Z-Axis Accelerations (micro-g's)
Time (seconds)
12000
8000
4000
0
-4000
-8000
-12000
0
20
40
60
80

OMS Burn - NSR







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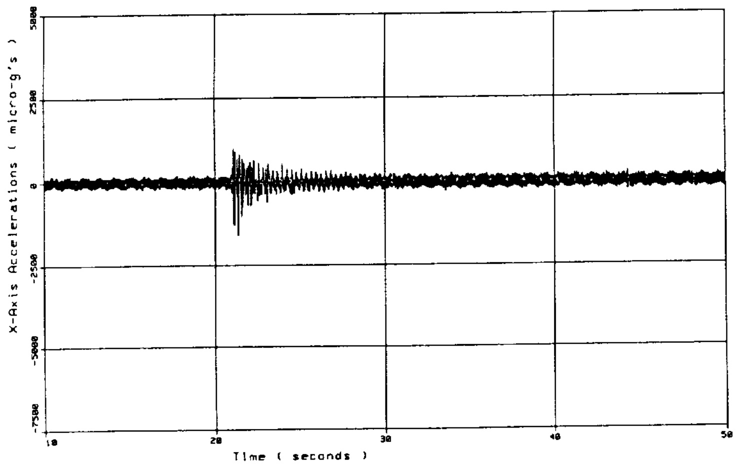

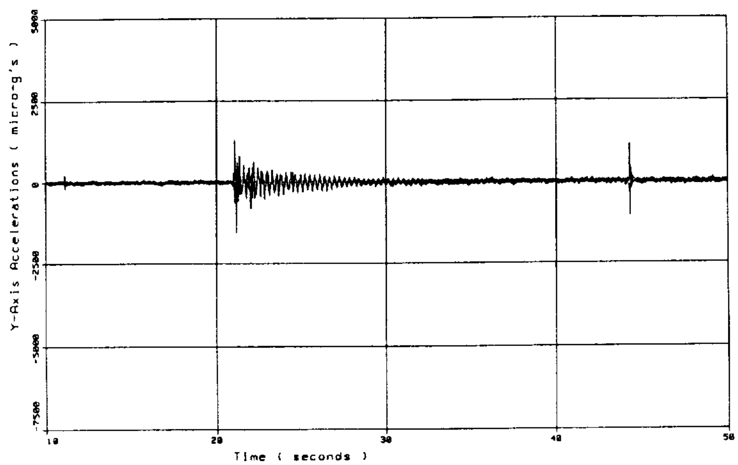

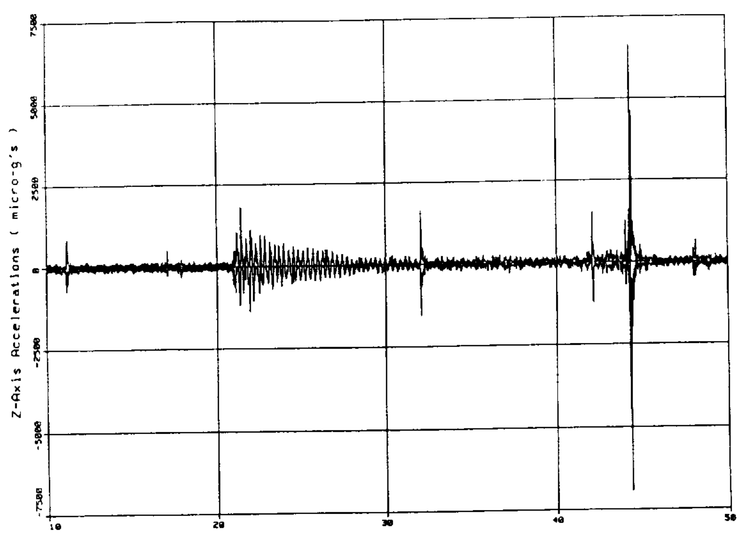

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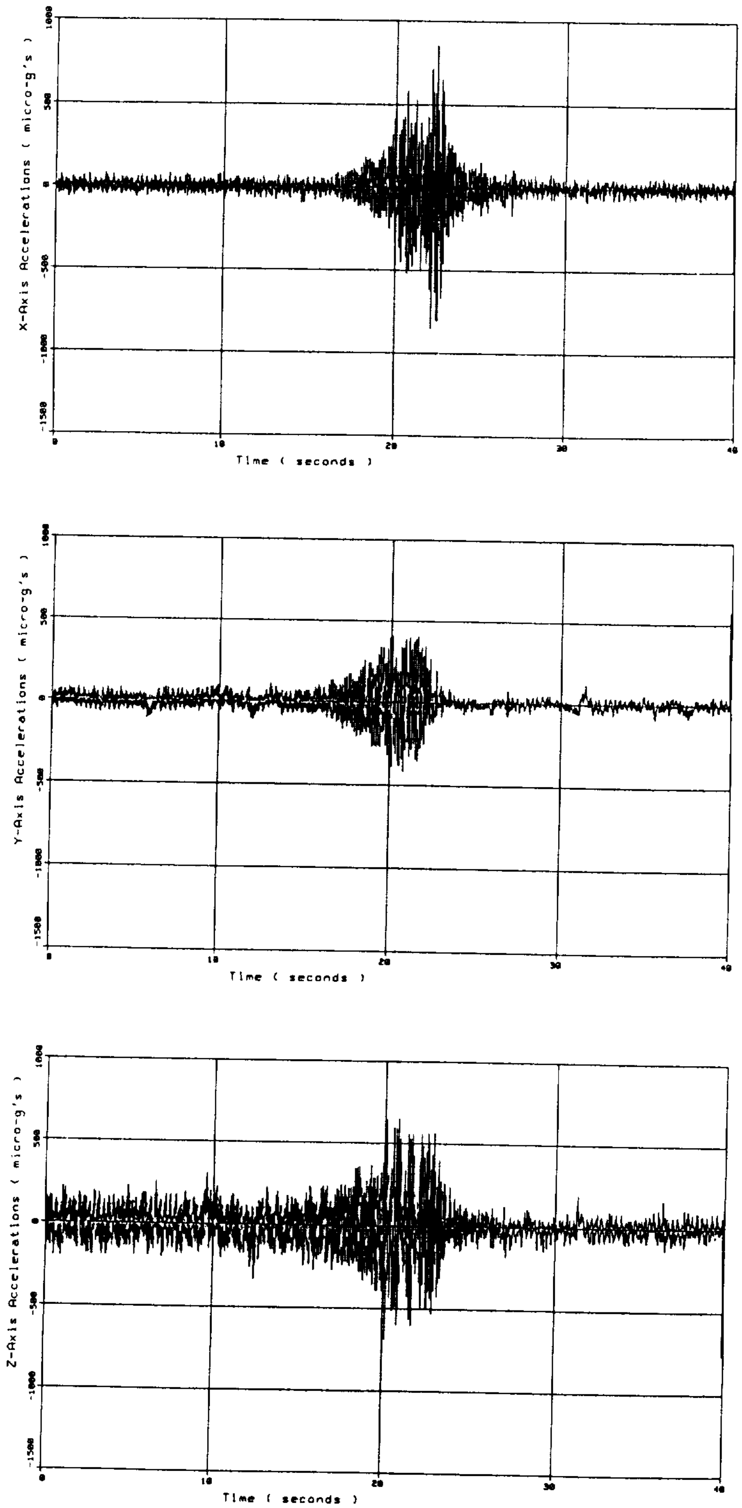

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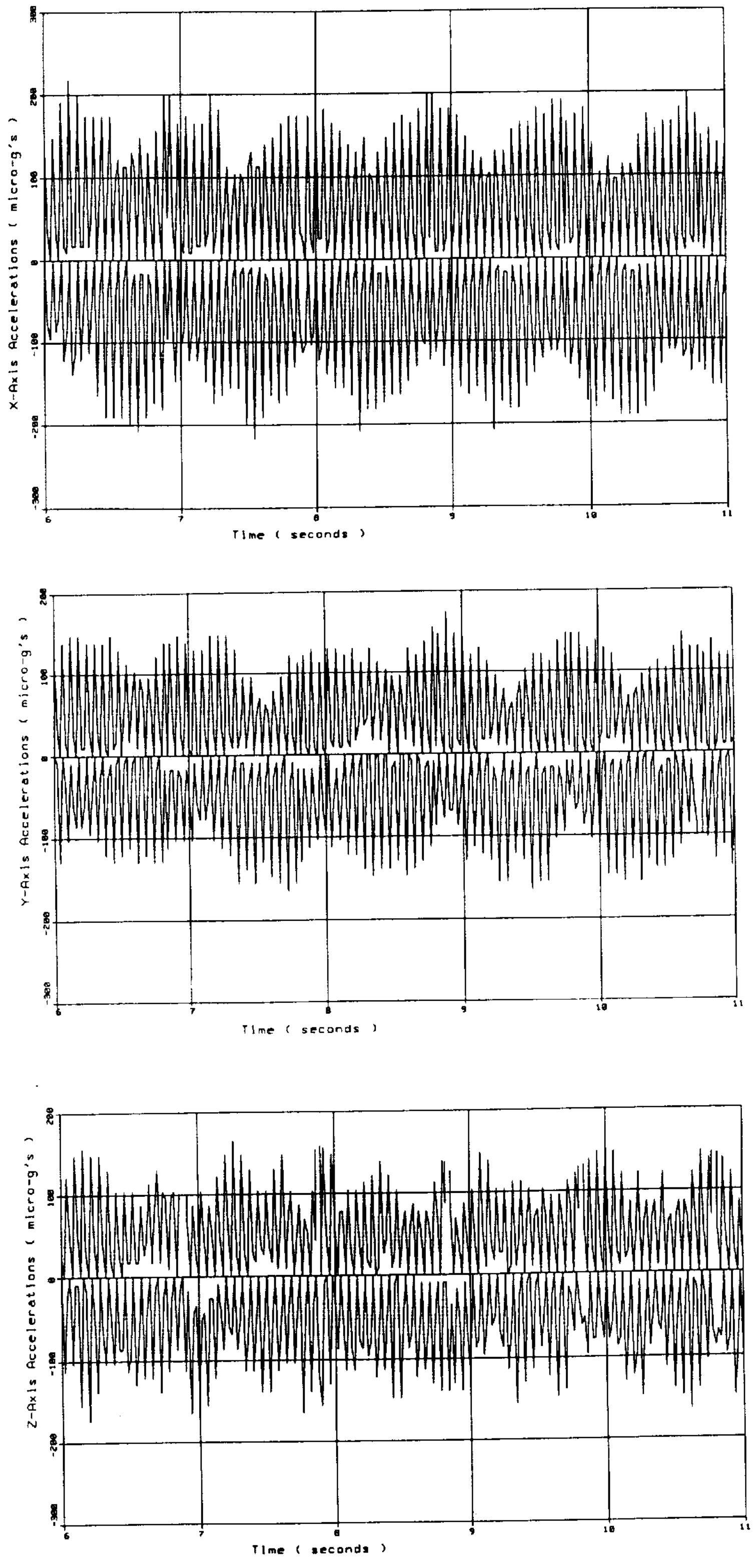
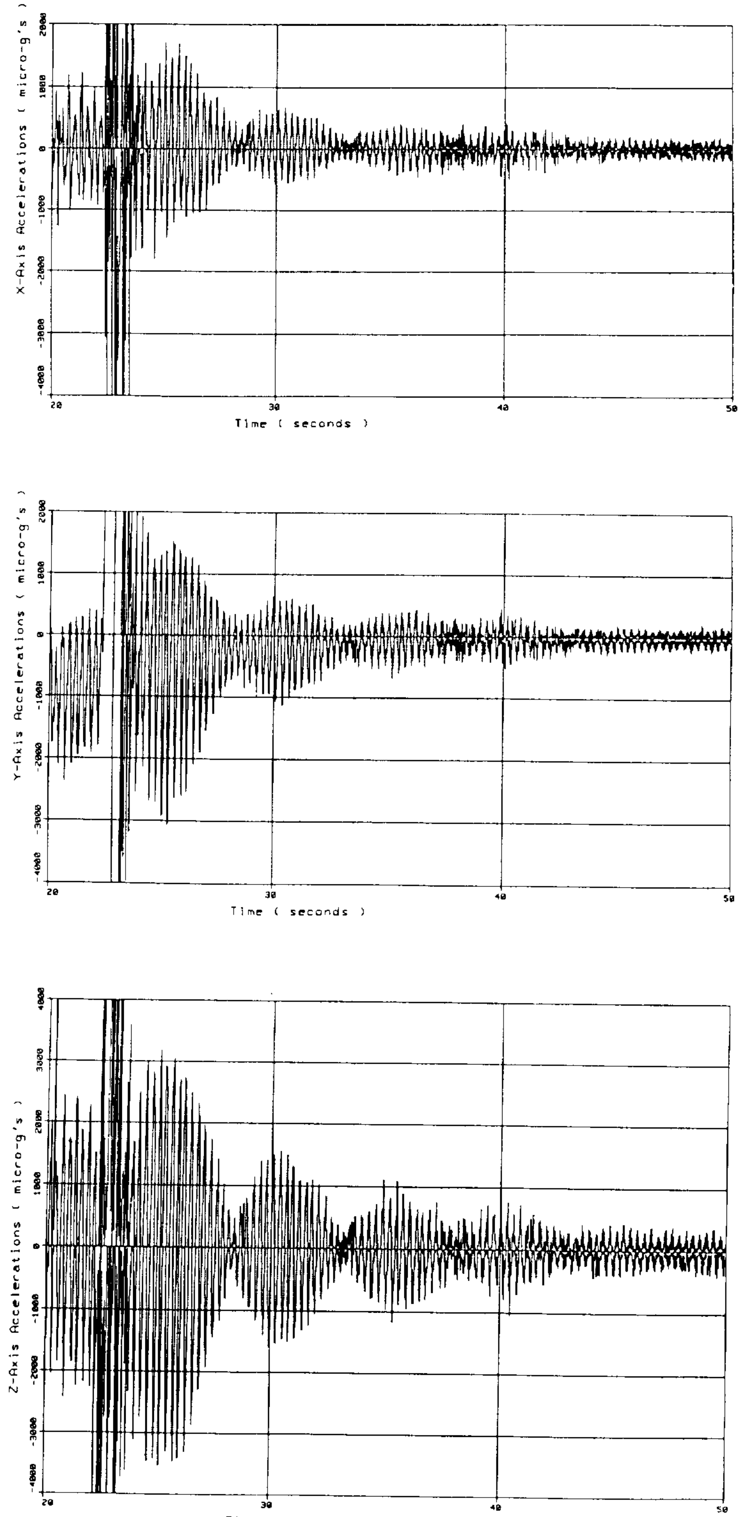


Beat Frequency - treadmill walking



Beat Frequency - post MC4 burn

APPENDIX B

OMS and RCS Engines Description

Reaction Control System (RCS)

The reaction control system (RCS) consists of 44 individual thrusters located in 3 separate modules in the Orbiter (forward, aft-left, aft-right). There are 38 primary jets and 6 vernier jets. Each primary jet is rated at 870 lb. of thrust, and each vernier jet is rated at 24 lb. of thrust. The primary jets are used to control the motion of the Space Shuttle vehicle through a combination of translation and/or rotational movement. The vernier jets are only used on orbit for fine attitude control. The location of the RCS thrusters in relationship to the Orbiter is shown in figure B-1, and details of the jet locations and plume directions are shown in figure B-2. While most thrusters are aligned with the Orbiter body axes, it should be noted that many of the thrusters in the forward module are off-axis. This is further illustrated in figure B-3. The six vernier thrusters are shown on figure B-2 as F5R, F5L, L5L, L5D, R5R, and R5D.

Orbital Maneuvering System (OMS)

The OMS engines provide propulsion for the Space Shuttle vehicle during the orbit phase of flight. They are used for orbital insertion maneuvers after the main propulsion system has shut down. They are also the primary propulsion system for orbital transfer maneuvers and the deorbit maneuver.

There are two OMS engines per Orbiter. Each OMS engine produces 6000 lb. of thrust. The location of the OMS engines in relationship to the Orbiter is shown in figure B-1. As shown in figure B-4, the OMS engines are canted 15.8° upward and 6.5° outboard with respect to the Orbiter body axes. The OMS engines can be pivoted up and down ($\pm 6°$) and from side to side ($\pm 7°$) from their null position.

Orbiter Engine Burn Designations

The four PRCS burn designations (NCC, TI, MC3, and MC4) and two OMS burn designations (NH1 and NSR) listed in table 3 are specific types of engine burns performed during nominal Orbiter rendezvous operations and were executed on STS-32 during the LDEF rendezvous sequence. A brief description of each is provided.

NCC - The NCC burn is used to correct the Orbiter trajectory to achieve a desired offset position from the target. It is usually a combination of three maneuvers and is the first onboard targeted burn using sensor data.

TI - The TI burn is one of the final burns in the rendezvous sequence and is also known as the target intercept burn.

MC - The MC burns (MC1, MC2, MC3, MC4) are a series of burns used as mid-course corrections to intercept the final target. These burns would generally follow the TI burn.

NH - The NH burn is used for height adjustment and is generally a posigrade or retrograde burn.

NSR - The NSR burn is used to enter a co-eliptical orbit with the target. There is generally one NSR burn per rendezvous.

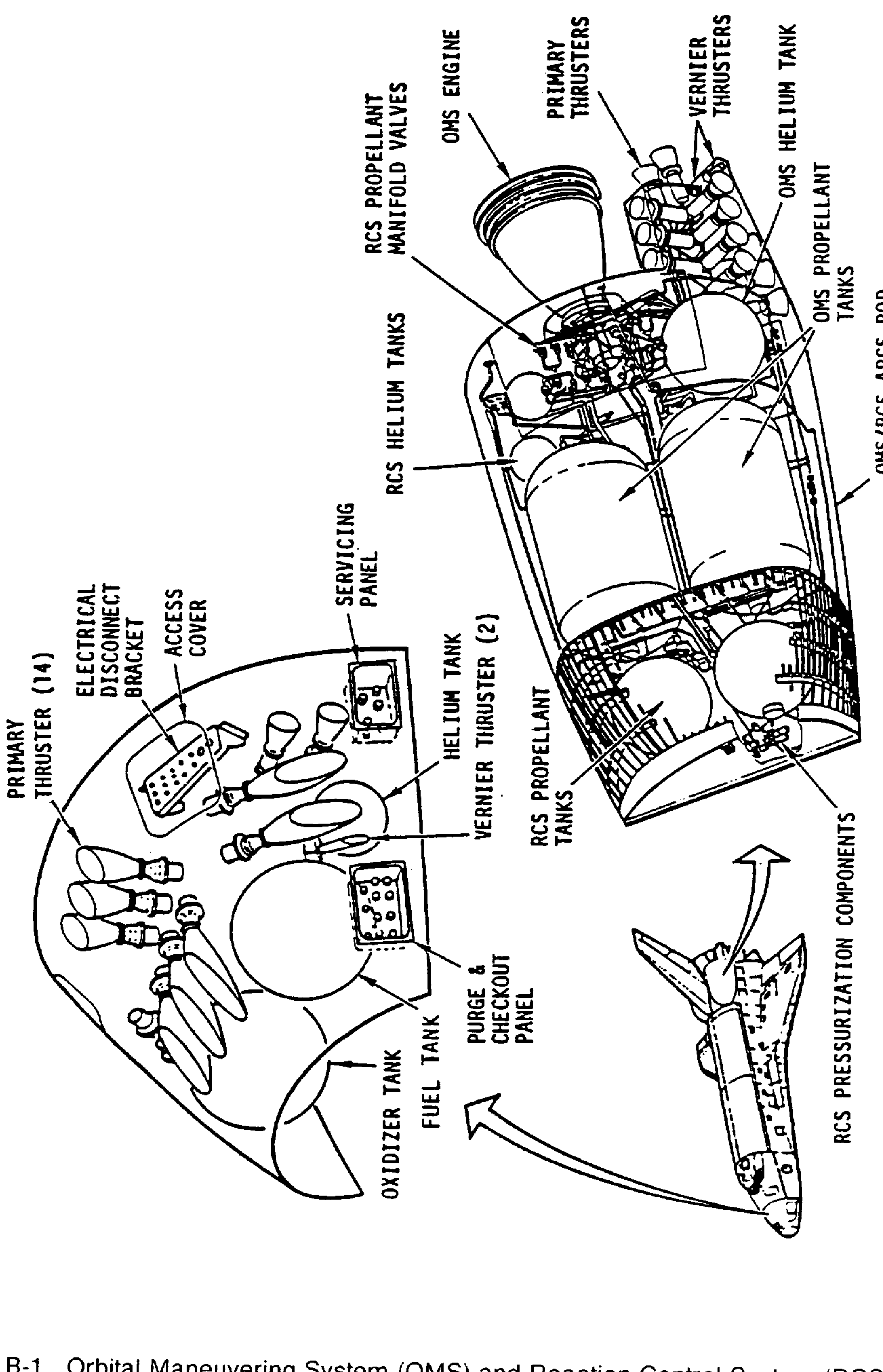


Figure B-1. Orbital Maneuvering System (OMS) and Reaction Control System (RCS) Engine Locations

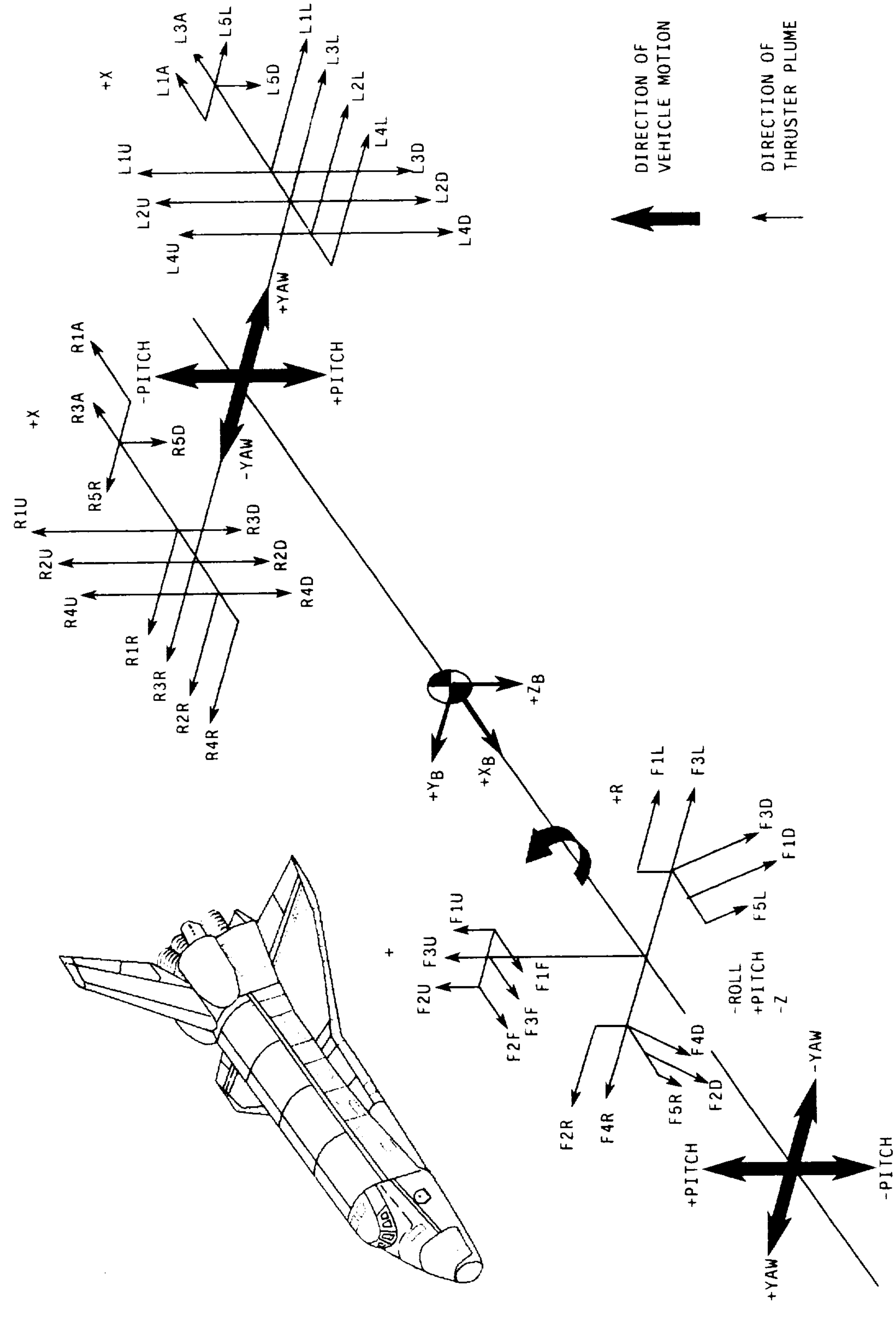


Figure B-2. RCS Jet Locations and Plume Directions

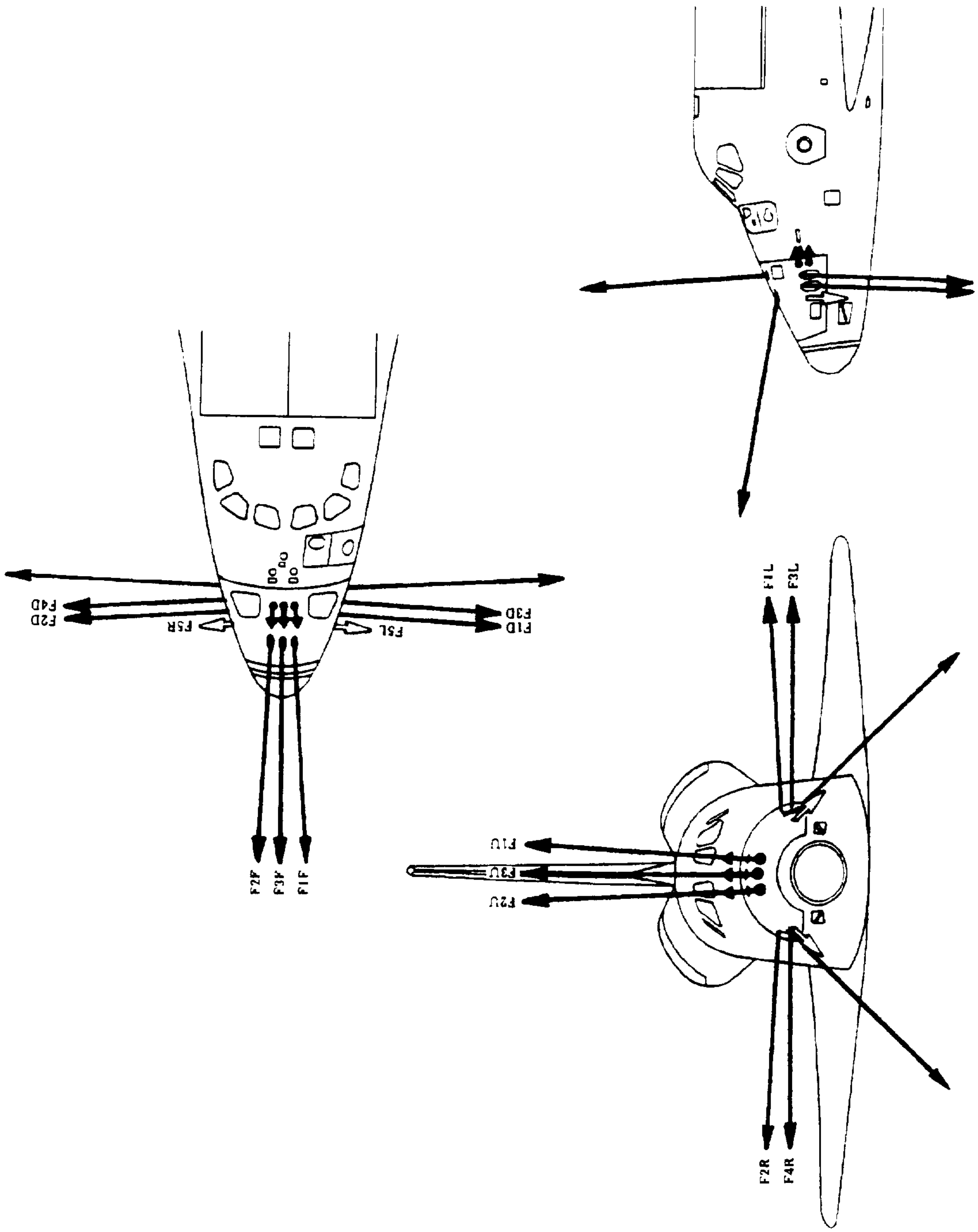


Figure B-3. Detail of RCS Plume Directions

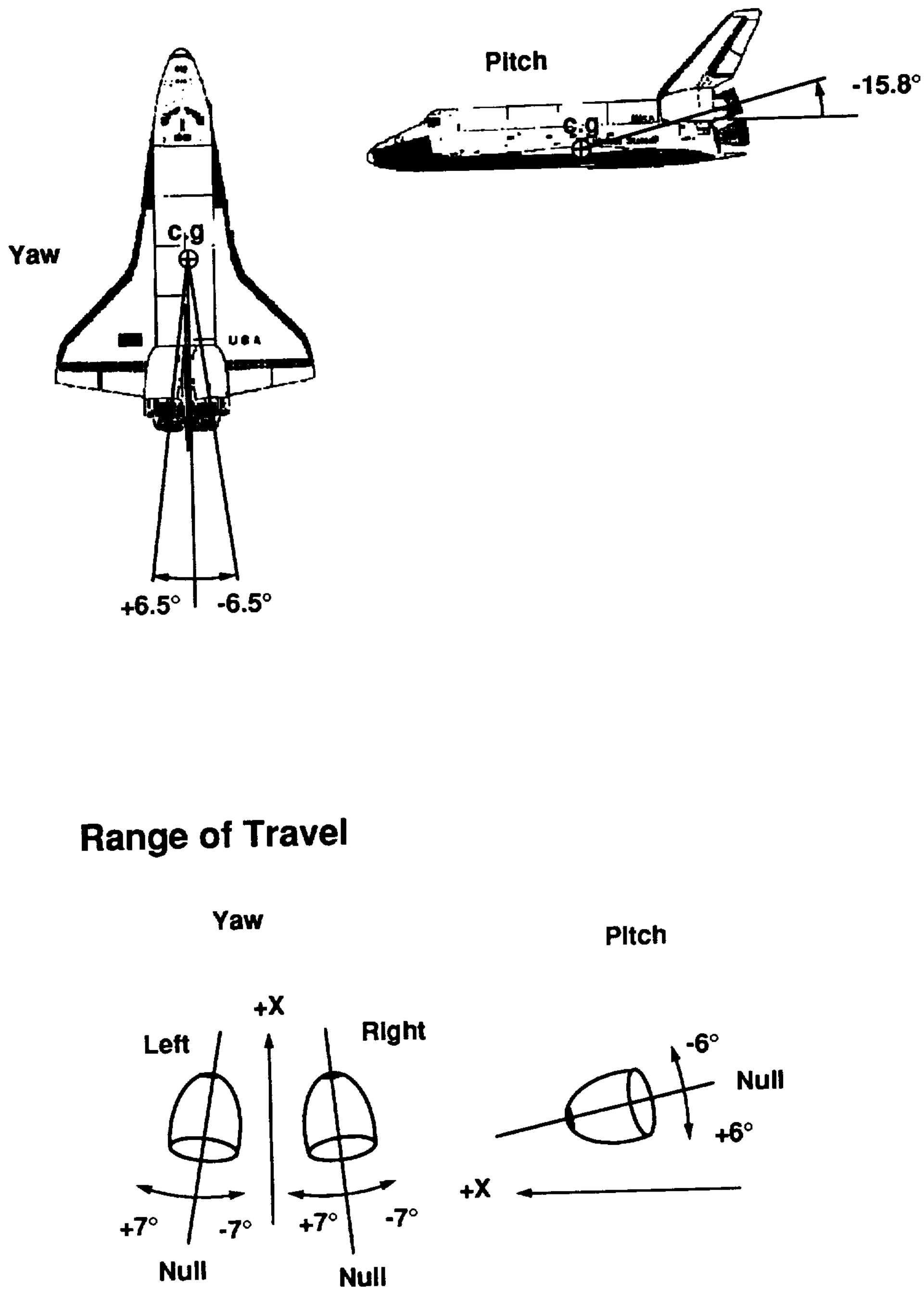


Figure B-4. OMS Engine Alignment with Orbiter

APPENDIX C

Contributors

The following individuals made valuable contributions to this project.

The crew maximized the scientific return from the experiment by their support and commitment to the STS-32 mission.

Capt. Daniel C. Brandenstein, Commander
James Wetherbee, Pilot
Bonnie J. Dunbar, Mission Specialist #1
Marsha Ivins, Mission Specialist #2
G. David Low, Mission Specialist #3

A. Max Vallejo, Rockwell International, FEA project engineer, led the team that modified the FEA to accommodate the HISA.

Donald De Laquil, Rockwell International, led the team that developed the software for recording the HISA data.

Saverio Gaudiano, NASA Johnson Space Center, Data Systems Branch, led the team that developed the HISA Orbiter interface hardware and oversaw the certification of the hardware for flight.

Charles E. Chassay, NASA Johnson Space Center, NSTS Program Office, was tireless in his efforts in negotiating the use of the HISA on STS-32.

Earl Cooke, 3M Company, St. Paul, Minnesota, cooperated to the fullest and provided rapid turnaround of the HISA hardware after its flight on STS-34.

Joseph E. Rogers, NASA Johnson Space Center, Structures and Mechanics Division, developed the software and plotting routines for the many plots presented in this report.

Robert L. Giesecke, NASA Johnson Space Center, reviewed the accelerometer data and assisted in the interpretation.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
November 1991

3. REPORT TYPE AND DATES COVERED
Technical Paper

4. TITLE AND SUBTITLE
The Microgravity Environment of the Space Shuttle Columbia Middeck During STS-32

5. FUNDING NUMBERS

6. AUTHOR(S)
Bonnie J. Dunbar, Donald A. Thomas, and Jeff N. Schoess

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Astronaut Office
NASA/Johnson Space Center
Houston, Texas 77058

8. PERFORMING ORGANIZATION REPORT NUMBER
S-640

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-001

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
NASA TP-3140

11. SUPPLEMENTARY NOTES
Bonnie J. Dunbar and Donald A. Thomas: Lyndon B. Johnson Space Center, Houston, Texas.
J. N. Schoess: Honeywell Incorporated, Bloomington, Minnesota.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Unclassified/Unlimited
Subject Category 88

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Four hours of three-axis microgravity accelerometer data were successfully measured at the MA9F locker location in the Orbiter middeck of Columbia as part of the Microgravity Disturbances Experiment (MDE) on STS-32. This data was measured using the Honeywell In-Space Accelerometer (HISA), a small three-axis accelerometer that was hard-mounted onto the Fluids Experiment Apparatus (FEA) to record the microgravity environment at the exact location of the MDE. Data were recorded during specific mission events such as Orbiter quiescent periods, crew exercise on the treadmill, and numerous Orbiter engine burns. Orbiter background levels were measured to be in the 3×10^{-5} to 2×10^{-4}g range, treadmill operations in the 6×10^{-4} to 5×10^{-3}g range, and Orbiter engine burns from 4×10^{-3} to in excess of 1.0×10^{-2}g. These data represent some of the first microgravity accelerometer data ever recorded in the middeck area of the Orbiter.

14. SUBJECT TERMS
Microgravity, Accelerometers, Crystal Growth, Space Flight

15. NUMBER OF PAGES
60

16. PRICE CODE
A04

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
UL