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Space Acceleration Measurement System (SAMS) / Orbital Acceleration Research Experiment (OARE)

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ONE YEAR REPORT FOR SAMS AND OARE ON STS-78/LMS

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1. INTRODUCTION

The Life and Microgravity Spacelab (LMS) payload flew on the Orbiter Columbia on mission STS-78 from June 20th to July 7th, 1996. The LMS payload on STS-78 was dedicated to life sciences and microgravity experiments. Two accelerometer systems managed by the NASA Lewis Research Center (LeRC) flew to support these experiments, namely the Orbital Acceleration Research Experiment (OARE) and the Space Acceleration Measurements System (SAMS). In addition, the Microgravity Measurement Assembly (MMA), managed by the European Space Research and Technology Center (ESA/ESTEC), and sponsored by NASA, collected acceleration data in support of the experiments on-board the LMS mission. OARE downlinked real-time quasi-steady acceleration data, which was provided to the investigators. The SAMS recorded higher frequency data on-board for post-mission analysis. The MMA downlinked real-time quasi-steady as well as higher frequency acceleration data, which was provided to the investigators.

The Principal Investigator Microgravity Services (PIMS) project at NASA LeRC supports principal investigators of microgravity experiments as they evaluate the effects of varying acceleration levels on their experiments. A summary report [1] was prepared by PIMS to furnish interested experiment investigators with a guide to evaluate the acceleration environment during STS-78, and as a means of identifying areas which require further study. The summary report provides an overview of the STS-78 mission, describes the accelerometer systems flown on this mission, discusses some specific analyses of the accelerometer data in relation to the various activities which occurred during the mission, and presents plots resulting from these analyses as a snapshot of the environment during the mission.

Numerous activities occurred during the STS-78 mission that are of interest to the low-gravity community. Specific activities of interest during this mission were crew exercise, radiator deployment, Vernier Reaction Control System (VRCS) reboost, venting operations, Flight Control System (FCS) checkout, rack excitation, operation of the Life Sciences Laboratory Equipment Refrigerator/Freezer (LSLE R/F), operation of the JSC Projects Centrifuge, crew sleep, and attitude changes. The low-gravity environment related to these activities is discussed in the summary report.

2. ACCELEROMETER SYSTEMS

Two NASA LeRC accelerometer systems, OARE and SAMS, measured the low-gravity environment of the Space Shuttle Columbia during the STS-78 mission. The OARE was designed to measure quasi-steady accelerations from below 1×10^{-8} g up to 2.5×10^{-3} g. It is mounted near the center of gravity of the space shuttle vehicle. On STS-78, the SAMS unit was located in the Spacelab module in rack 7 in support of LMS experiments. Three SAMS triaxial sensor heads (TSH) were located remotely at experiment sites (Table 1). The signals from these sensor heads were filtered by low-pass filters with cutoff frequencies listed in Table 1. These signals were then sampled, and the data were recorded on optical disks.

The MMA unit on LMS consisted of four Microgravity Sensor Packages (MSPs) and one Accelerometer Spatiale Triaxiale Electrostatique (ASTRE). The MSPs are triaxial sensor heads capable of measuring disturbances in the 0.1 to 100 HZ range. The ASTRE is a quasi-steady sensor designed to measure disturbances at frequencies below 1HZ. The ASTRE and one MSP reside within the MMA unit which was located in rack 3. The remaining three MSP sensor heads were located remotely at the BDPU (Rack 8), AGHF (Rack 3) and APCF (Rack 7) experiment sites within the Spacelab.

3. COORDINATE SYSTEMS

The OARE data is typically presented in the Orbiter body coordinate system (X_b, Y_b, Z_b). In this coordinate system, the direction from tail to nose of the Orbiter is $+X_b$. The direction from port wing (left wing) to starboard wing (right wing) is $+Y_b$, and the direction from the top of the fuselage to the Orbiter belly is $+Z_b$. This coordinate system is centered at the center of gravity (C.G.) of the Orbiter [1].

The SAMS data is typically presented in the Orbiter structural coordinate system (X_o, Y_o, Z_o). In this coordinate system the direction from nose to tail of the Orbiter is $+X_o$. The direction from port wing to starboard wing is $+Y_o$, and the direction from the Orbiter belly to the top of the Orbiter fuselage is $+Z_o$. This coordinate system is centered at the tip of the Orbiter external fuel tank [1].

4. COLUMBIA MICROGRAVITY ENVIRONMENT - STS-78

The microgravity environment measured by an accelerometer system on the Orbiter has many components. The quasi-steady microgravity environment is related to orbital phenomena such as aerodynamic drag and rotational motion and to gravity gradient effects based on the distance from the Orbiter center of gravity. In addition to these quasi-steady acceleration, all ongoing operations of crew life support systems and activities and operations of the Orbiter, crew, carrier, and experiments tend to have transient and vibratory components that contribute to the background acceleration environment. The following subsections describe some of the most interesting events which contributed to the microgravity environment during the mission.

4.1 Radiator Deploy

The STS-78 Space Shuttle Mission Report [2] lists the time of the port radiator deploy as MET 002/03:23:53. Following the examination of the SAMS data around this time frame, it was concluded that this time corresponds to the end of the radiator deploy operation. Three 25-second windows were chosen, corresponding to the times before, during and after the deploy operations. For each period PSDs were computed from the SAMS TSH a data acquired, and the Root-Sum-of-Squares (RSS) of the three axes were plotted in overlapping fashion (Figure 1). It can be seen from Figure 1 that the PSD for the during-deploy period shows the addition of a 6.30 HZ and a 9.47 HZ peak, which do not appear in either the before deploy or after deploy periods. These two peaks may be related to the motor which drives the radiators away from the payload bay doors. The after deploy period shows the addition of a 3.37 HZ peak which does not appear in the before deploy spectrum.

4.2 VRCS Reboost Demonstration

During LMS, a detailed test objective called the Vernier Reaction Control System Reboost Demonstration was performed. During this test, the Orbiter was in a -XLV/-ZVV attitude while two pairs of VRCS jets (F5L/F5R and L5D/R5D) were alternately fired in a precise pattern to slightly raise the Orbiter's attitude. This pattern can be seen in Figure 2 where the forward (FWD) and AFT vernier jet firings are indicated by the top and bottom rows of "+" markers, respectively. As a result, the Orbiter was ratcheted to a higher altitude as is suggested by the pitch angle data due to this region of the spectrum having been masked due to an increase in broad-band noise. The impulsive transients which occur roughly every 20 seconds during the checkout procedure are the cause of the increase PSD noise floor.

No disturbance to the microgravity environment were detected during the phase 2 of the FCS checkout procedure, as expected, as this is a test of the electronics and command channels.

4.4 Venting Operations

Supply and waste water dumps are performed using nozzles on the port side of the Orbiter. Figures 4 and 5 show a simultaneous supply/waste water dump and a supply water dump, respectively. These water dumps show contributions to the Y_b-axis and, unexpectedly, to the Z_b-axis. The reason for the Z_b-contribution is unknown at this time.

Another venting system, the Flash Evaporator System (FES), is a component of the Orbiter Active Thermal Control System. The flash evaporators are located in the aft fuselage of the Orbiter. No discernible effects of FES operations were seen in the OARE data for this mission.

4.5 Orbiter Attitude

The LMS mission was flown predominantly in two attitudes: -XLV/+ZVV and -ZLV/-XVV. [illegible]

4.7 Ergometer Exercise

During this mission, ergometer exercise was performed in both the Spacelab module and on the flight deck. Analysis of the SAMS data has shown that this type of exercise resulted in a disturbance with frequency about 2 to 3 Hz on all three axes, most notably the Y_o- and Z_o-axes. More detailed analysis of exercise can be found in Reference 1.

4.8 Rack Excitation

During the BDPU experiment operations, it became necessary for Payload Specialist Jean-Jaques Favier to close the front-panel of the BDPU experiment module in Rack 8 of the Spacelab. Acceleration data from SAMS TSH A, which was mounted on the BDPU Rack, is shown in Figure 9 for this time frame. As seen, the transitory disturbance induced by this action is prevalent on the Y_o- and Z_o-axes. The acceleration vector magnitude during this operation peaked at about $3x10^{-3}g$ [1].

4.9 Life Sciences Laboratory Equipment Refrigerator/Freezer

Two LSLE R/F units were flown side-by-side in Rack 9.From the SAMS data it is appears that two acceleration signals with frequencies around 22.00 and 23.07 Hz are the primary disturbances seen from the two LSLE R/F units. Harmonics of the fundamental frequencies of 22.00 and 23.07 Hz are seen at approximately 44 and 46 Hz. In addition to these signals, signal aliasing is believed to be present [1].

A third signal, with frequency of 23.61 Hz, and with a harmonic at 47.00 Hz, and aliases at 48.64 and 51.34 Hz is believed to be related to the LSLE R/F units.

4.10 JSC Projects Centrifuge

A centrifuge was mounted in Rack 12 of the Spacelab module. Analysis of the SAMS TSH C data and the MMA MSP APCF and MSP BDPU data show the disturbance generated by the centrifuge which had a rotational frequency of 39.8 Hz. Two other lower frequency disturbances at 15.7 and 24.1 Hz are thought to be related to the operation of the centrifuge [1].

5. CONCLUSIONS

The microgravity environment of the Space Shuttle Columbia was measured during the STS-78 mission using three accelerometer systems, namely the NASA LeRC OARE and SAMS, and the European MMA. The OARE provided investigators with real-time quasi-steady acceleration measurements. SAMS recorded higher frequency data on-board, which was analyzed post-mission. The MMA provided investigators with real-time quasi-steady and higher frequency acceleration measurements. The microgravity environment related to several different Orbiter, crew, and experiment operations was presented and interpreted.

A radiator deploy, the Flight Control System checkout, and the vernier reaction control system reboost demonstration had minimal effects on the acceleration environment. Frequency components at 6.3 and 9.47 Hz were present in the SAMS data during the port radiator deploy. These frequencies may be related to the motor which drives the radiators away from the payload bay doors. During the FCS checkout period, regular impulse accelerations of about 5×10^{-3} to 10×10^{-3}g were evident in the SAMS data. Flash Evaporator System venting had no noticeable effect on the environment while supply and waste water dumps caused excursions of 2×10^{-6} to 4×10^{-6}g in the Y_b and Z_b directions. Crew sleep and ergometer exercise periods can be clearly seen in the acceleration data, as expected. Accelerations related to the two Life Science Laboratory Equipment Refrigerator/Freezers were apparent in the data with fundamental frequencies of 22 and 23 Hz. These signals showed different characteristics than on previous missions. The cause for the differences is being investigated. Accelerations caused by the JSC Projects Centrifuge were evident at about 40 Hz. Disturbances at 15.7 and 24 Hz appear to be temporally related.

The SAMS and MMA MSP sensor data compare well for the times studied. No detailed comparisons have been made for the OARE and MMA quasi-steady, ASTRE sensor data.

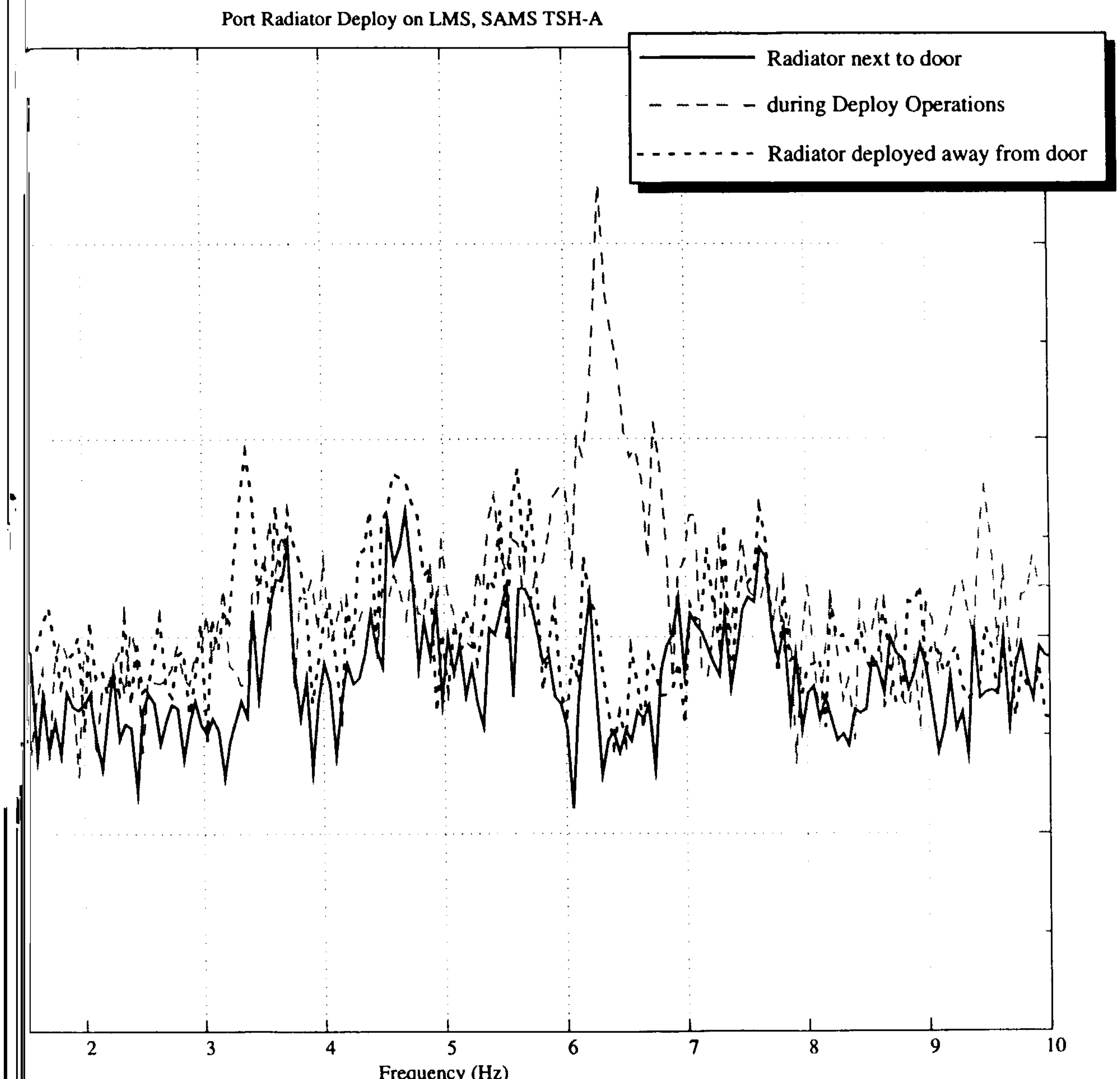
REFERENCES

1. R. Hakimzadeh, et. al. *"Summary Report of Mission Acceleration Measurements for STS-78"*, NASA TM 107401.

2. STS-78 Space Shuttle Mission Report, NSTS-37409, August 1996.

Sensor Head	Cutoff Frequency	Sampling Rate (samples/sec)	Sensor Location
TSH A	10 Hertz	50	Rack 8 (behind front panel)
TSH B	10 Hertz	50	Rack 3 (behind front panel)

Table 1. STS-78 SAMS Head Locations



A data PSDs for periods before, during, and after port radiator deploy. Note differences at 3.37, 6.30, and 9.47 Hz.

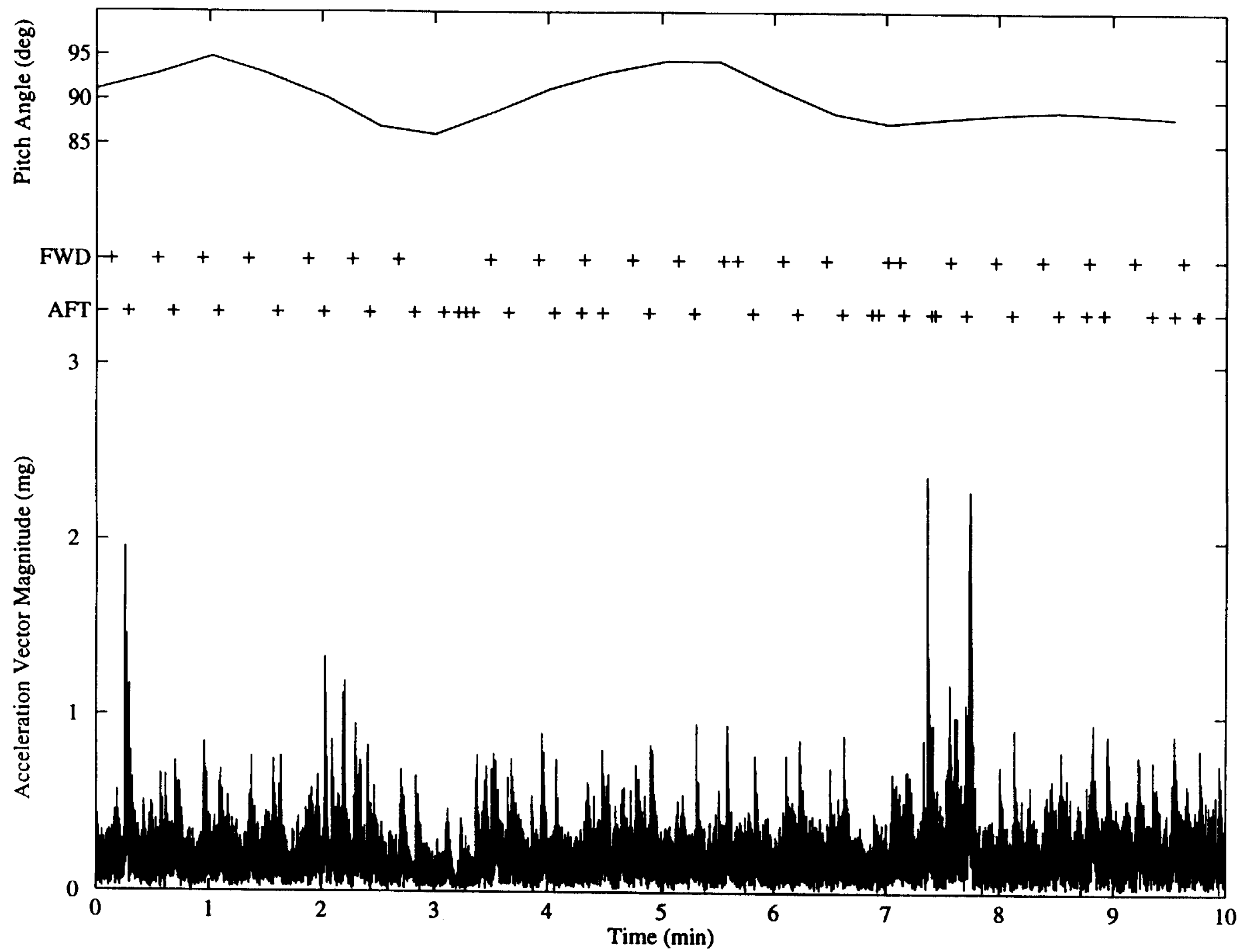


Figure 2. SAMS TSH A data for VRCS Reboost Demonstration. Also indicated are the firing events for two pairs of VRCS jets (FWD and AFT) and the Orbiter pitch angle for this period.

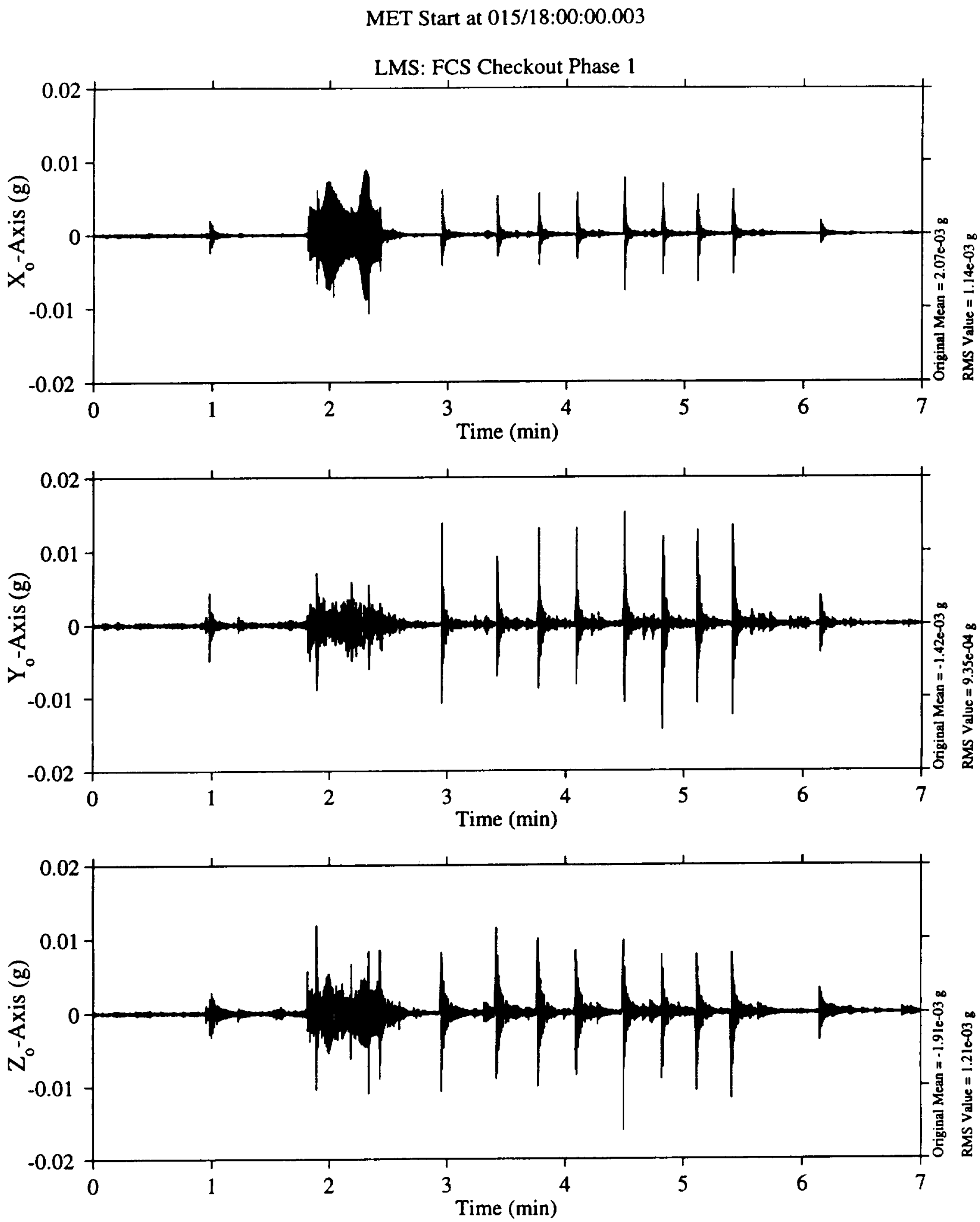


Figure 3. SAMS TSH A data for Flight Control System checkout phase 1

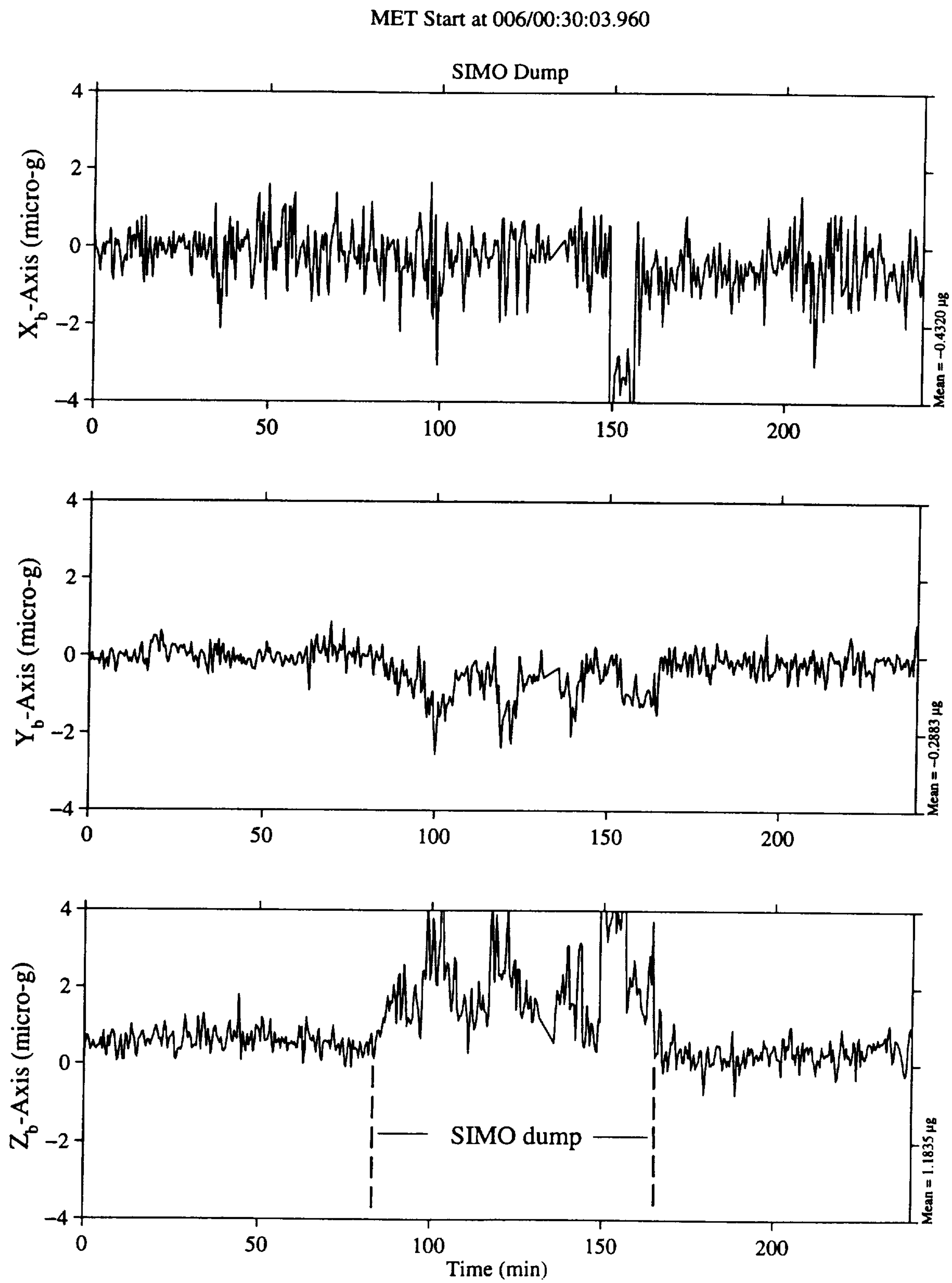


Figure 4. OARE data collected during a simultaneous supply and waste water dump at MET 006/00:30

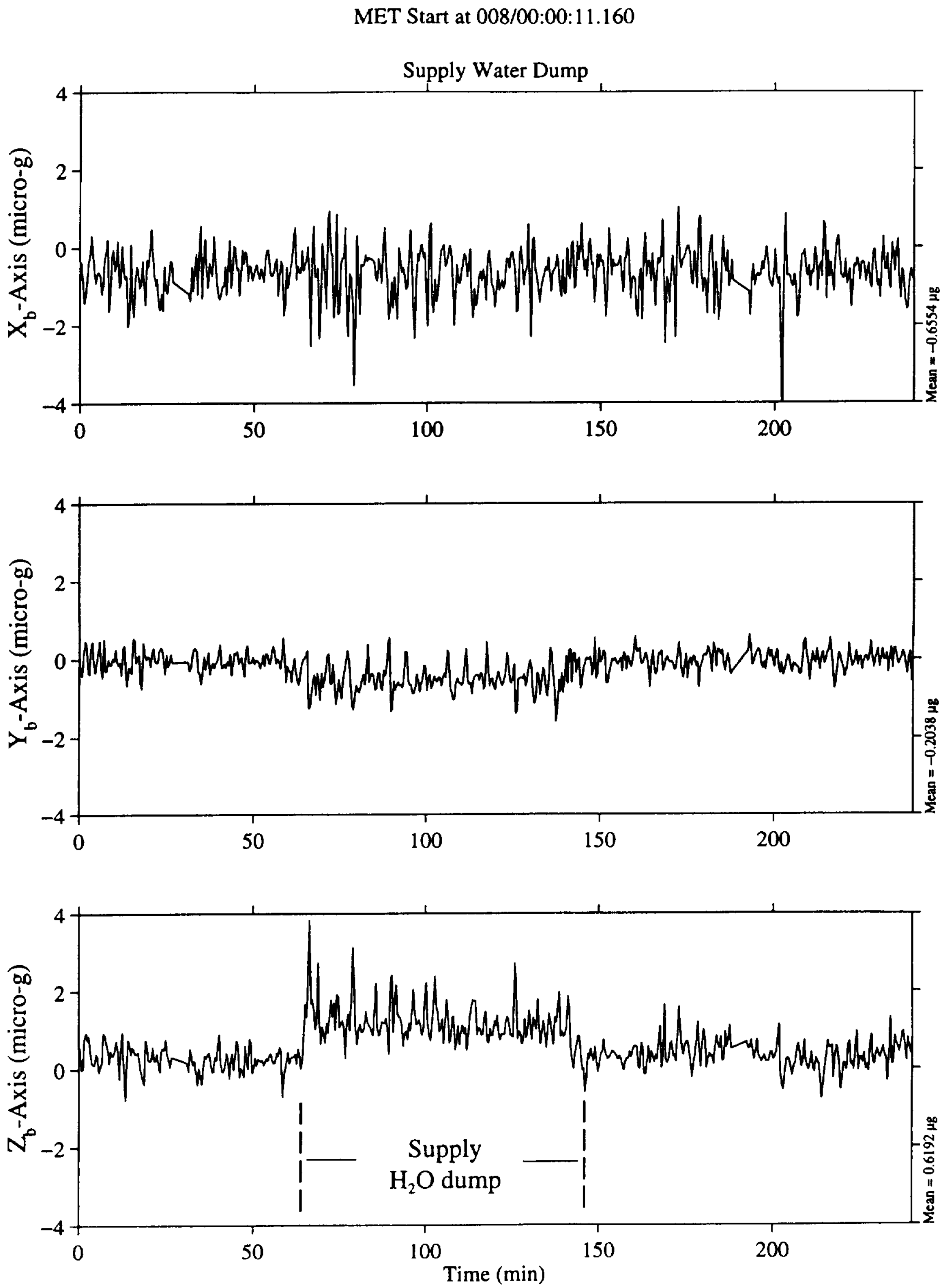


Figure 5. OARE data collected during a supply water dump at MET 008/00:00.

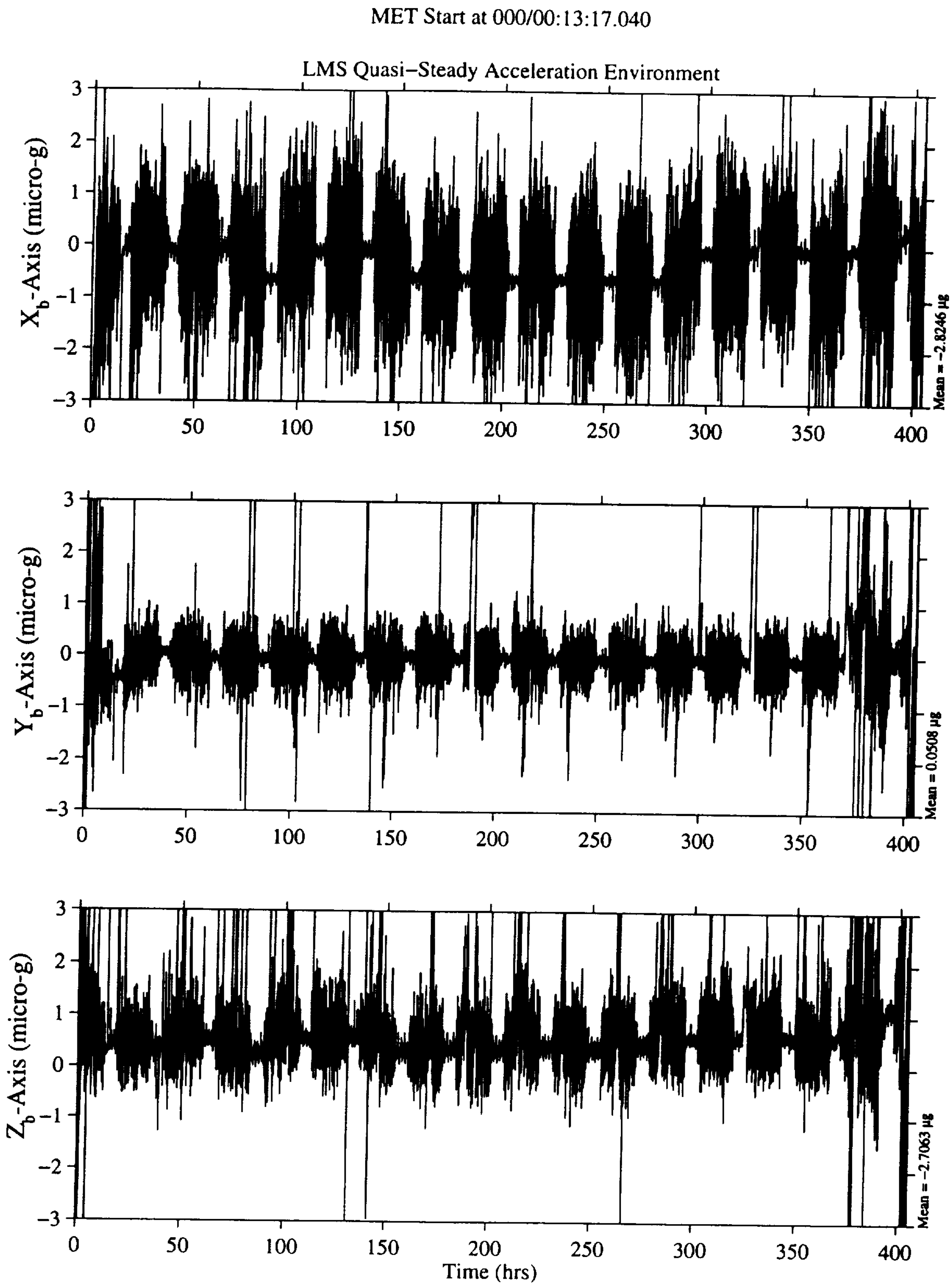


Figure 6. Trimmean filtered OARE data for the STS-78 mission.

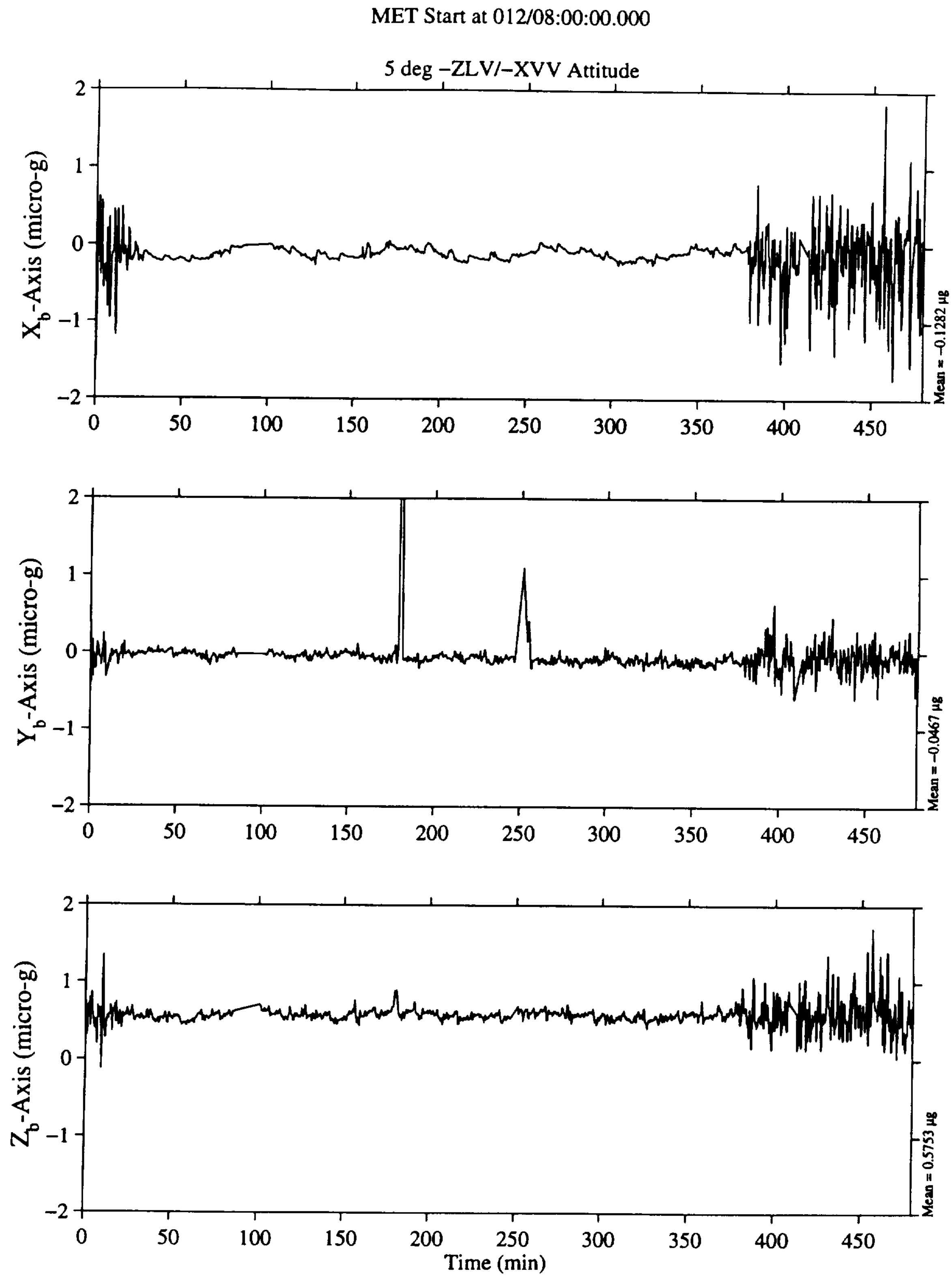


Figure 7. Trimmean filtered OARE data for STS-78 with Columbia in -ZLV/-XVV attitude, MET start 012/08:00.

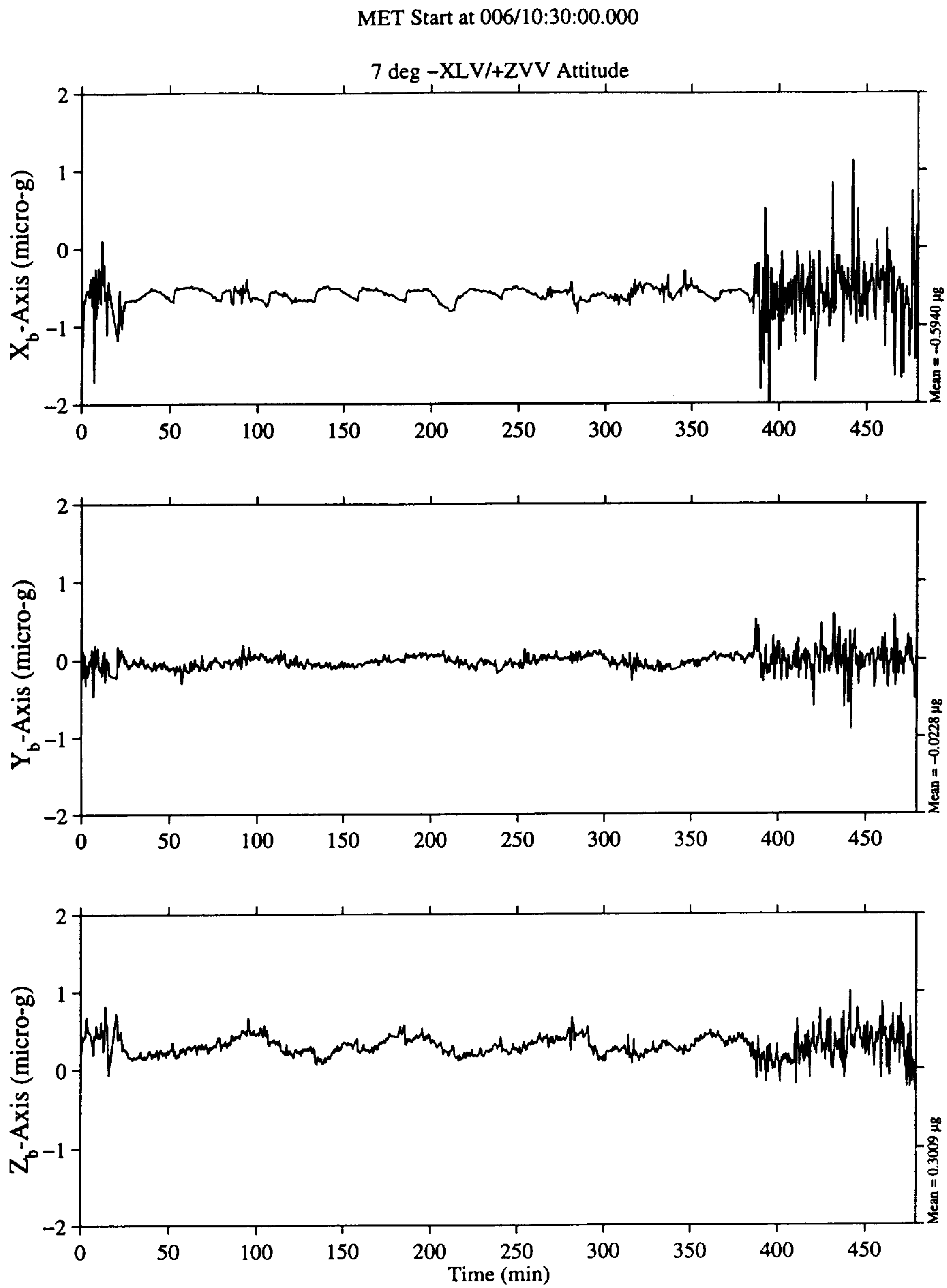


Figure 8. Trimmean filered OARE data for STS-78 with Columbia in -XLV/+ZVV attitude, MET start 006/10:30.

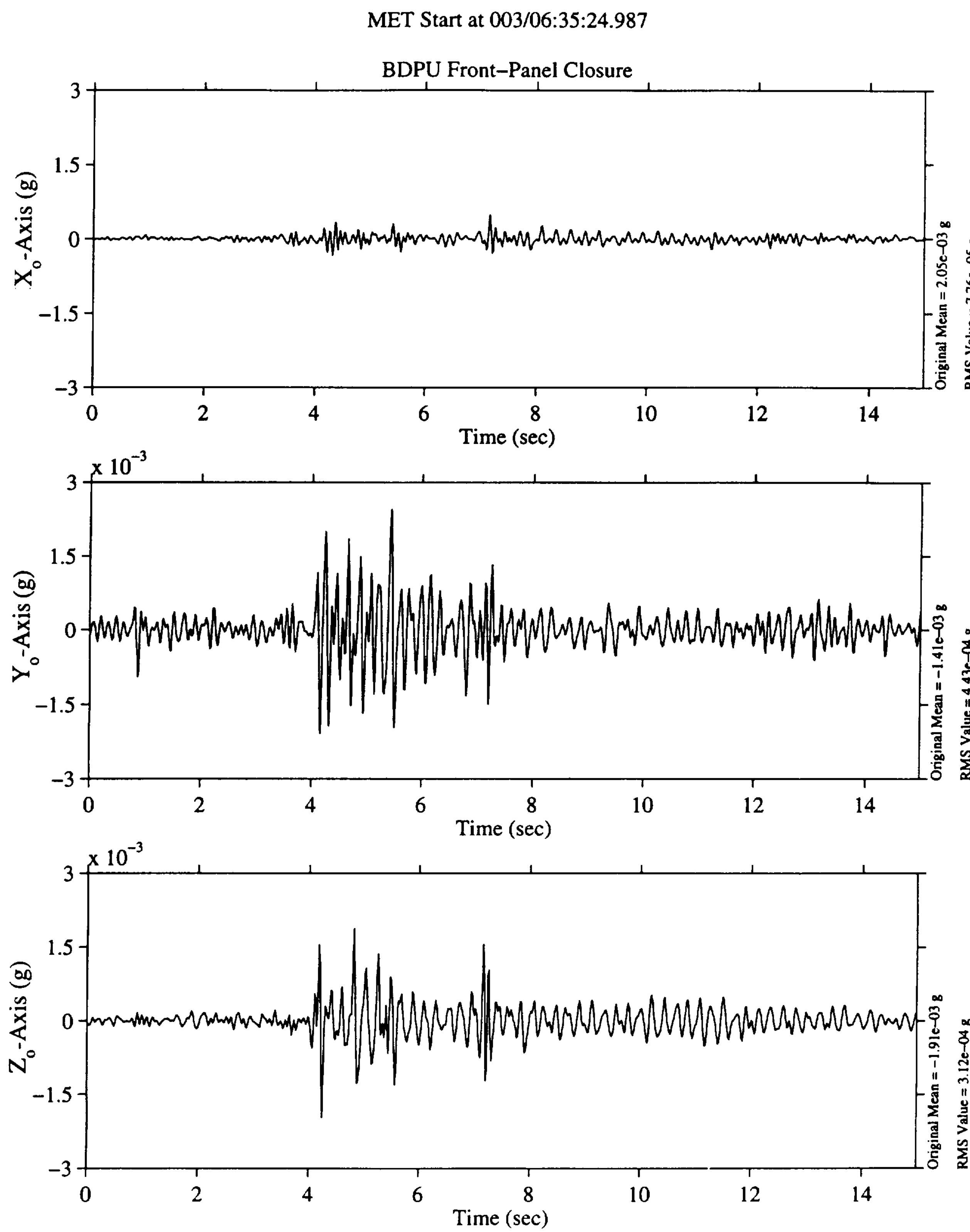


Figure 9. SAMS TSH A data for BDPU panel closing, MET 003/06:35:24.987.