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AIAA-2000-0572

Principal Investigator Microgravity Services Role in ISS Acceleration Data Distribution

K. McPherson
NASA Glenn Research Center
Cleveland, OH

38th Aerospace Sciences
Meeting & Exhibit
January 10–13, 2000 / Reno, NV

NASA/TM—1999-209774

AIAA–2000–0572

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Space Administration

Glenn Research Center

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Kevin M. McPherson
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135, USA

Abstract

Measurement of the microgravity acceleration environment on the International Space Station will be accomplished by two accelerometer systems. The Microgravity Acceleration Measurement System will record the quasi-steady microgravity environment, including the influences of aerodynamic drag, vehicle rotation, and venting effects. Measurement of the vibratory/transient regime comprised of vehicle, crew, and equipment disturbances will be accomplished by the Space Acceleration Measurement System-II. Due to the dynamic nature of the microgravity environment and its potential to influence sensitive experiments, Principal Investigators require distribution of microgravity acceleration in a timely and straightforward fashion. In addition to this timely distribution of the data, long term access to International Space Station microgravity environment acceleration data is required. The NASA Glenn Research Center's Principal Investigator Microgravity Services project will provide the means for real-time and post-experiment distribution of microgravity acceleration data to microgravity science Principal Investigators.

Real-time distribution of microgravity environment acceleration data will be accomplished via the World Wide Web. Data packets from the Microgravity Acceleration Measurement System and the Space Acceleration Measurement System-II will be routed from on-board the International Space Station to the NASA Glenn Research Center's Telescience Support Center. Principal Investigator Microgravity Services' ground support equipment located at the Telescience Support Center will be capable of generating a standard suite of acceleration data displays, including various time domain and frequency domain options. These data displays will be updated in real-time and will periodically update images available via the Principal Investigator Microgravity Services web page.

In addition to generating images for real-time distribution to Principal Investigators via the World Wide Web, the Principal Investigator Microgravity Services project will maintain an archive of the International Space Station acceleration data generated by the Microgravity Acceleration Measurement System and the Space Acceleration Measurement System-II. The archives include both the unprocessed data packets as received by the Principal Investigator Microgravity Services' ground support equipment and processed data files. The processed data files contain implicit time information, acceleration data from three orthogonal axes, and ancillary data that describes

the conditions and circumstances under which the acceleration data were obtained. In particular, an accelerometer's location and orientation in the International Space Station, sampling rate, and processing coefficients are included in the ancillary data set. These processed accelerometer data archives, coupled with automated data analysis servers, will allow microgravity Principal Investigators the ability to request either processed data files or customized data analysis support.

Acronyms

AOS	Acquisition of Signal
GSE	Ground Support Equipment
ISS	International Space Station
LOS	Loss of Signal
MAMS	Microgravity Acceleration Measurement System
MESA	Miniature Electrostatic Accelerometer
OARE	Orbital Acceleration Research Experiment
PAD	PIMS Acceleration Data
PI	Principal Investigator
SAMS	Space Acceleration Measurement System
SAMS-II	Space Acceleration Measurement System-II
SOFBALL	Structure of Flame Balls at Low Lewis Numbers
STS	Space Transportation System
TSC	Telescience Support Center
USMP	United States Microgravity Payload
WWW	World Wide Web

Acceleration Measurement Program

The NASA Glenn Research Center (GRC) Principal Investigator Microgravity Services (PIMS) project supports NASA's Microgravity Research Division Principal Investigators (PIs) by providing acceleration data analysis and interpretation for a variety of microgravity carriers including the International Space Station (ISS), the Space Shuttle, the Russian Mir Space Station, parabolic aircraft, sounding rockets, and drop towers. The PIMS project is funded by the NASA Headquarters Office of Life and Microgravity Sciences and Applications (OLMSA) and is part of the NASA Glenn Research Center's Microgravity Measurement and Analysis Project (MMAP) which integrates the analysis and interpretation component of PIMS with the various NASA sponsored acceleration measurement systems.

The PIMS project's acceleration data support efforts involve the processing, analysis, interpretation, archival and dissemination of accelerometer data from a variety of accelerometer systems supporting a variety of microgravity platforms. PIMS supports users of microgravity platforms by identifying microgravity acceleration disturbance sources related to vehicle systems, experiment hardware, and other systems. The identification of microgravity acceleration disturbance sources is useful to PIs whose experiments were exposed to the disturbances as well as to future PIs who need to understand the microgravity environment under which their experiment will ultimately operate. The design of acceleration data analysis techniques and the creation of displays per user requirements further enhance an investigator's ability to understand the results of their experiment [1]. PIMS continually strives to educate users about the microgravity environment and available data analysis techniques. PIMS has conducted characterization efforts in support of PIs conducting experiments on parabolic aircraft, sounding rockets, the Russian Mir Space Station, and the Space Shuttle. This effort will continue during the PIMS characterization of the microgravity acceleration environment of the ISS.

Acceleration Measurement Systems for the International Space Station

The ISS microgravity acceleration environment is comprised of a quasi-steady, a vibratory, and a

transient component as depicted in Figure 1. From a measurement perspective, the vibratory and transient components are typically considered together to form the vibratory/transient regime. The result is an overall ISS microgravity acceleration environment consisting of two regimes: the quasi-steady regime and the vibratory/transient regime. As a result of the unique characteristics of each regime, measurement of the microgravity acceleration environment on the ISS requires two accelerometer systems. For the ISS, the measurement of these two regimes is accomplished by the Space Acceleration Measurement System-II (SAMS-II) and the Microgravity Acceleration Measurement System (MAMS).

The vibratory/transient environment, consisting of vehicle, crew, and equipment disturbances and covering the frequency range 0.01 – 300 Hz, will be measured by the SAMS-II. Due to the localized nature of these vibrations, this frequency range requires measurement of the environment near the experiment hardware of interest. SAMS-II provides this distributed measurement system through the use of Remote Triaxial Sensor systems (RTS). An individual RTS consists of an Electronics Enclosure (EE) and two Sensor Enclosures (SE). An Interim Control Unit (ICU) housed in an International Subrack Interface Standard (ISIS) drawer collects data from all active EE's and prepares the data for downlink. For initial ISS operations, three EE's and five SE's will be available for vibratory/transient acceleration environment measurement.

The MAMS will record the quasi-steady microgravity environment (below 0.01 Hz), including the influences of aerodynamic drag, vehicle rotation, and venting effects. The MAMS unit will be located in the United States Laboratory Module in a double mid-deck locker enclosure. While MAMS contains accelerometers capable of measuring both the vibratory/transient (MAMS High Resolution Accelerometer Package (HiRAP)) and quasi-steady (MAMS Miniature

Electro-Static Accelerometer (MESA)) acceleration regimes, PIMS will utilize MAMS primarily for its ability to sense the quasi-steady regime. The MESA sensor is a flight spare from the Orbital Acceleration Research Experiment (OARE) program that was used to characterize the quasi-steady acceleration environment of the Space Shuttle Columbia. Like the OARE data recorded during eleven Space Transportation System (STS) missions, utilizing rigid body assumptions at these low frequencies will allow MAMS MESA data to be mapped to alternate locations within the ISS using ISS body rates and body angles data.
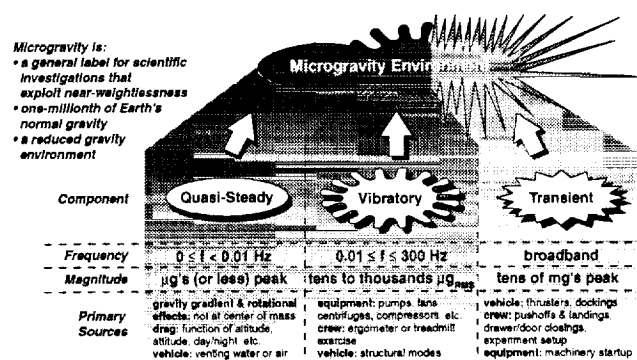

Figure 1 - Components of the Microgravity Environment

PIMS Operational Philosophy

During ISS operations involving SAMS-II and MAMS, several operational challenges must be addressed. The anticipated Acquisition of Signal (AOS)/Loss of Signal (LOS) profiles require a means to merge the AOS and LOS data streams. Additionally, the long operational period for the acceleration measurement systems requires the ability to accommodate a large volume of data arriving in a nearly continuous fashion. Finally, the MAMS and each SAMS-II accelerometer will not always be actively acquiring and transmitting data. As a result, a varying active accelerometer configuration profile is created. The discussions detailing real-time operations, near real-time operations, and offline data access will address each of these challenges.

As previously mentioned, both MAMS and SAMS-II are anticipated to be operational throughout the life of the ISS program. As a

result, the underlying operational philosophy needs to address basic, core functions while allowing flexibility to address needs that develop over the course of operations. With this issue in mind, a core set of functions and capabilities are in development. These core capabilities are based on operational experience acquired by PIMS during real-time and offline operations with STS acceleration data acquired by the Space Acceleration Measurement System (SAMS) and the OARE and with Mir acceleration data acquired by SAMS. Additional capabilities will be added on an increment to increment basis as required. The origin of such additional requirements will be PI specific needs not addressed by the core functions and operational enhancements identified by PIMS during the course of operations.

PIMS will store processed acceleration data files for direct access by investigators. A user-friendly directory hierarchy has been developed to simplify access to the processed acceleration data. The PIMS offline operations center around the need to characterize the microgravity acceleration environment for PIs conducting experiments on board the ISS. Offline operations address two primary functions served by PIMS. First, PIs require analysis and interpretation of the measured environment in direct support of their science measurements. Time domain and frequency domain analysis conducted on the acceleration data can assist the PI in understanding the environment under which their experiment was conducted. The second function addresses the need to conduct a general characterization of the microgravity environment in anticipation of future investigators. For the vibratory/transient regime, obtaining such a general characterization requires access to acceleration measurements distributed throughout the ISS.

Real-Time ISS Operations

The routing of SAMS-II and MAMS acceleration data from on board the ISS to PIMS Ground Support Equipment (GSE) located at the NASA

Glenn Research Center's Telescience Support Center (TSC) is the primary focus of PIMS real-time operations. A simplified representation of this data flow is depicted in Figure 2. The PIMS GSE must provide the means to receive, process, display, and archive the acceleration data received at the TSC. The display and archive functions will be discussed separately here, but operationally will occur in parallel.
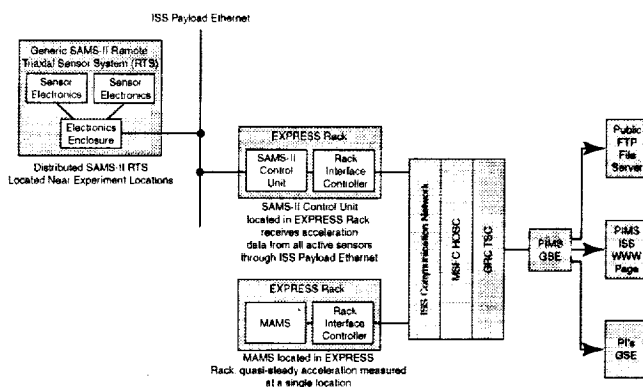

Figure 2 - ISS Acceleration Data Flow

PIMS GSE located at the TSC will be capable of generating a standard suite of acceleration data displays, including various time domain and frequency domain options. These data displays will be updated in real-time and will periodically update images available via the PIMS web page. The planned update rate is every two minutes.

Display processing software will access the data for a selected accelerometer and perform the requested processing for that accelerometer. Since the individual triaxial accelerometers are controlled by PIs, the processing performed on a given accelerometer's data will be driven primarily by PI requirements. In order to perform real-time analysis of the data, processing of a given accelerometer's data may also be influenced by PIMS requirements. PIMS GSE will be capable of generating a standard suite of acceleration data displays including the time domain and frequency domain options identified in Tables 1 and 2. In general, no frequency domain analysis is performed on the quasi-steady acceleration data. However, the time domain techniques listed in Table 1 identify the time

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domain processing options for quasi-steady and vibratory/transient acceleration data.

The displays generated by the PIMS GSE will be updated in real-time as new packets are received. Periodically, electronic snapshots of the displayed images will be generated by the display software and those images will be routed to the PIMS ISS World Wide Web (WWW) page for viewing by interested PIs. The PIMS WWW page will provide access to the acceleration data displays for all active accelerometers.

Figures 3, 4, 5, and 6 offer examples of acceleration data plots generated by PIMS GSE from various STS missions. Figure 3 is a trimmean filter acceleration versus time plot using OARE data from the fourth United States Microgravity Payload (USMP-4) mission (STS-87). The step function observed in the Orbiter Y_b-axis and the Orbiter Z_b-axis results from the de-pressurization of the crew cabin in preparation for an Extra-Vehicular Activity. This step function represents an extremely large acceleration change in the quasi-steady regime.

Figure 4 is a cumulative Root-Mean-Square (RMS) acceleration versus frequency plot using SAMS data from the USMP-3 mission (STS-75). The two traces on the plot depict a crew exercise period (the curve with steps at approximately 1.3 Hz and 2.5 Hz) and a non-crew exercise period and clearly quantify the effects of exercise on the microgravity environment.

Figure 5 is a color spectrogram that provides a Power Spectral Density (PSD) versus time versus frequency representation of six hours of data from the Life and Microgravity Spacelab (LMS) mission (STS-78). In general, the color spectrogram is used to provide a clear indication of start/stop events and clearly illustrate the frequency of various disturbance sources in the overall microgravity environment. For Figure 5, the repeated traces in the 22 Hz range represent the on/off cycling of refrigerators used to support the LMS experiments. Four exercise events and

their corresponding excitation of the Orbiter structural modes are present in the 1-3 Hz range.

Figure 6 is a plot illustrating the relationship between raw OARE data and radiometry data from the Structure of Flame Balls at Low Lewis Numbers (SOFBALL) experiment. This clear relationship between the microgravity acceleration environment and SOFBALL experiment data demonstrates the primary reason PIMS provides its service. Based on correlation between radiometry data and OARE acceleration data, the SOFBALL experiment team was able to maximize their science by making adjustments to their experiment operating plan during the MSL-1 mission (STS-94).

Near Real-Time Operations

The primary functions of the near real-time operations are to receive acceleration data from LOS periods and to generate processed data files for use in the PIMS offline processing system or in a PIs equipment at their remote operations facility. Upon receipt by the PIMS GSE, LOS acceleration data packets will be inserted in the real-time database, where they are effectively merged with AOS acceleration data packets. Overlap between AOS and LOS packets will be addressed by the removal of any such redundant packets upon insertion into the database. The resultant data set represents time ordered data with redundant packets removed.

PIMS has developed a standard format for storing processed acceleration data files termed PIMS Acceleration Data (PAD) files. The need for an acceleration storage standard originated from lessons learned from STS operations, where many accelerometer data systems were utilized to characterize the microgravity environment. These various accelerometer data systems include NASA's SAMS and the OARE, ESA's Microgravity Measurement Assembly (MMA), ESA's Accelerometre Spatiale Triaxiale Electrostatique (ASTRE), and DLR's Quasi-Steady Acceleration Measurement (QSAM). The

raw data and the processed data obtained from these multiple accelerometer system were stored in differing file formats, resulting in unnecessary difficulties regarding analysis of data from these accelerometer systems. Further, data comparison between systems was made unintentionally complicated. The ubiquity afforded by a universal file format allows PIs straightforward access to pertinent microgravity acceleration data, irrespective of the accelerometer system or its location within the ISS.

The PAD file processor becomes active at fixed intervals throughout operations. It operates on a fixed amount of raw acceleration data after all AOS and LOS data packets for a given period of time have been received and inserted into the database. The PAD file processor returns to a dormant state after converting the raw acceleration data into PAD file format data.

As an example, the current estimate to insure all AOS and LOS data have been received is twelve hours. The PAD file processor is scheduled to become active every thirty minutes. Stated more directly, after twelve hours it is assumed all AOS and LOS data for a particular accelerometer system have been transmitted through the system. At this twelve-hour point, the PAD file processor converts the oldest thirty minutes of data currently available in the database to PAD file format. The thirty minutes of data just processed are subsequently removed from the database and the PAD file processor again becomes dormant, waiting for the next thirty minute time interval to be reached.

The PAD file format allows the storage of acceleration data and ancillary data together in a single file, greatly simplifying the offline processing of the data. The ancillary data describes the conditions and circumstances under which the acceleration data were obtained. The following items represent the current list of ancillary data parameters to be stored by PIMS in each processed data file: t-zero, t-end, sampling rate, cutoff frequency, head ID, gain, ISS CG, station configuration, location, orientation,

coordinate system, bias coefficients, scale factor, and data quality measure. A change in any of these ancillary parameters can result in the current file closing and a new data file being opened. Consequently, the ancillary data in each resultant file is representative of each data point within the file.

Offline Operations

The PAD files generated during near real-time operations will be archived and available for offline processing. The analysis options listed in Tables 1 and 2 are available for offline analysis of SAMS-II and MAMS acceleration data. As part of the PIMS microgravity environment characterization effort, PIMS data analysts will extract information from the acceleration data during offline operations. Processing time and resources for offline operations are not time-critical and therefore afford more detailed analysis of the acceleration data. The salient features of the ISS microgravity environment will be summarized in summary reports similar to those generated during STS operations [2]. These summary reports will be generated on an increment-to-increment basis in an effort to educate upcoming PIs about the ISS microgravity environment. A handbook of acceleration disturbance sources for the ISS will be developed and maintained to provide a concise visualization of the ISS disturbance database accumulated through each increment.

In addition to the data analysis conducted by PIMS, PIs can make requests for analysis directly through PIMS or through the PIMS analysis request form available through the PIMS WWW page. Tables 1 and 2 list the standard time domain and frequency domain plot options available to investigators. The analysis will performed by PIMS analysts or will be performed automatically by PIMS offline processing software. Additionally, since the processed acceleration data will reside on a PIMS data file server, direct access to the processed data will be available through anonymous File Transfer Protocol (FTP). Whether data plots or

acceleration data files are requested, the resultant products will be made available to the investigator in a straightforward, timely manner.

Summary
The International Space Station provides a long duration experiment facility for microgravity science Principal Investigators. The Space Acceleration Measurement System-II and the Microgravity Acceleration Measurement System will accomplish measurement of the acceleration environment. The Principal Investigator Microgravity Services Project will provide analysis and interpretation of the ISS microgravity acceleration environment through real-time data processing and the generation of

processed data files for post-experiment access by microgravity science Principal Investigators.

References
[1] M.J.B. Rogers, K. Hrovat, K. McPherson, M. Moskowitz, T. Reckart, Accelerometer Data Analysis and Presentation Techniques, NASA Technical Memorandum TM–113173, September 1997

[2] M.J.B. Rogers, K. Hrovat, K. McPherson, R. DeLombard, T. Reckart, Summary Report of Mission Acceleration Measurements for STS–87, NASA Technical Memorandum TM—1999-208647, January, 1999

Display Format	Regime(s)	Notes
Acceleration vs. Time	Quasi-steady, Vibratory	• Precise accounting of measured data with respect to time; best temporal resolution
Interval Min/Max Acceleration vs. Time	Vibratory, Quasi-steady	• Displays upper and lower bounds of peak-to-peak excursions of measured data • Good display approximation for time histories on output devices with resolution insufficient to display all data in time frame of interest
Interval Average Acceleration vs. Time	Vibratory, Quasi-Steady	• Provides a measure of net acceleration of duration greater than or equal to interval parameter
Interval RMS Acceleration vs. Time	Vibratory	• Provides a measure of peak amplitude for pure sinusoids
Trimmed Mean Filtered Acceleration vs. Time	Quasi-steady	• Removes infrequent, large amplitude outlier data
Quasi-Steady Mapped Acceleration vs. Time	Quasi-steady	• Use rigid body assumption and using vehicle rates and angles to compute acceleration at any point in the vehicle

Table 1 - Time Domain Analysis Options

Display Format	Notes
Power Spectral Density vs. Frequency	• Displays distribution of power with respect to frequency
Spectrogram (PSD vs. Frequency vs. Time)	• Displays power spectral density variations with time • Identify structure and boundaries in time and frequency
Cumulative RMS Acceleration vs. Frequency	• Quantifies RMS contribution at and below a given frequency
Frequency Band(s) RMS Acceleration vs. Time	• Quantify RMS contribution over selected frequency band(s) as a function of time
RMS Acceleration vs. One-Third Frequency Bands	• Quantify RMS contribution over proportional frequency bands • Compare measured data to ISS vibratory requirements

Table 2 - Frequency Domain Analysis Options

MET Start at 004/08:00:23.040

Cabin De-Pressurization for EVA #1
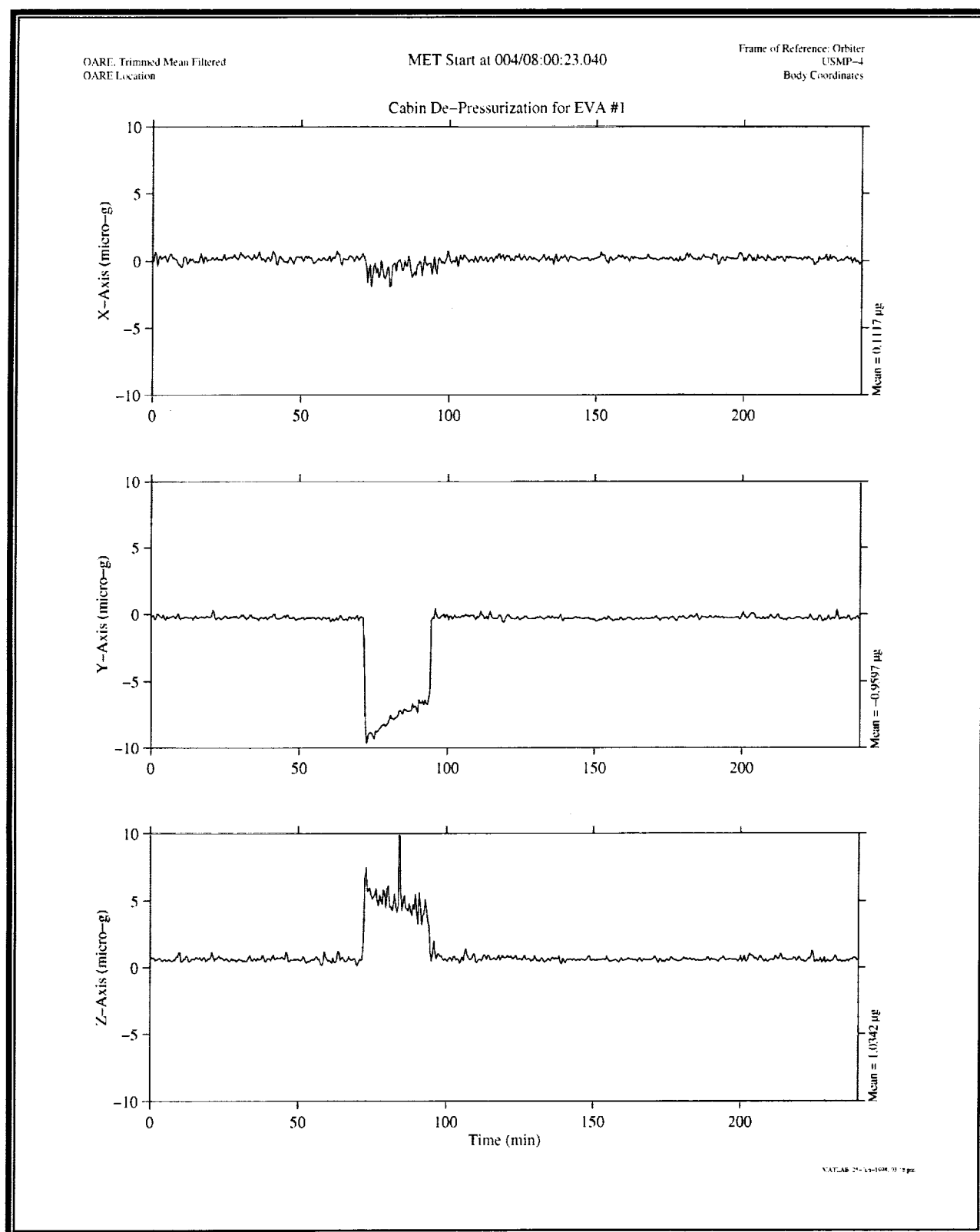
**Figure 3 – USMP-4 TMF Acceleration Versus Time During
Cabin De-Pressurization, OARE Data**
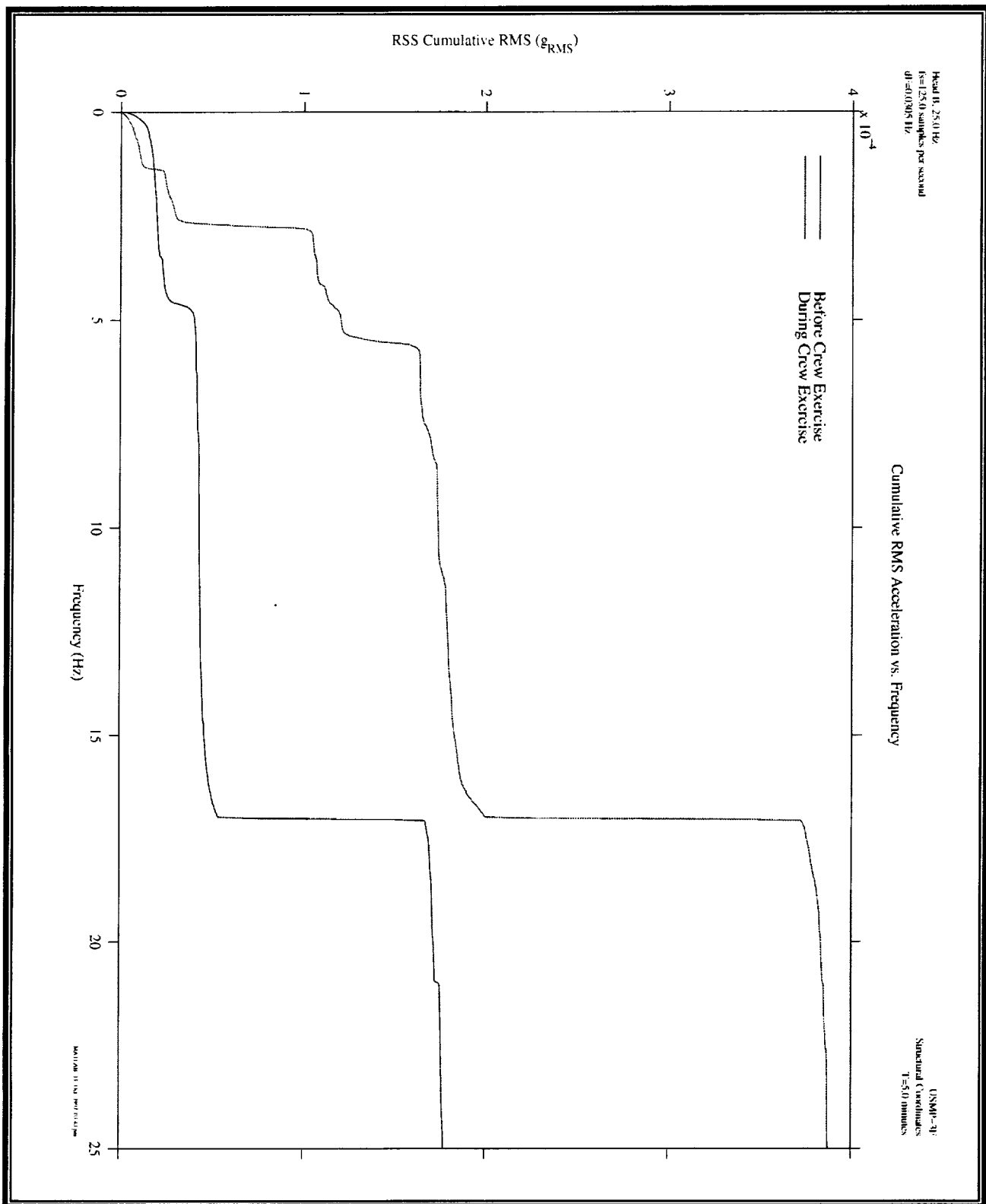
**Figure 4 – USMP-3 Mission Cumulative RMS Acceleration
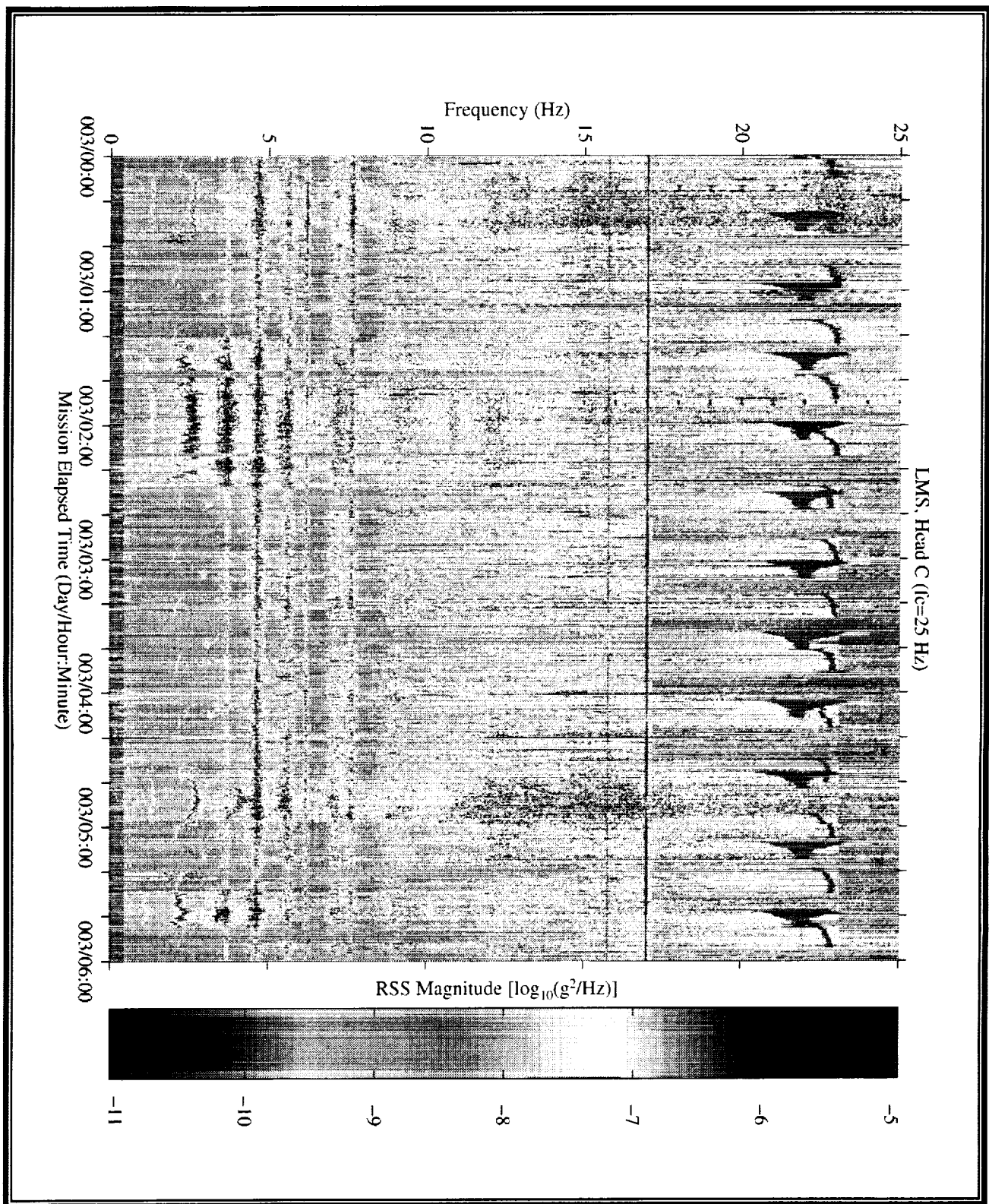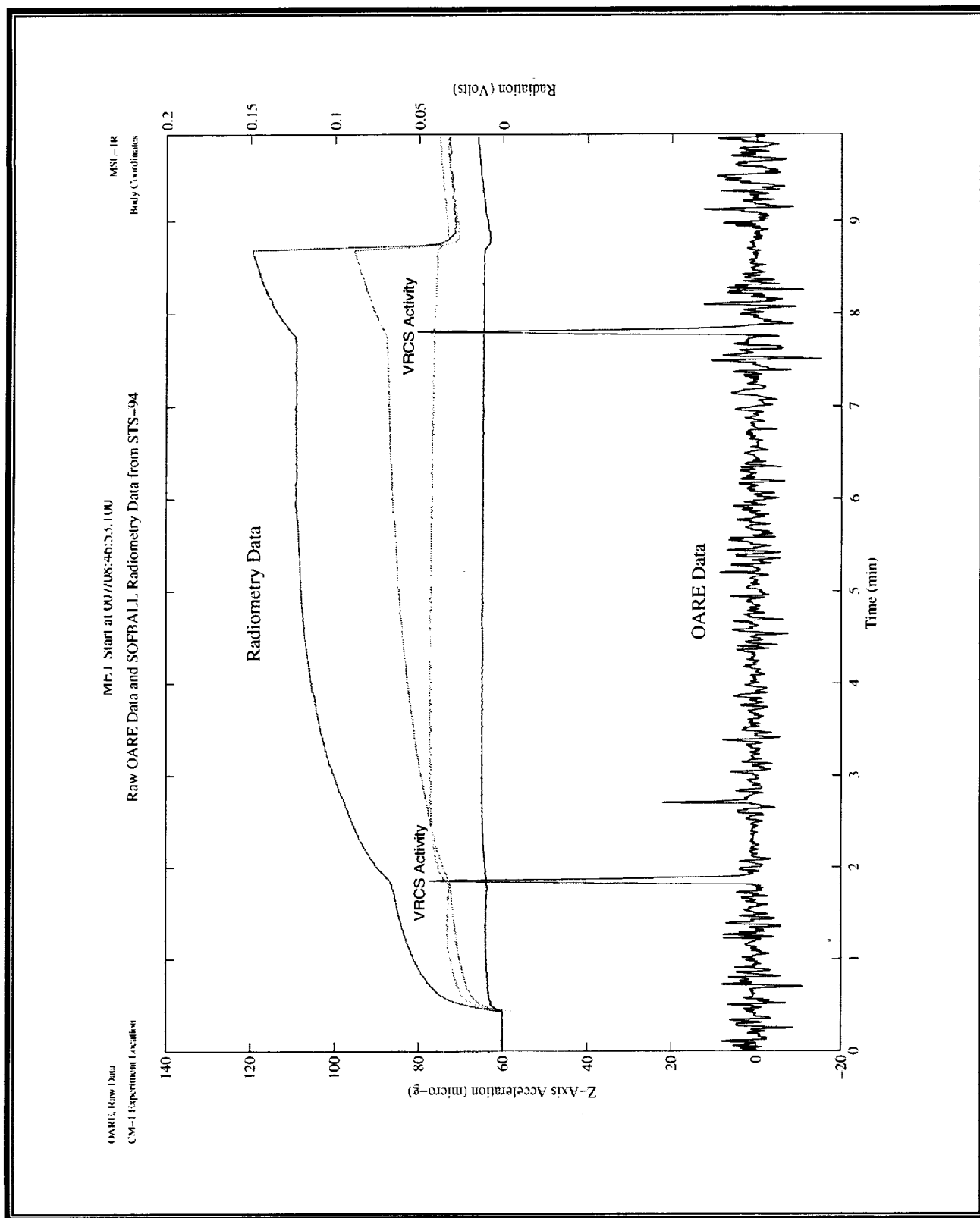Versus Frequency, SAMS Data**

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Figure 5 – LMS Mission Color Spectrogram, SAMS Data

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Figure 6 – MSL-1 Mission, SOFBALL Radiometry Data, Filtered OARE Data

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REPORT DOCUMENTATION PAGE

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE December 1999	3. REPORT TYPE AND DATES COVERED Technical Memorandum

4. TITLE AND SUBTITLE

Principal Investigator Microgravity Services Role in ISS Acceleration Data Distribution

5. FUNDING NUMBERS

WU–398–95–0G–00

6. AUTHOR(S)

K. McPherson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–12054

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—1999-209774
AIAA–2000–0572

11. SUPPLEMENTARY NOTES

Prepared for the 38th Aerospace Sciences Meeting and Exhibit sponsored by the American Institute of Aeronautics and Astronautics, Reno, Nevada, January 10–13, 2000. Responsible person, K. McPherson, organization code 6727, (216) 433–6182.

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Unclassified - Unlimited
Subject Category: 31   Distribution: Nonstandard

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12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

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14. SUBJECT TERMS

Microgravity; Acceleration; PIMS; SAMS-II; MAMS; International Space Station

15. NUMBER OF PAGES
17

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT