Final Science Report for OARE and SAMS on STS-94 / MSL-1

Milton Moskowitz, Kenneth Hrovat
Tal-Cut Company, North Olmsted, Ohio

Kevin McPherson, Peter Tschen, Richard DeLombard
NASA Lewis Research Center, Cleveland, Ohio

Maurizio Nati
European Space Research and Technology Center
Noordwijk, The Netherlands

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ABSTRACT

Four microgravity acceleration measurement instruments were included on MSL-1 to measure the accelerations and vibrations to which science experiments were exposed during their operation on the mission. The data were processed and presented to the principal investigators in a variety of formats to aid their assessment of the microgravity environment during their experiment operations.

Two accelerometer systems managed by the NASA Lewis Research Center (LeRC) supported the MSL-1 mission: the Orbital Acceleration Research Experiment (OARE), and the Space Acceleration Measurement System (SAMS). In addition, the Microgravity Measurement Assembly (MMA) and the Quasi- Steady Acceleration Measurement (QSAM) system, both sponsored by the Microgravity Research Division, collected acceleration data as a part of the MSL- 1 mission. The MMA was funded and designed by the European Space Agency in the Netherlands (ESA/ESTEC), and the QSAM system was funded and designed by the German Space Agency (DLR).

The Principal Investigator Microgravity Services (PIMS) project at the NASA Lewis Research Center (LeRC) supports Principal Investigators (PIs) of the microgravity science community as they evaluate the effects of acceleration on their experiments. PIMS' primary responsibility is to support NASA-sponsored investigators in the area of acceleration data analysis and interpretation.

A mission summary report was prepared and published by PIMS in order to furnish interested experiment investigators with a guide for evaluating the acceleration environment during the MSL-1 mission.

OBJECTIVE(S)

The objective of microgravity measurement instruments manifested on MSL-1 was to measure the accelerations and vibrations to which science experiments were exposed during their operation on the mission. The data were processed and presented to the principal investigators in a variety of formats to aid their assessment of the microgravity environment during their experiment operations.

BACKGROUND

Two accelerometer systems managed by the NASA Lewis Research Center (LeRC) supported the MSL-1 mission: the Orbital Acceleration Research Experiment (OARE), and the Space Acceleration Measurement System (SAMS). These accelerometers were funded by the Microgravity Research Division (MRD) of the NASA Office of Life and Microgravity Sciences and Applications. In addition, the Microgravity Measurement Assembly (MMA) and the Quasi- Steady Acceleration Measurement (QSAM) system, both sponsored by the Microgravity Research Division, collected acceleration data as a part of the MSL- 1 mission. The MMA was funded and designed by the European Space Agency in the Netherlands (ESA/ESTEC), and the QSAM system was funded and designed by the German Space Agency (DLR).

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Numerous activities occurred during the MSL-1 mission that are of interest to the low-gravity community. Specific activities of interest during STS-94 were:

1. crew activities
2. experiment operations,
3. orbiter attitude
4. venting operations
5. microgravity glovebox (MGBX) circulation fans
6. crew exercise
7. Public Affairs Office (PAO) events/quiet periods
8. Physics of Hard Spheres Experiment (PHaSE) activation/ deactivation
9. PHaSE mixer

10. Combustion Module-1 (CM-1) mallet pounding for setup
11. CM-1 gas chromatograph vacuum pump
12. effect of leaving free drift
13. accelerations related to the Astro/Plant Generic Bioprocessing Apparatus (ASTRO/PGBA)
14. accelerations related to the Droplet Combustion Experiment (DCE)
15. accelerations related to the electromagnetic containerless processing facility (TEMPUS)

The low-gravity environment related to these activities is discussed in the summary report prepared by PIMS for the mission (see Bibliography). Disturbances which are common to Orbiter missions were also apparent, including the Ku band antenna dither, orbital maneuvering system and primary reaction control system firings, and attitude changes.

METHODS OF DATA ACQUISITION AND ANALYSIS

DATA ACQUISITION

Four accelerometer systems measured the microgravity and vibration environment of the Orbiter Columbia during the MSL-1 mission: the Orbital Acceleration Research Experiment (OARE), the Space Acceleration Measurement System (SAMS), the Microgravity Measurement Assembly (MMA), and the Quasi-Steady Acceleration Measurement (QSAM) System.

OARE measured quasi-steady accelerations from below $1x10^{-8}$ g up to $2.5x10^{-3}$ g at a location on the Shuttle keel, near the center of mass.

SAMS measured the low-gravity environment of the Orbiters in support of microgravity science payloads. The SAMS configuration for MSL-1 consisted of two remote triaxial sensor heads (TSHs), connecting cables, and a central processing unit with a data recording system using standard commercial hard drives that have been upgraded for space use. The main unit was located in the center aisle of the Spacelab module. The locations of the SAMS sensor heads were in the Combustion Module rack and on the Microgravity Glovebox. The data from one of the two active TSHs was deemed unusable due to a high number of sporadic gain changes. Therefore, the data used for the post-mission analysis was predominantly that from the MMA.

MMA measured the low-gravity environment of the Orbiters in support of microgravity science payloads. These sensor heads consist of six Microgravity Sensor Packages (MSPs) and one Accelerometre Spatiale Triaxiale Electrostatique (ASTRE).

The ASTRE and one MSP resided within the MMA unit, one MSP was located on the Droplet Combustion Experiment, and one MSP was located on the Large Isothermal Furnace.

QSAM measured accelerations from quasi-steady up to 50 Hz. QSAM was located in Rack 3 (next to the TEMPUS facility). In order to assess the quasi- steady acceleration level, QSAM suppresses the sensor's bias and noise by rotating the sensor's sensitive axis. QSAM utilizes four rotating sensors to allow for a three-dimensional quasi-steady acceleration detection.

DATA ANALYSES

PIMS had the opportunity to work closely with the Structure of Flame Balls at Low Lewis-number (SOFBALL) and the Coarsening in Solid-Liquid Mixtures (CSLM) experiment teams during the pre-mission Investigator Working Group meetings.

During the mission, the PIMS group analyzes the data available via downlink and forwarded the analysis results to the PIs.

The SAMS real-time displays on the Internet included acceleration versus time plots (for the X-, Y-, and Z-axes), and a color spectrogram for the root- sum-of-squares (RSS) combination of the three axes for the TSH B (MGBX), and TSH C (LIF) data. The color spectrograms served as an overview of the recent microgravity environment. These plots allowed the PIMS team to determine exercise activity, and alert the TEMPUS experiment team in near-real-time when exercise was currently underway. This real-time feedback allowed the TEMPUS group to closely monitor and control their critical experiment activities, attempting to minimize the impact of acceleration disturbances on their experiment.

In addition, a customized analysis display was developed for the CSLM experiment. This customized analysis contained plots of root-mean-square (RMS) acceleration versus time for five different frequency intervals. The total range of these frequency intervals was from 0.05 to 25 Hz. The specific intervals were chosen based upon discussions between the CSLM and PIMS groups.

Post-mission, the data were analyzed via time-domain and frequency-domain analysis tools. Time-domain tools used were acceleration versus time and trimmean acceleration versus time. The frequency-domain analysis tools were the power spectral density (PSD) versus frequency and the power spectral density versus frequency versus time (spectrogram).

Additionally, the quasi-steady data were analyzed via a histogram method called the Quasi-steady Three-Dimensional Histogram.

FLIGHT RESULTS COMPARED WITH GROUND RESULTS

This item does not apply to the accelerometer instruments on-board this mission.

CONCLUSIONS

This report describes the acceleration environment recorded during the STS-94 flight of Columbia, including accelerations related to Orbiter attitude, Orbiter venting operations, a variety of experiment-specific fans, pumps, and compressors, crew exercise, and crew quiet periods.

Low-frequency acceleration variations result from changes in the Orbiter's attitude. Primarily, these accelerations are due to aerodynamic drag, gravity gradient, and rotational effects within the Orbiter. Atmospheric density changes resulting from day/night transitions cause variations, which have been seen in the past, and have been noted for this mission. Vehicle venting operations (such as water dumps) produce a quasi-steady shift of the acceleration vector, related to the venting force and direction. As seen in figure 1, typical acceleration changes are on the order of -1.5 μg for the Y_b-axis, and 1.7 μg for the Z_b- axis, for simultaneous supply and waste water dump operations.

Accelerations related to crew activity and Orbiter system operations have been noted. Specifically, crew exercise produced acceleration disturbances resulting from a shoulder-sway motion (1-1.5 Hz), the fundamental pedaling frequency (2.5-3 Hz), and harmonics of these frequencies. Exercise for this mission were typically on the order of 100-200 μg_{RMS}. PAO events and crew conferences were shown (figure 2) to be quieter microgravity periods, lasting for up to 30 minutes at a time, with a nominal 40 μg_{RMS} quieting of the acceleration environment. The 17 Hz dither of the Orbiter's Ku-band communication antenna was present throughout the mission, with magnitudes around 75-105 μg_{RMS}. The distributed nature of the three MMA sensor heads allowed the magnitude variations of this signal to be seen as a function of distance from the disturbance source.

A number of acceleration sources were identified which were related to experiment or facility operations. Some of note include the MGBX work area circulation fans (63.5, 66.5, 98.6, and 127.0 Hz with magnitudes up to 180 μg_{RMS}), the PHaSE mixer (2000-3000 μg vector magnitude increase), the CM-1 gas chromatograph vacuum pump (46 and 55 Hz, 170 μg_{RMS} magnitude), the Astro/ PGBA air circulation pump (31.8, 44.4, 45.0, and 63.5 Hz, ranging between 5 and 750 μg_{RMS} in magnitude), and the TEMPUS water pump (42.5-43 Hz, 250 μg_{RMS} magnitude). Some other sources include one or more unidentified components on the PHaSE and the DCE experiments.

Direct correlations were made by the SOFBALL team between their radiometry data and firing of the VRCS thrusters, figure 3.

PIMS provided an analysis showing the microgravity effects of leaving free drift. This showed there were an increased number of thruster firings as the Orbiter maneuvered back to the desired attitude.

Correlations between the MMA ASTRE sensor were made with the OARE instrument. For the venting operations (water dumps), both instruments measured approximately the same magnitude and direction for the acceleration vector.

Utilization of high-frequency data from three MMA sensor heads enabled a unique opportunity for the localization and identification of a number of disturbance sources. This proved to be an invaluable tool for the analysis and interpretation of the MSL-1 microgravity environment.

BIBLIOGRAPHY

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2. Canopus Systems, Inc., OARE Technical Report 151, STS-94 (MSL-1) Final Report. CSI-9704, August 1997

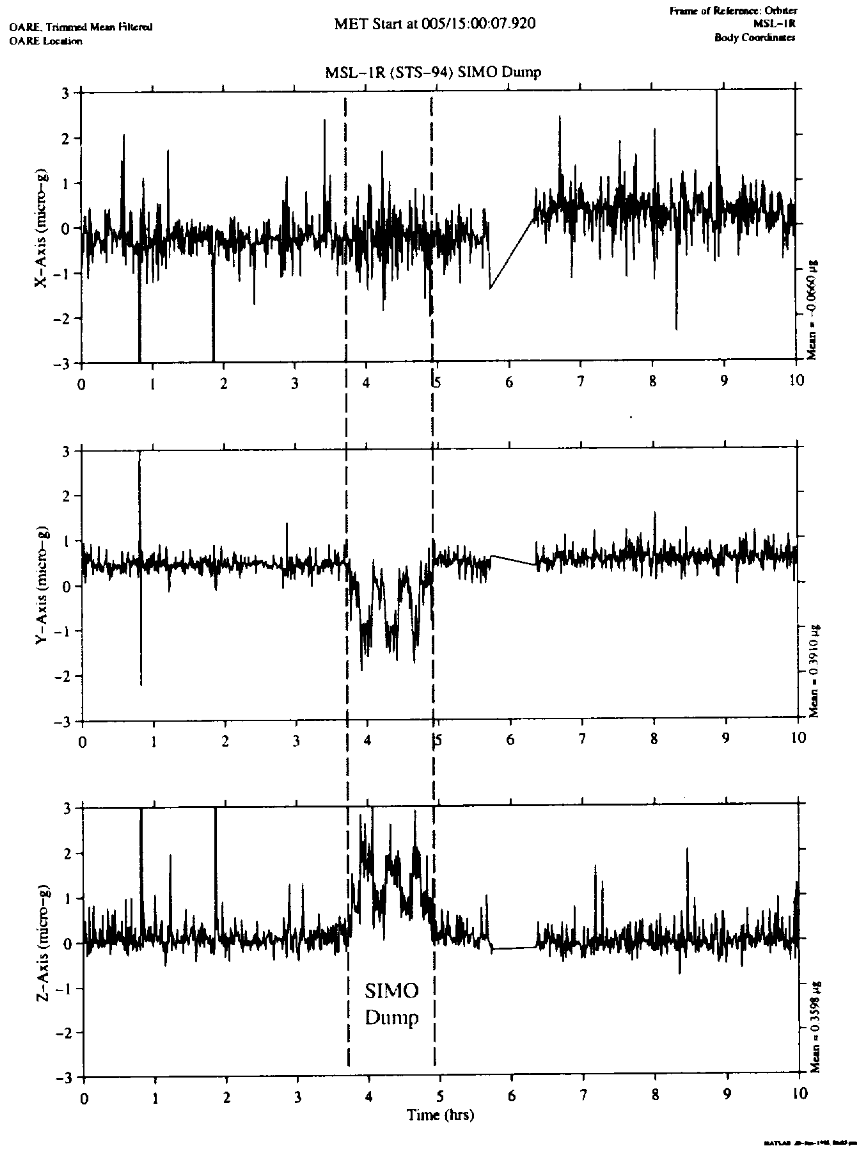

Figure 1. OARE Data Collected During a Simultaneous Supply and Waste Water Dump at MET 005/15:00.

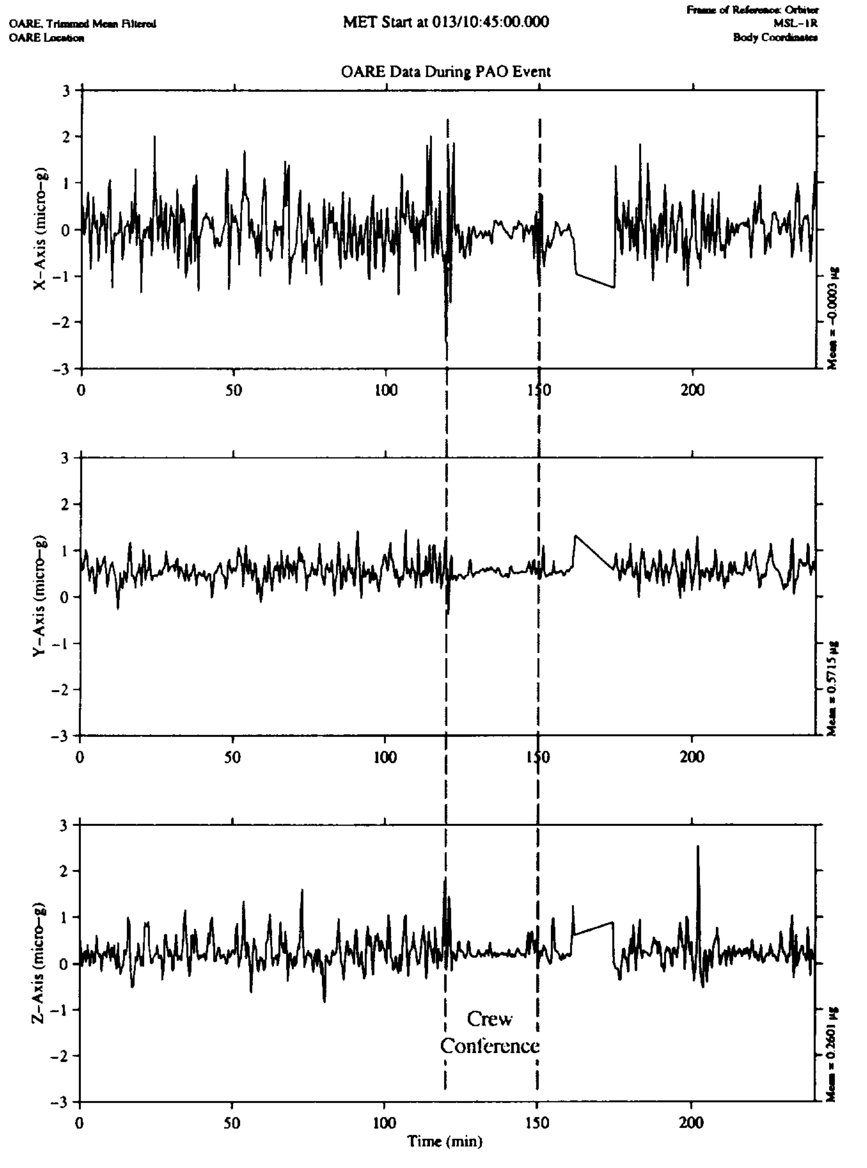

Figure 2. Trimmean Filtered OARE Data Collected During an STS-94 Crew Conference, MET 013/10:45.

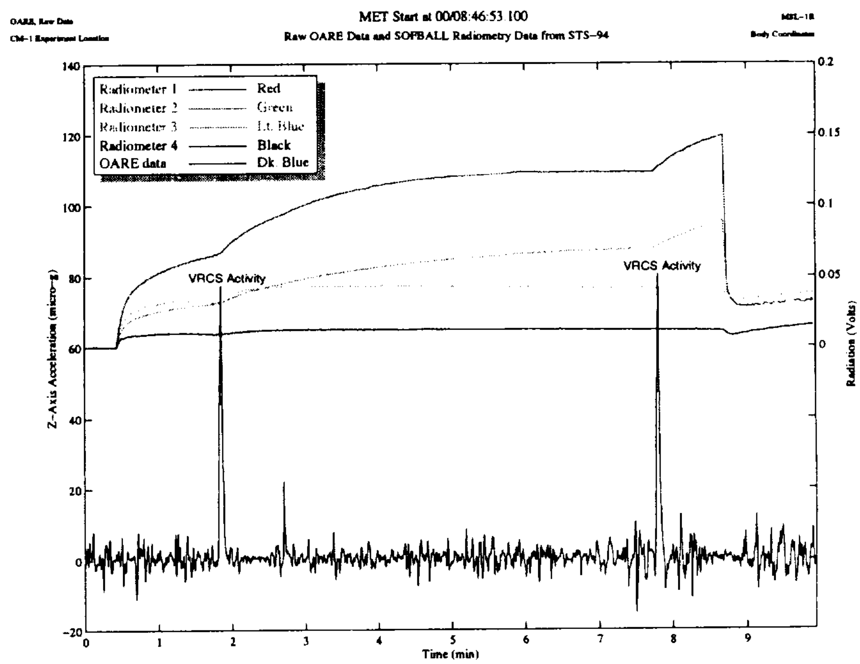

Figure 3. Raw (10 samples per second) OARE Data with SOFBALL Radiometry Data from STS-94, SOFBALL Test Point 14A. MET Start 007/08:46:53.