NASA Technical Memorandum 107483

Effects of Experiment Location and Orbiter Attitude on the Residual Acceleration On-Board STS-73 (USML-2)

Roshanak Hakimzadeh and Kevin M. McPherson
Lewis Research Center
Cleveland, Ohio

Brian P. Matisak
Teledyne Brown Engineering
Huntsville, Alabama

William O. Wagar
Lewis Research Center
Cleveland, Ohio

Prepared for the
Materials Research in Low Gravity Conference
sponsored by the Society of Photo-Optical Instrumentation Engineers
San Diego, California, July 27—August 1, 1997

National Aeronautics and
Space Administration

Effects of Experiment Location and Orbiter Attitude on the Residual Acceleration On-Board STS-73 (USML-2)

Roshanak Hakimzadeh[a], Kevin M. McPherson[a], Brian P. Matisak[b], and William O. Wagar[a]

[a]NASA Lewis Research Center, Cleveland, OH
[b]Teledyne Brown Engineering, Huntsville, AL

ABSTRACT

A knowledge of the quasi-steady acceleration environment on the NASA Space Shuttle Orbiter is of particular importance for materials processing experiments which are limited by slow diffusive processes. The quasi-steady (<1 HZ) acceleration environment on STS-73 (USML-2) was measured using the Orbital Acceleration Research Experiment (OARE) accelerometer. One of the facilities flown on USML-2 was the Crystal Growth Furnace (CGF), which was used by several Principal Investigators (PIs) to grow crystals. In this paper the OARE data mapped to the sample melt location within this furnace is presented. The ratio of the axial to radial components of the quasi-steady acceleration at the melt site is presented. Effects of Orbiter attitude on the acceleration data is discussed.

Keywords: Quasi-steady, acceleration, OARE.

1. INTRODUCTION

The second United States Microgravity Laboratory (USML-2) payload flew on the Orbiter Columbia on mission STS-73 from October 20th to November 5th, 1995. The USML-2 payload on STS-73 was dedicated to microgravity experiments. These experiments ranged from a variety of scientific disciplines including biotechnology, combustion science, fluid physics and materials science. The USML-2 facilities and experiments are listed in reference 1. These experiments were conducted on the NASA Space Shuttle Orbiter to take advantage of the reduced gravity environment resulting from the continuous free fall state of the low-earth orbit. The environment on the Orbiter, however, consists of a variety of disturbances, which can be measured in units of the earth acceleration, namely $g=9.8\ ms^{-2}$. The disturbances on a body at any given location range from quasi-steady disturbances, arising from aerodynamic and orbital mechanical forces, to higher frequency disturbances, such as thruster firings and oscillatory vibrations due to on-board machinery, and crew activity.

The total quasi-steady acceleration on a particle located on the Orbiter at any given time is sum of the aerodynamic drag effects, gravity gradient (GG) effects and rotational effects[2,3,4,5]. The drag effects are functions of atmospheric density, the projected area of the Orbiter, the drag coefficient of the Orbiter, and the Orbiter mass. The GG effects are a function of the distance of a particle from the Orbiter center of gravity (c.g.). This results in the particle's tendency to slowly drift towards or away from the c.g., due to differences in its orbital period as compared to that of the Orbiter. The rotational effects of the acceleration are the results of centrifugal forces acting on a particle located away from the c.g. of the Orbiter. The combined GG and the rotational effects are often referred to as tidal effects. The net residual acceleration vector is, therefore, obtained from the vector summation of the quasi-steady drag and tidal effects.

A quasi-steady accelerometer managed by NASA Lewis Research Center, the Orbital Acceleration Research Experiment (OARE) [4,5,6], flew on this mission to support the microgravity experiments. OARE is mounted near the c.g. of the space shuttle vehicle. The OARE contains a tri-axial accelerometer which uses a single free-floating electrostatically suspended cylindrical proofmass, and was designed to measure quasi-steady accelerations from below 1×10^{-8} g up to 2.5×10^{-3}g. The error in the measurements is less than 5×10^{-8} g, which results from uncertainties in the measurement and the sensor bias estimate. The accelerometer sensor assembly is mounted to a microprocessor-controlled, dual-gimbal platform in order to perform in-flight calibrations. During the STS-73 mission the OARE data were telemetered to NASA receiving stations, in real-time for the first time.

Also during this mission, the Teledyne Brown Engineering group supported by NASA Marshall Space Flight Center (MSFC) predicted the quasi-steady environment of the Orbiter by means of an aerodynamic model and algorithms to calculate tidal acceleration contributions based on real-time orbital parameters. This real-time analytical method of mapping and displaying the quasi-steady environment was accomplished successfully using the Microgravity Analysis Workstation (MAWS)[7]. Plots of the X-, Y- and Z-components of this prediction as a function of time were provided to the scientific community in real-time during the mission. For the first time the OARE measurement of the quasi-steady acceleration was compared to the prediction in real-time. The results, which show a remarkable agreement, are presented here.

2. COORDINATE SYSTEMS

The OARE data is typically presented in Orbiter body coordinates, X_b, Y_b, Z_b (Figure 1). This coordinate system is centered at the c.g. of the Orbiter. The direction from tail to nose of the Orbiter is $+X_b$. The direction from port (left) wing to starboard (right) wing is $+Y_b$. The direction from the top of the fuselage to the Orbiter belly is $+Z_b$. The sign convention of the data presented in this paper is such that when there is a forward thrust of the Orbiter (such as during an OMS firing), it is presented as a negative X_b acceleration. This convention is referred to as the Orbiter frame of reference.

The CGF is rotated about X_b by 12° in the clockwise direction. Hence, to present the quasi-steady acceleration at the crystal site in parallel (axial) and perpendicular (radial) to the growth direction, a CGF coordinate system is defined (Figure 1). In this coordinate system + Z_{CGF} is the direction of crystal growth (cold zone to hot zone) within the furnace. During the mission the OARE data was mapped to and presented to the CGF PIs in the CGF coordinate system and in real-time.

3. ORBITER MICROGRAVITY ENVIRONMENT

The microgravity environment measured by an accelerometer system on the Orbiter has many components. Orbital phenomena (such as aerodynamic drag), along with rotational and GG effects contribute to the quasi-steady microgravity environment. The following sub-sections define interesting events for which the OARE data is presented.

3.1 Orbiter Attitude

For microgravity missions several factors define the determination of the Orbiter attitudes. These include Orbiter thermal conditions, maximizing continuous communications as well as experiment operations requirements. For STS-73 the Orbiter attitudes included a Solar Inertial attitude for thermal conditioning, a nominal USML-2 GG attitude, an attitude designed specifically for the Geophysical Fluid Flow Cell (GFFC) experiments, and an attitude designed specifically for the CGF experiments. These attitudes are shown in Figure 2. In the Solar inertial attitude the Orbiter is fixed relative to the Sun, in that the Orbiter belly continuously points at the Sun. This attitude was used during STS-73 to condition the temperature of the tires. The quasi-steady environment obtained at the OARE location while in this attitude is shown in Figure 3. Theoretically, the vector sum of the induced acceleration from drag and tidal forces at a location in the Orbiter would net to zero over one orbit (~90 minutes)[8]. It can be seen from Figure 3 that this is indeed the case. The orientation of the resultant quasi-steady vector in this attitude is continuously changing in both magnitude and direction. Hence, this attitude, though useful for tire warming, is not so desirable for experiments where the resultant vector needs to be controlled in both magnitude and direction, such as crystal growth experiments. In the GG, GFFC and CGF attitudes the Orbiter position is fixed along a radius emanating from the Earth's center of mass. These attitudes are maintained with fewer thruster firings, and are more desirable for many experimenters because the resultant quasi-steady vector varies only slightly in magnitude and direction. The results obtained during the CGF attitude are particularly interesting to the materials scientists. In this attitude the CGF is approximately aligned with the velocity vector. Hence, theoretically, the magnitude of the axial to radial components of the resultant quasi-steady acceleration is optimized. For the first time, results of the OARE data were compared to that of MAWS to validate this prediction. Figure 4 shows a comparison of such data at the OARE location for a typical time slice.

3.2 Crew Activity

The seven member crew of STS-73 worked on a dual shift schedule. Figure 5 shows the OARE data for the extent of the STS-73 mission obtained at the OARE location. Note that unlike single-shift missions[9], the quasi-steady environment represented by these data is relatively constant throughout the mission. Daily cycles in the acceleration levels may be seen in the X_b-axis. These are due to the daily mission activities of experiment operation and crew cycles.

3.3 Water Dump Operations

Supply and waste water dumps are performed using nozzles on the port side of the Orbiter. Sixteen water dumps can clearly be seen in Figure 5 plot of the OARE data for the entire mission. It can be seen that the effect of such a dump is primarily on the Y_b-axis as expected, and is on the order of -1×10^{-6} g. These dumps each lasted for about one hour.

4. COMPARISON OF OARE DATA WITH THE MAWS PREDICTION

The MAWS was developed by Teledyne Brown Engineering to support USML-2. MAWS consisted of a PC-based system configured to acquire real-time Orbiter dynamics data and use the data to calculate the combined levels of the aerodynamic drag and tidal effects using a six degree of freedom model. MAWS successfully acquired and processed data for the entire mission. This data was compared in real-time with the OARE measurements, and they agreed remarkably well. This was true for all attitudes flown. Notable differences between the two data sets were due to Orbiter venting operations that are not modeled by MAWS, and due to OARE instrument drift. Regular OARE calibration operations consistently corrected for this drift and returned the data sets to within 5×10^{-8} g differences. Figure 6 shows a comparison of OARE and MAWS data, at the OARE location, for a time period when a water dump was performed. Note that this operation was not modeled by MAWS.

5. OARE DATA AT THE CGF SAMPLE MELT

During USML-2 several crystal growth experiments were performed using the CGF. In support of these experiments the real-time OARE data, mapped to the CGF sample melt location, was provided to the PIs. A comparison of the results obtained at the OARE location and those mapped to the CGF sample location is shown in Figure 7.

In body coordinates, the locations of the OARE sensor and the CGF sample melt were (-60.14 in., 0.94 in., 56.78 in.) and (6.75 in., 42.59 in., -23.66 in.) respectively. It can be seen from Figure 7 that a mapping from the OARE sensor to the CGF sample melt location, while the Orbiter is in the CGF attitude, results in a sign change in the X_b-component of the acceleration. This result is expected since the X_b-coordinates of these locations vary in sign, and therefore are on opposite sides of the Orbiter c.g.. Hence, tidal effects are the predominant contributor to the X_b-component of the acceleration. Although the Z_b-coordinates of the sensor and melt locations also vary in sign, the corresponding accelerations do not. This is as expected, since, in the CGF attitude, the - Z_b-axis points in the direction of flight, therefore, drag is the predominant contributor to the Z_b-component of the acceleration. Figure 7(b) clearly shows the quasi-steady nature of the axial (Z_b) component of the acceleration, the magnitude of which is seen to vary sinusoidally with a frequency equal to about one orbital period.

In addition to aligning the crystal growth direction with the velocity vector, during this mission the crystal growth PIs expressed a desire to maintain the radial component of the acceleration ($\sqrt{[X_{CGF}^2 + Y_{CGF}^2]}$) $\leq 0.1 \times 10^{-6}$ g, the axial component (Z_{CGF}) $< 1 \times 10^{-6}$ g, and to optimize the ratio of axial/radial components. Figure 8 shows plots of these parameters with respect to time, for the same time slice as Figure 7.

6. CONCLUSIONS

The quasi-steady acceleration measured by the OARE during STS-73 was presented. A comparison of the data with the MAWS prediction showed a remarkable agreement. Events such as water dumps, though not modeled by the MAWS model, are clearly seen in the OARE data.

The effect of experiment location within the Orbiter was discussed. Position relative to the Orbiter c.g. can significantly impact the tidal contributions of the acceleration. The component(s) of the acceleration that is most affected by this would depend on the attitude flown.

ACKNOWLEDGMENTS

Canopus Systems, Inc. processed the OARE data under NASA contract NAS3-26556. The authors are grateful to Mr. Larry French for providing the MAWS data, and to Mr. Tim Reckart for providing graphics support.

REFERENCES

1. M.J.B. Rogers and R. Delombard; *"Summary Report of Mission Acceleration Measurements for STS-73"*. **NASA TM 107269** (July 1996).

2. B.P. Matisak, M.J.B. Rogers and J.I.D. Alexander; *"Analysis of the Passive Accelerometer System (PAS) Measurements During USML-1"*. **AIAA 94-0434**. Presented at the AIAA 32nd Aerospace Sciences Meeting, Reno, NV (Jan. 10-13, 1994).

3. E.S. Nelson, *"An Examination of Anticipated g-Jitter on Space Station and Its Effects on materials Processes"*. **NASA TM 103775** (1991).

4. R.C. Blanchard, J.Y. Nicholson, and J.R. Ritter, *"STS-40 Orbital Acceleration Research Experiment Flight Results During a Typical Sleep Period"*, **Microgravity Sci. Technol. 2**; 86-93 (1992).

5. R.C. Blanchard, M.K. Hendrix, J.C. Fox, D.J. Thomas, and J.Y. Nicholson, *"Orbital Acceleration Research Experiment"*, **J. Spacecraft and Rockets 24 (6)**; 504-511 (1987).

6. J.E. Rice, *"STS-73 (USML-2) Final Report"*. **NASA CR 198553** (1996).

7. B.P. Matisak and L.A. French, *"Microgravity Analysis Workstation (MAWS) Real-time Acceleration Monitoring"*. **AIAA 95-3560**. Presented at the AIAA Space Programs and Technologies Conference, Huntsville, AL (Sept. 26-28, 1995).

8. B. Feuerbacher, H. Hamacher and R. Jilg," *Compatibility of Microgravity Experiments With Spacecraft Disturbances"*. **Z Flugwiss Weltraumforsch 12**; 145-151 (1988).

9. M.J.B. Rogers and R. DeLombard, *"Summary Report of Mission Acceleration Measurements for STS-62"*. **NASA TM 106773** (Nov. 1994).

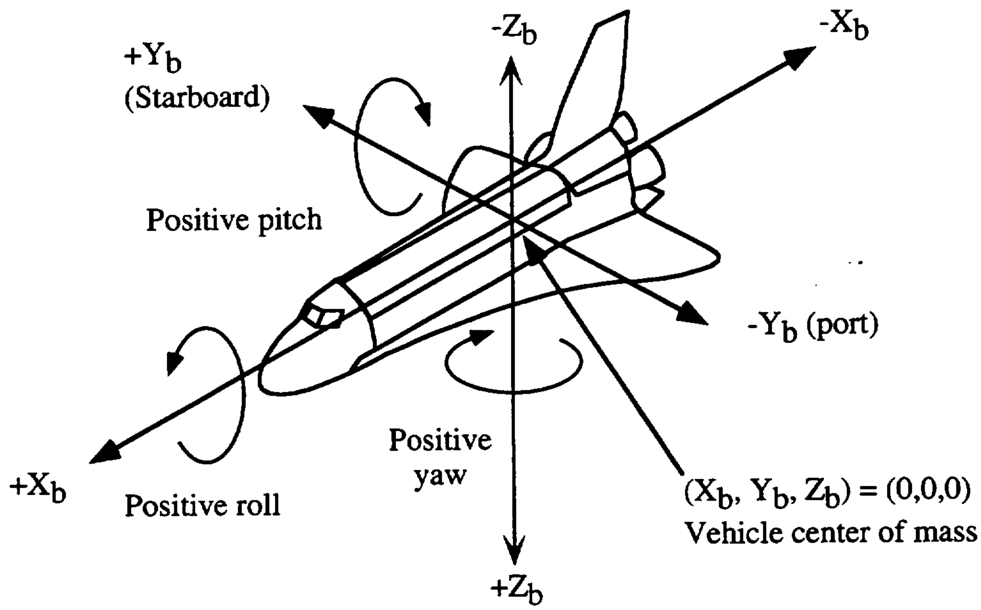


Fig. 1a. Orbiter body coordinate system (X_b, Y_b, Z_b).

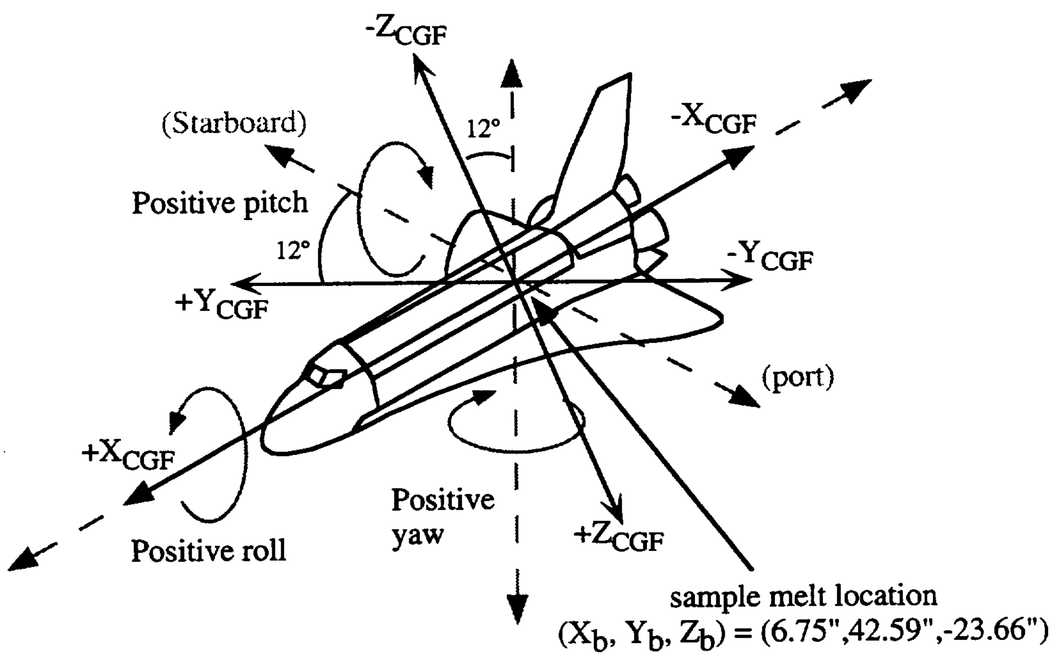


Fig. 1b. CGF coordinate system (X_{CGF}, Y_{CGF}, Z_{CGF}).

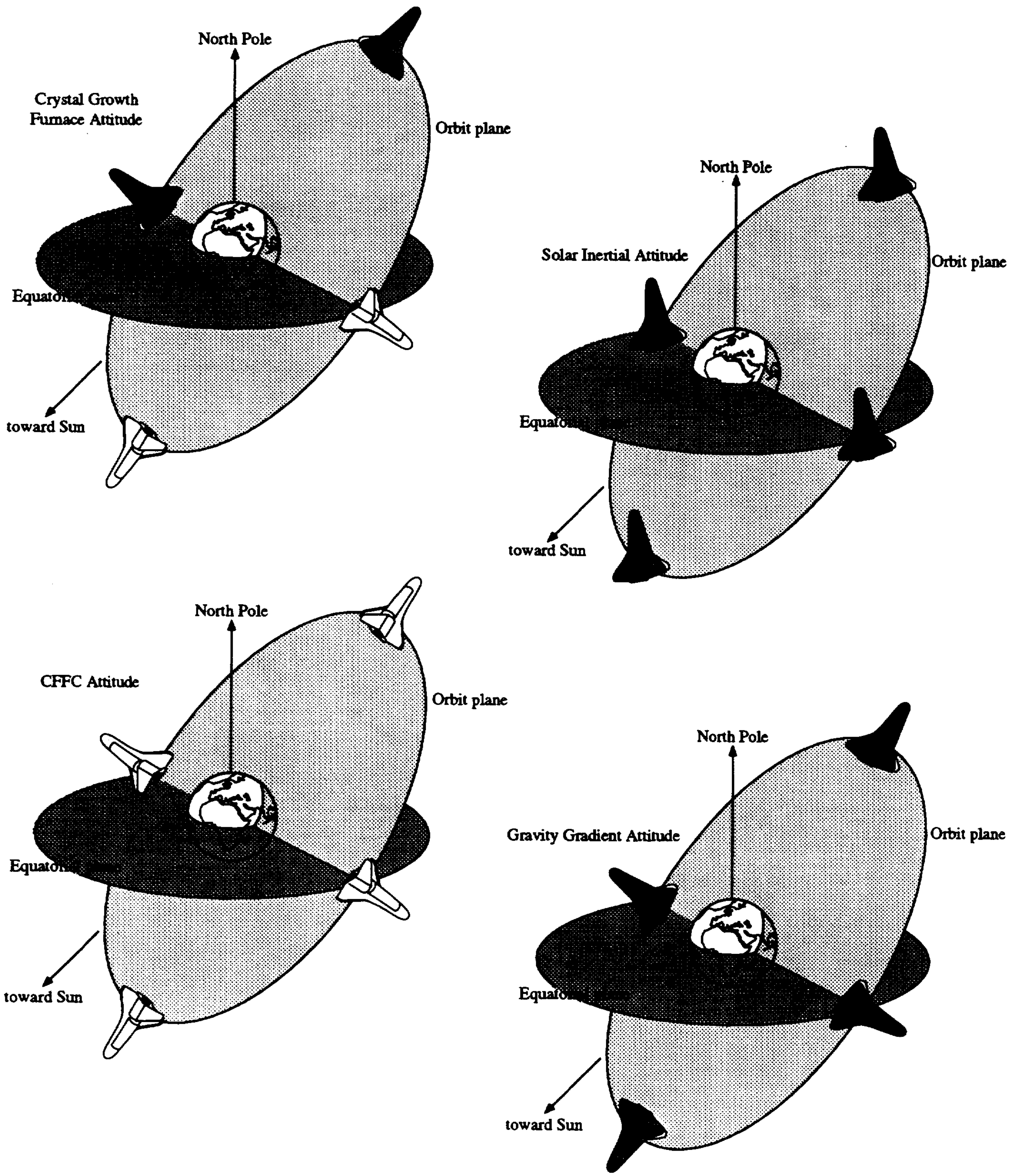


Fig. 2. USML-2 Major attitudes.

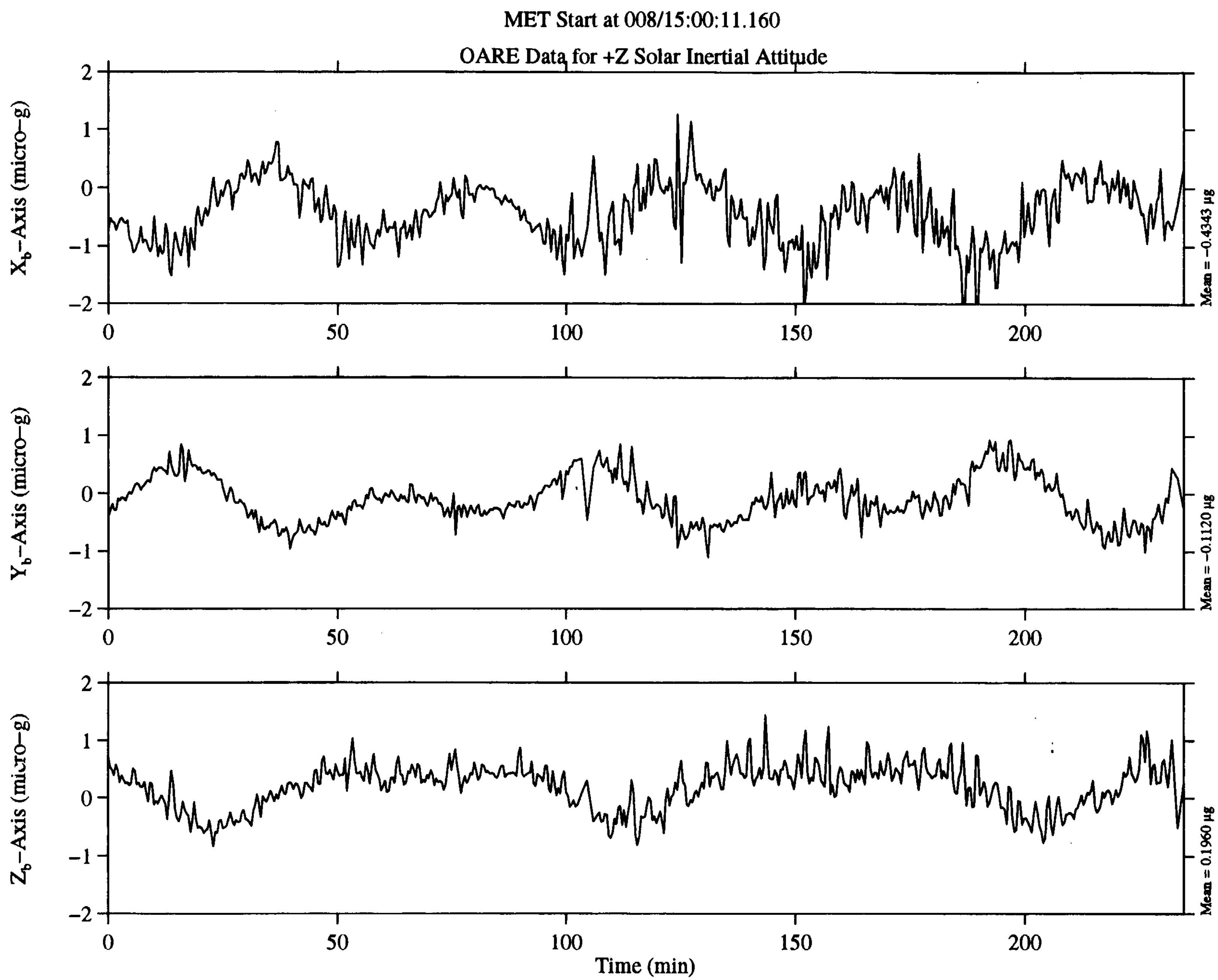


Fig. 3. Trimmean filter OARE data at OARE location for period when Columbia was in the solar inertial attitude for tire warming.

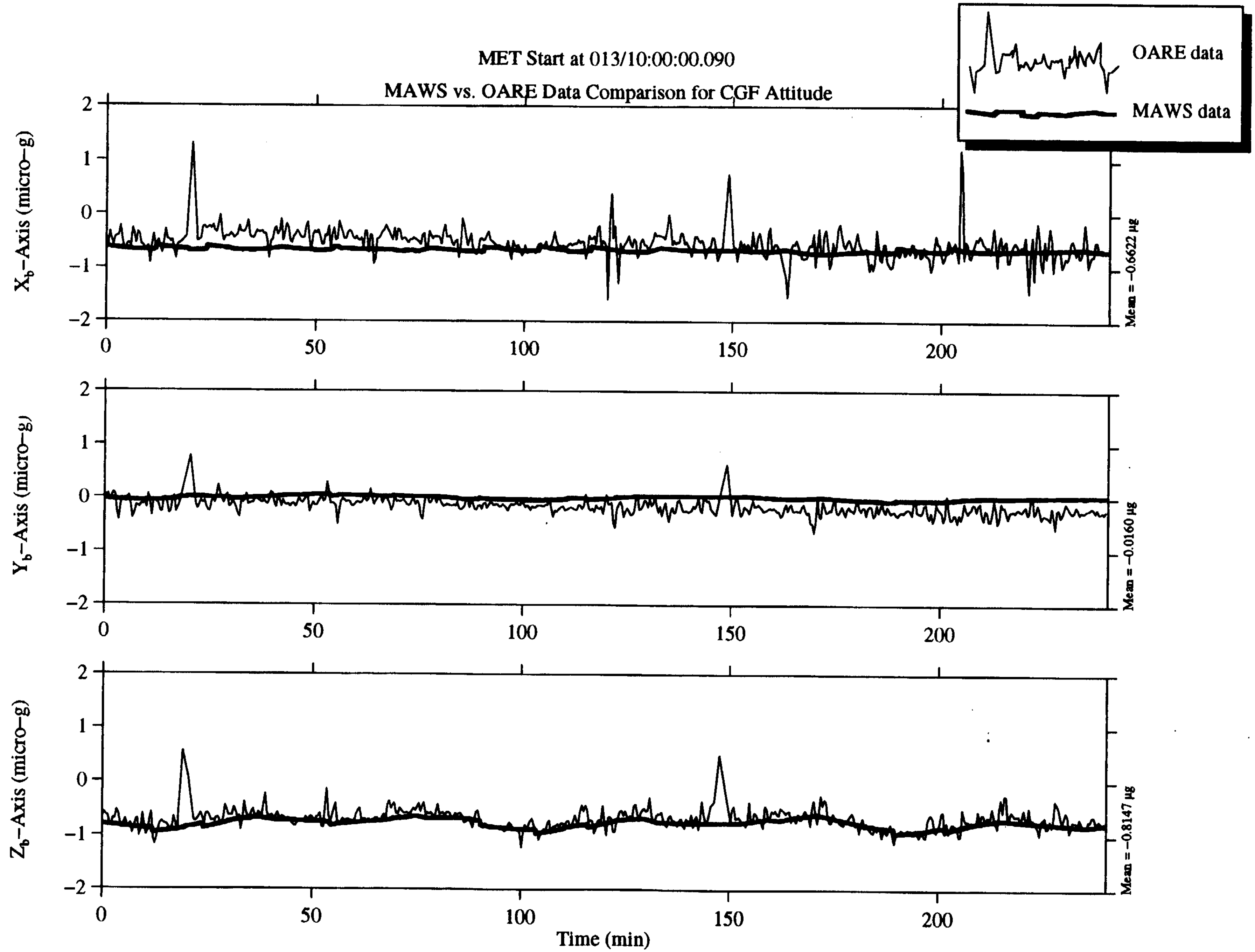


Fig. 4. Comparison of trimmean filter OARE data with MAWS data, at OARE location, for period when Columbia was in the CGF attitude.

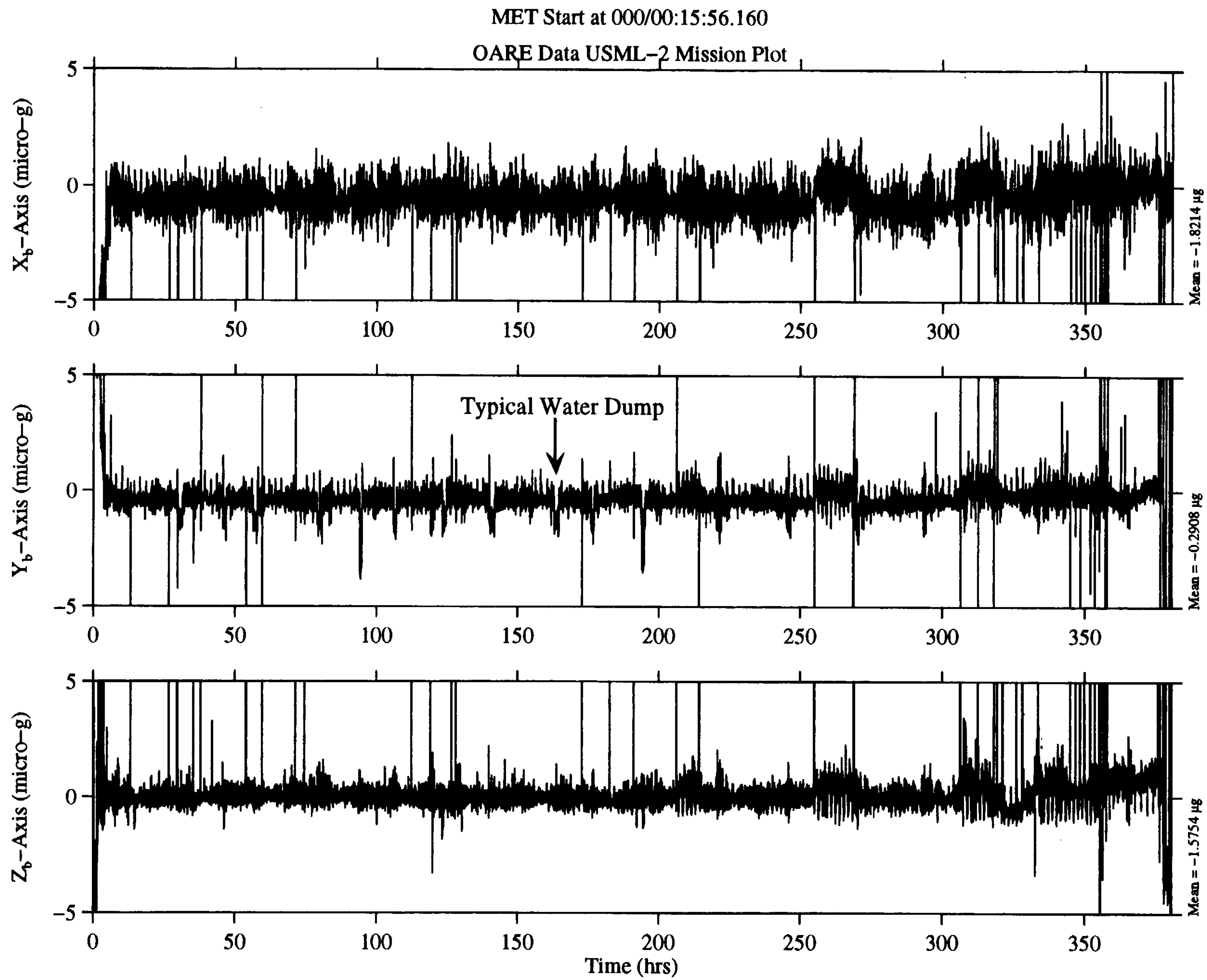


Fig. 5. Trimmean filter OARE data for entire STS-73 mission, at OARE Location.

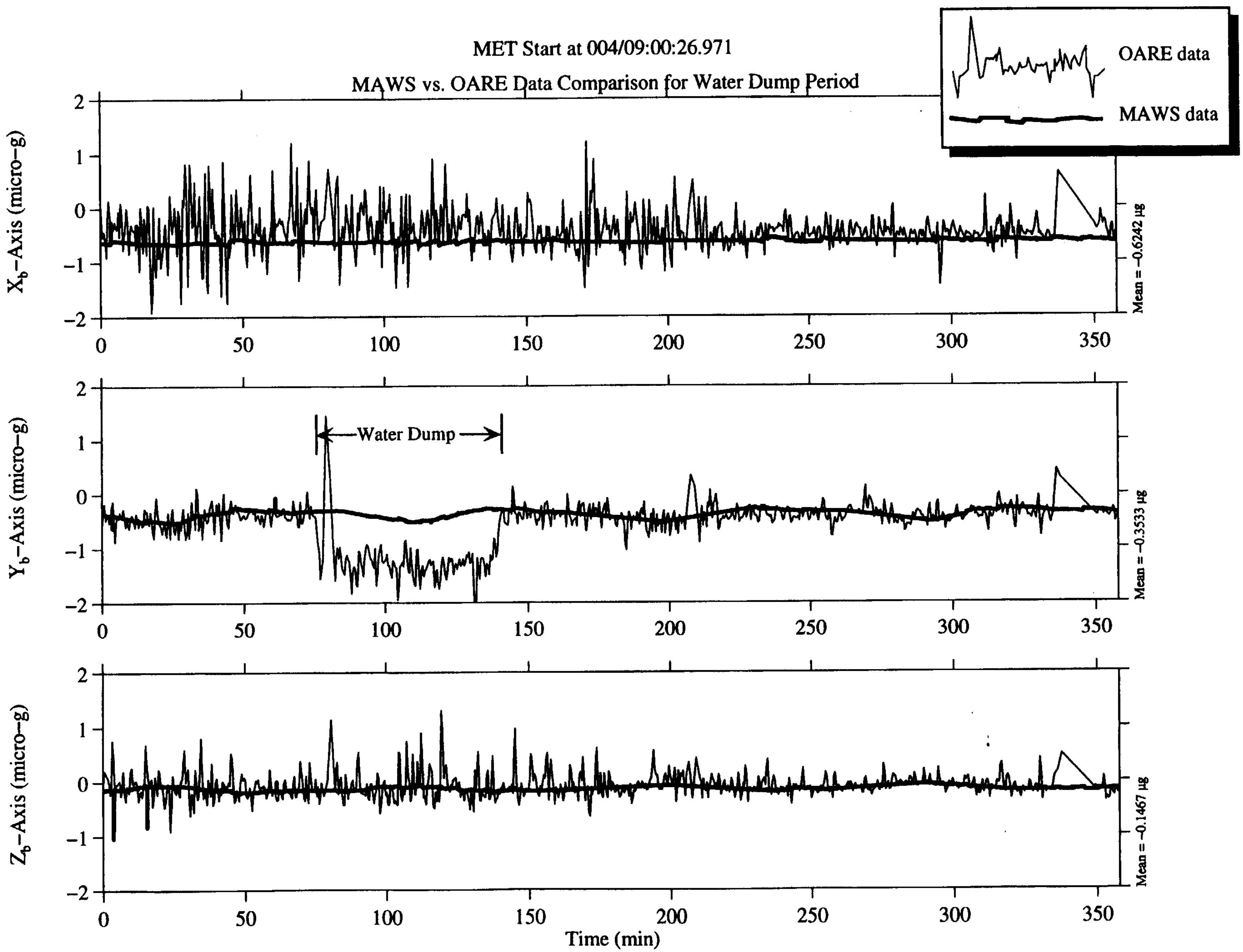


Fig. 6. Comparison of trimmean filter OARE data with MAWS data, at OARE location, during a water dump operation.

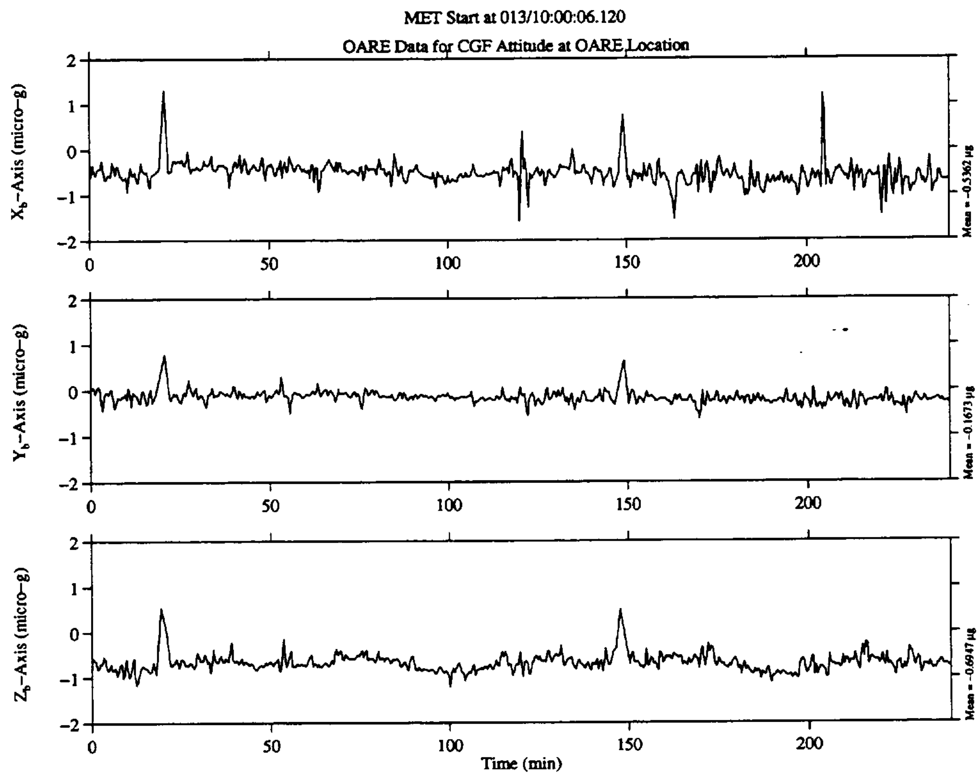


Fig. 7a. Trimmean filter OARE data for period when Columbia was in the CGF attitude, at OARE location.

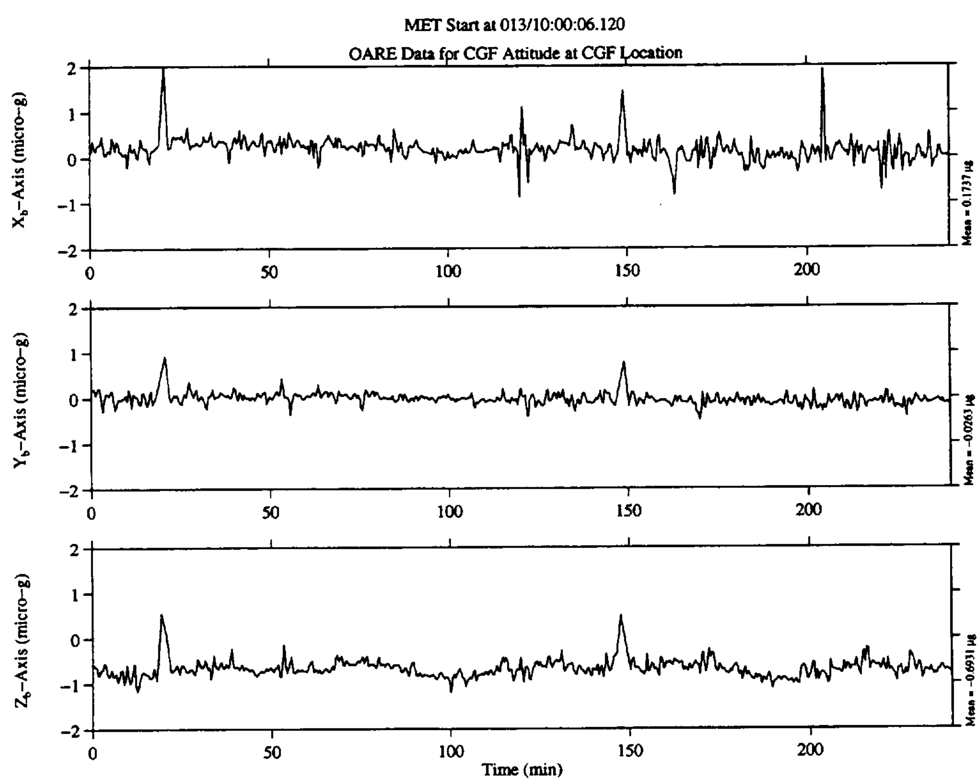
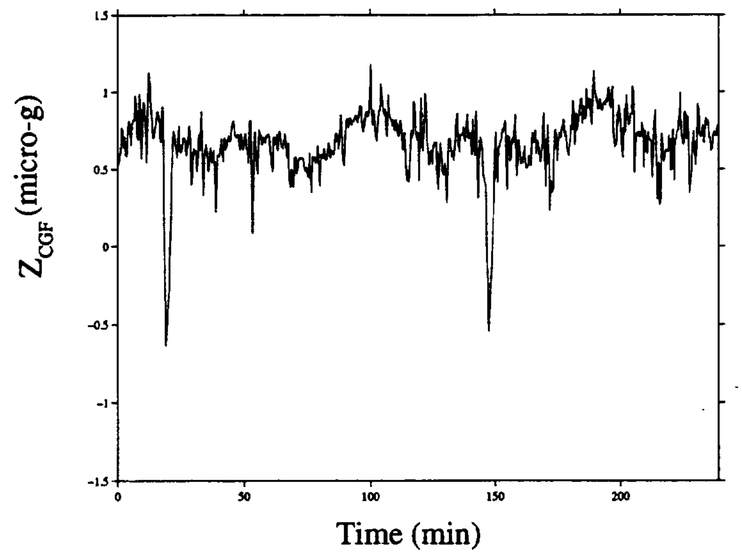
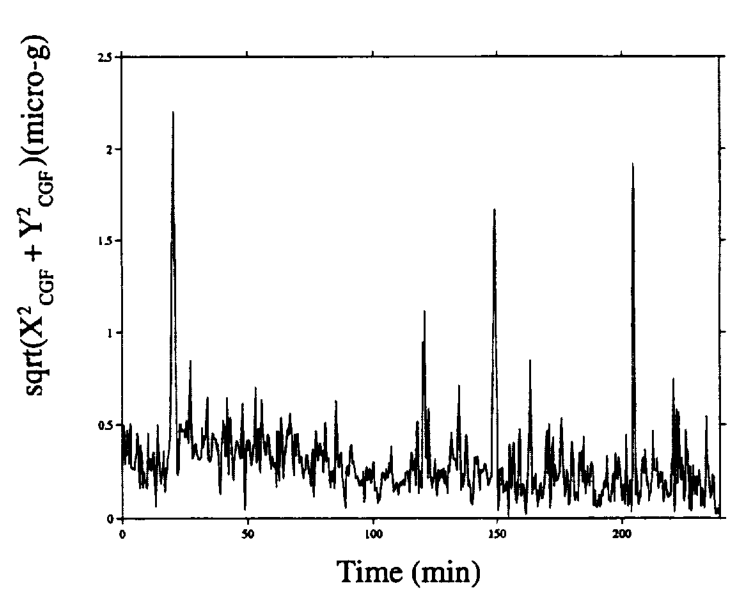


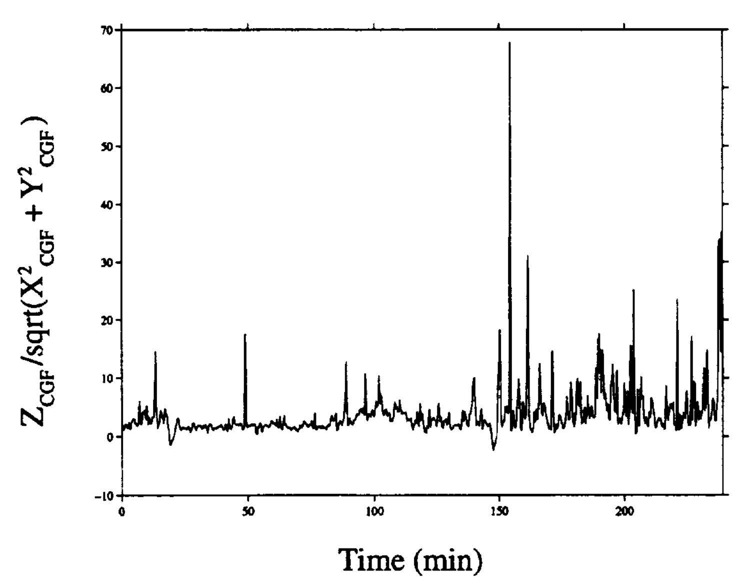
Fig. 7b. Trimmean filter OARE data for period when Columbia was in the CGF attitude, mapped to the CGF sample melt location.



a).



b).



c).

Fig. 8. Trimmean filter OARE data, at the CGF sample melt location and in CGF coordinates, for a period when Columbia was in the CGF attitude, a) Axial component of acceleration, b) Radial component of acceleration, c) Ratio of the axial to radial components of acceleration.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1997

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Effects of Experiment Location and Orbiter Attitude on the Residual Acceleration On-Board STS-73 (USML-2)

5. FUNDING NUMBERS
WU-963-60-0K-00

6. AUTHOR(S)
Roshanak Hakimzadeh, Kevin M. McPherson, Brian P. Matisak, and William O. Wagar

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135-3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E-10778

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-107483

11. SUPPLEMENTARY NOTES
Prepared for the Materials Research in Low Gravity Conference sponsored by the Society of Photo-Optical Instrumentation Engineers, San Diego, California, July 27—August 1, 1997. Roshanak Hakimzadeh, Kevin M. McPherson, and William O. Wagar, NASA Lewis Research Center; Brian P. Matisak, Teledyne Brown Engineering, 300 Sparkman Drive, M.S. 172, Bldg. 2, Huntsville, Alabama 35807. Responsible person, Roshanak Hakimzadeh, organization code 6727, (216) 433-8738.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 29

This publication is available from the NASA Center for AeroSpace Information, (301) 621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

A knowledge of the quasi-steady acceleration environment on the NASA Space Shuttle Orbiter is of particular importance for materials processing experiments which are limited by slow diffusive processes. The quasi-steady (<1 HZ) acceleration environment on STS-73 (USML-2) was measured using the Orbital Acceleration Research Experiment (OARE) accelerometer. One of the facilities flown on USML-2 was the Crystal Growth Furnace (CGF), which was used by several Principal Investigators (PIs) to grow crystals. In this paper the OARE data mapped to the sample melt location within this furnace is presented. The ratio of the axial to radial components of the quasi-steady acceleration at the melt site is presented. Effects of Orbiter attitude on the acceleration data is discussed.

14. SUBJECT TERMS
Quasi-steady; Acceleration; OARE

15. NUMBER OF PAGES
14

16. PRICE CODE
A03

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