

MICROGRAVITY ENVIRONMENT CHARACTERIZATION PROGRAM

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ABSTRACT

The Microgravity Science and Applications Division (MSAD), a division within NASA's Office of Life and Microgravity Science and Applications, sponsors a broad range of space-based research in biotechnology, combustion science, fluid physics, fundamental physics, and materials science. To better understand and exploit the orbital environment, MSAD has developed methods and hardware to characterize accelerations on microgravity experiment carriers. MSAD supports research to verify analytically derived acceleration requirements for experiments and provides vibration isolation for sensitive experiments.

The Microgravity Measurement and Analysis Project (MMAP), supported by MSAD, incorporates four projects: the Space Acceleration Measurement System (SAMS), the Orbital Acceleration Research Experiment (OARE), the SAMS for International Space Station (SAMS-II), and the Principal Investigator Microgravity Services (PIMS). SAMS was developed to record microgravity accelerations and the OARE was developed to record very low-frequency microgravity accelerations on-board the NASA Orbiters. The SAMS is also used for cooperative investigations on the Russian Mir space station. The SAMS-II is being developed for the same function on-board the International Space Station (ISS). PIMS utilizes microgravity acceleration data to develop a description of each microgravity mission's acceleration environment and to support microgravity investigators in interpreting possible effects of the acceleration environment on their experiments. These elements of the MSAD program will be used to define acceleration requirements for future Orbiter and ISS payloads.

This paper describes the MMAP and summarizes the products and services available to principal investigators and other users. This paper also presents some microgravity acceleration characterization results from the last six years of Orbiter microgravity missions.

INTRODUCTION

Biotechnology, combustion science, fluid physics, fundamental physics, and materials science experiments are conducted on the NASA Space Shuttle Orbiters to take advantage of the reduced gravity environment resulting from the continuous free fall state of low earth orbit. Accelerometer systems are flown on the Orbiters to record the microgravity environment which is composed of quasi-steady accelerations and vibrations of the Orbiter, equipment, and local structures.

The purpose of the Microgravity Measurement and Analysis Project (MMAP) at NASA Lewis Research Center is to measure and characterize the microgravity environment on-board the NASA space shuttle Orbiters, the Russian Mir space station, and the International Space Station (ISS) and to provide this information to the microgravity science community. The Principal Investigator Microgravity Services (PIMS) group within MMAP works closely with the microgravity science community to identify the various effects of the environment on their experiments.

Accelerometer data from a mission are acquired and processed in response to requirements by the Principal Investigators (PIs) of science experiments. These data are then provided to the microgravity science community in the form of reports and on a file server, and special analyses are performed to support specific requests by the experiment principal investigators (PIs). More information is available in reference [1] on how to obtain the data generated by the MMAP organization. Additional information on interpreting the microgravity environment on the Orbiters is available in reference [2].

The microgravity environment needs to be considered when analyzing the results of a science experiment conducted in orbital conditions. In experiments conducted on Earth, the force of gravity dominates the effects of other smaller disturbances on an experiment. In general low-level vibrations, such

as seismic disturbances and refrigerator and building air conditioner operations do not disturb ground-based experiments. With the "absence" of gravity due to the free-fall condition of orbit, smaller vibrations related to equipment operations (for example) can have a predominant effect on an experiment.

This paper provides a description of the microgravity environment on the Orbiters. The measurement techniques used by the SAMS and OARE organizations are described, and a summary of the services provided by PIMS to the microgravity experiment teams is provided. Also, typical microgravity acceleration data from the past space shuttle missions are presented.

INSTRUMENTATION

Space Acceleration Measurement System (SAMS)

SAMS was developed to measure the low-gravity environment of Orbiters in support of MSAD-sponsored science payloads. The first mission for SAMS was STS-40 in June 1991 and SAMS units have flown on sixteen missions since then. One of the seven flight units was installed on the Mir space station in 1994.

A SAMS unit consists of three remote triaxial sensor heads and a data acquisition unit. SAMS data has been acquired in the Orbiter middeck, on carriers in the cargo bay, in the Spacelab module, and in the SPACEHAB module. SAMS units measure the environment with low pass bandwidths of 2.5, 5, 10, 25, 50, or 100 Hertz. More detailed descriptions of the SAMS accelerometers are available in the literature [3, 4]. In this paper the SAMS data is presented in Orbiter structural coordinates [5].

A new generation accelerometer system, called SAMS-II, is being developed to support the science experiments on-board the ISS. This unit will have many new features to cater to the operational scenarios on-board the ISS [6].

Orbital Acceleration Research Experiment (OARE)

The OARE was designed to measure low-frequency (quasi-steady) accelerations from below 10 nano-g up to 25 milli-g. OARE consists of three-axis sensor, an in-flight calibration subsystem, and a data acquisition unit [7, 8]. The sensor output acceleration signal is filtered with a Bessel filter with a cut-off frequency of 1 Hertz. The output signal is digitized at 10 samples per second and is processed and digitally filtered with an adaptive trimmean filter prior to storage on-board.

The OARE instrument is mounted to the floor of Columbia's cargo bay on a keel bridge. Utilizing OARE data and Orbiter real-time parameters, the quasi-steady acceleration levels for locations separate from the OARE instrument may be estimated in real-time. In this paper the OARE data is presented in Orbiter body coordinates [5]. OARE has acquired data on nine Orbiter missions to date.

MICROGRAVITY ENVIRONMENT

The microgravity environment on-board the Orbiter is generally separated into three classes: quasi-steady, vibratory and transient.

The quasi-steady regime is generally considered to be at those frequencies below the lowest natural structural resonance frequency of the vehicle. For the NASA Orbiters this lowest frequency is about 0.4 Hertz. Below this frequency, the Orbiter responds to disturbing forces as a rigid body. In general three additive sources of acceleration contribute to the resultant quasi-steady environment: aerodynamic drag, gravity gradient and rotational effects. The gravity gradient and rotational components are both related to the distance from the center of gravity (c.g.) of the Orbiter. Examples of other quasi-steady disturbances include Orbiter maneuvers and venting forces. Figure 1 shows the OARE data and two attitudes of the Orbiter during the STS-62 mission. This data shows the effect on the Orbiter quasi-steady environment during a maneuver. Since the atmospheric drag is reversed in the Z-axis direction, the acceleration levels for the OARE Z axis data is seen to reverse sign from before to after the attitude change.

Above the natural frequencies, the vehicle structure responds to local disturbances and transmits vibration throughout its structure. These disturbances could be oscillatory and/or transient in nature. The response at a particular location is a complex combination of disturbances from multiple sources. Typical sources of oscillatory disturbances include pumps, fans, centrifuges, crew exercise, and antenna motions. Transient accelerations are caused by sudden and irregular disturbance sources on the vehicle. The most

apparent are the thrusters which are operated to maintain the Orbiter's attitude. Figure 2 indicates the vibratory and transient nature of the microgravity environment of the Orbiter Columbia during a portion of the STS- 47 mission. The disturbance in the first half of the plot was caused by the vibrations related to a refrigerator compressor. A transient is visible following the turn-off of the compressor.

EFFECTS OF THE MICROGRAVITY ENVIRONMENT ON SCIENCE

Experiments are performed in space to take advantage of the unique advantages offered by the space environment. However, researchers may discover that their experiments are affected by microgravity disturbances on the Orbiter. The effects on science which are caused by the microgravity environment can include convective flow of gases and fluids, sedimentation of impurities, and drift of free-floating droplets.

Many microgravity experimenters have been concerned with the acceleration environment during their experiment operations. Combustion researchers quite often request inhibits for thruster firing, crew activity, and other possible disturbances during the experiment operations. Crystal growers have required that low-frequency acceleration levels be minimized to limit the convective flow in the molten material. In addition, some crystal growth experiments desire optimum values of the axial to radial ratio of the residual quasi-steady acceleration at the sample melt location.

Oscillatory and transient disturbances have had dramatic effects on experiments operating on-orbit. On STS-32, the Microgravity Disturbance Experiment (MDE) demonstrated the effects of crew exercise on a liquid bridge of indium [9]. The MDE included the Rockwell Fluids Experiment Apparatus and the Honeywell In-space Accelerometer. Oscillation of the liquid bridge was observed and filmed by a crew member while another crew member exercised on the Orbiter treadmill. In some cases, the liquid bridge oscillated so violently that it hit the side walls of the chamber.

On STS-52 and STS-75, the MEPHISTO experiment observed large changes in the concentration when the experiment was exposed to transient forces from Orbiter thrusters being fired [10]. Even though the thruster events were only about 34 seconds long, the disturbance to the diffusion field lasted 15 minutes or longer.

On STS-73, oscillations were observed on the free liquid surface in the Surface Tension Driven Convection Experiment (STDCE). One possible source of this disturbance was identified to be the fans inside the glovebox, specifically the cooling and air circulation fans. To investigate this, the decision was made during the mission to turn these fans off. The data from a SAMS sensor head with a filter cut-off frequency of 25 Hertz (sample rate was 125 samples per second) indicated that disturbances with frequency components at 20, 38, 43, 48 and 53 Hertz may be attributed to these fans. Figure 3 shows a SAMS power spectral density (PSD) plot from this sensor head. Note that the PSD is displayed out to the highest frequency possible to show the higher frequency (> 25 Hertz) disturbances. A better picture is obtained from the color spectrogram plot of the data [11]. As a result of this, during the STS-73 mission, the STDCE team requested that the fans be turned off during critical operations of the STDCE. These disturbances should be considered when experiments are operated in the glovebox.

The expected effects of the microgravity environment need to be addressed early in the experiment and mission planning process. Incorporating plans for controlling the microgravity environment while developing a mission timeline is important. Some aspects of a mission which may be manipulated to help control the microgravity environment are the crew timeline, Orbiter attitude and control, Orbiter altitude, and payload equipment operations. In addition vibration isolation systems may be considered for particularly sensitive experiments [12].

CONCLUSIONS

Consideration of the microgravity environment must start early in the planning and execution of a microgravity experiment. The MMAP group is available for assistance with understanding the microgravity environment at any stage in this process.

For each mission, the individual experiment operation times are planned carefully to minimize the effects of microgravity. Although the microgravity environment of the space shuttle Orbiters have been well characterized, the effects of this environment on the scientific experiments need to be better understood. In the past few years, the PIMS group has worked closely with the microgravity PIs to identify the microgravity disturbances and effects on science. The PIMS project has collected a database of

disturbances and effects on science. However, further research needs to be performed to better understand the effects of microgravity on science in order to fully utilize future microgravity laboratories, such as the ISS.

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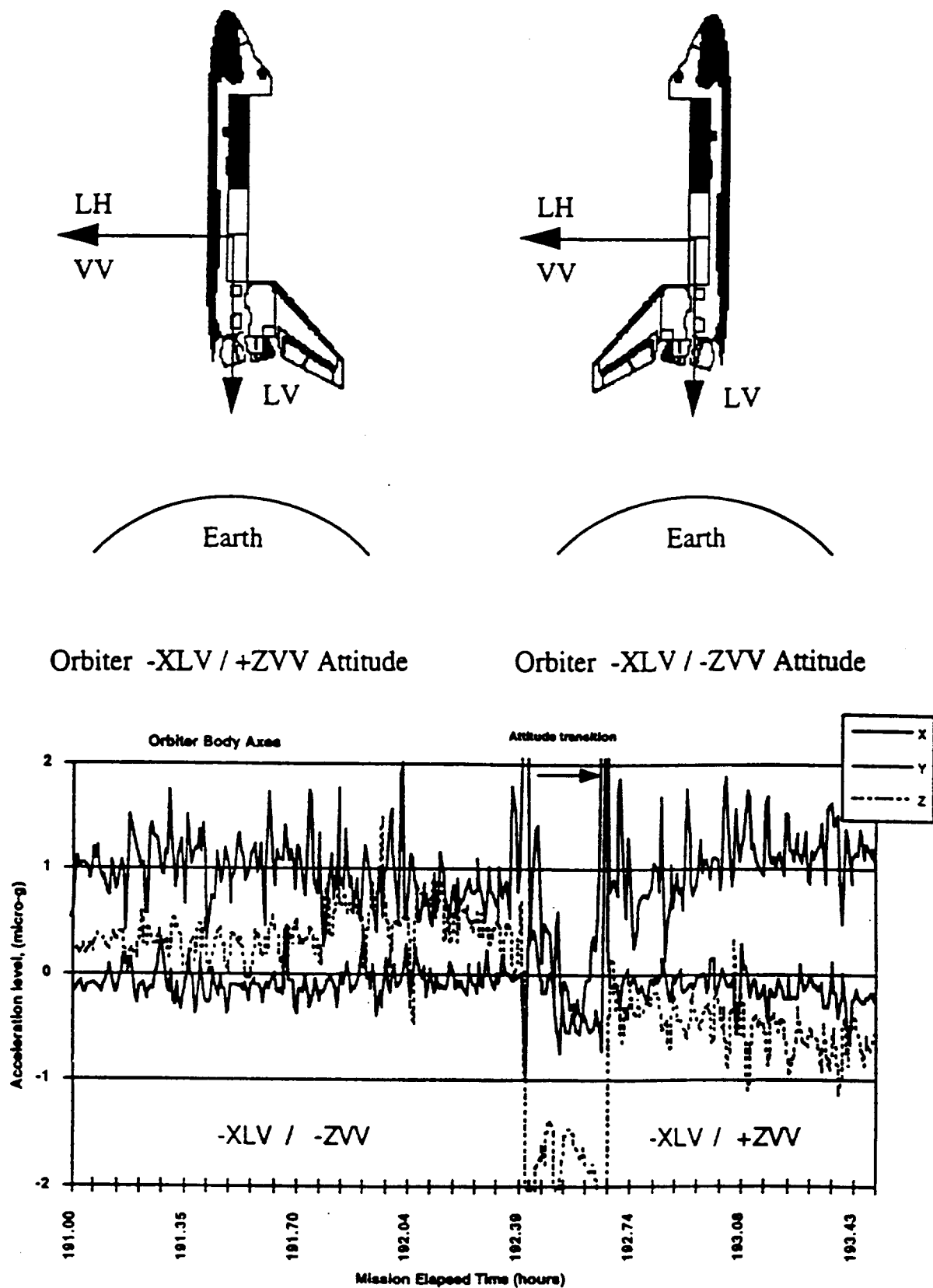


Figure 1: Attitude transition during USMP-2 operations (-XLV/-ZVV to -XLV/+ZVV)

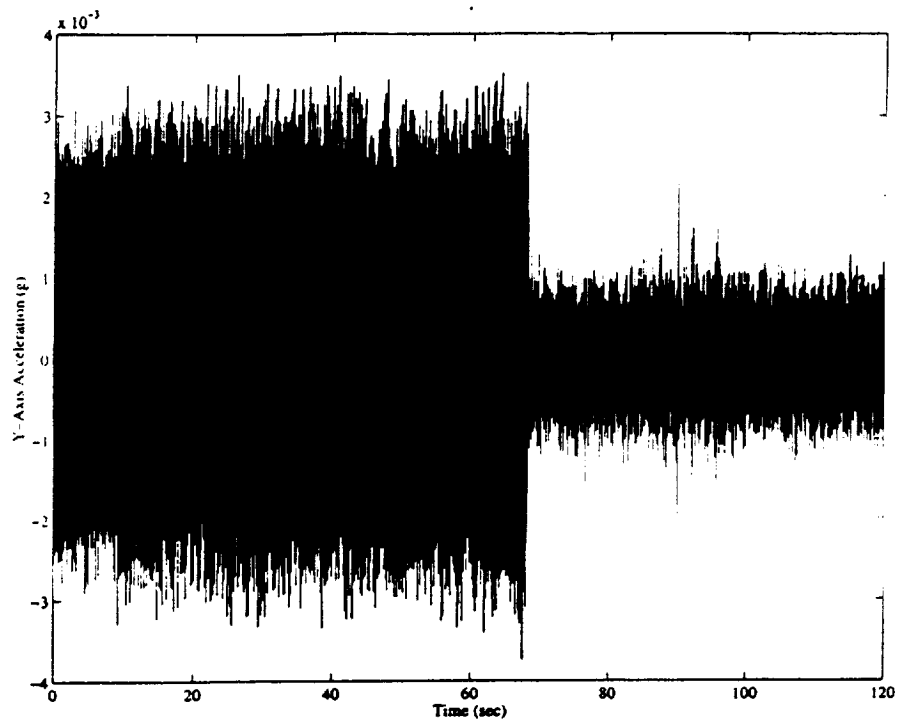


Figure 2: SAMS data showing deactivation of refrigerator compressor at about 70 seconds and a transient acceleration event at about 90 seconds.

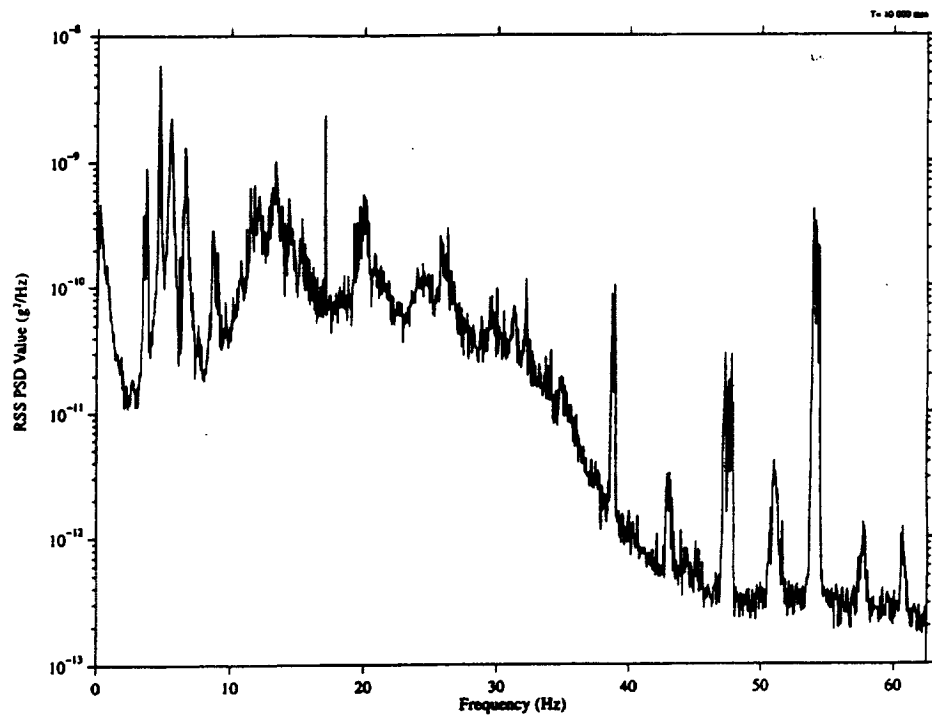


Figure 3: SAMS data showing accelerations related to glovebox facility fans at 20, 38, 43, 48, and 53 Hz.