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Low Gravity Environment On-board Columbia During STS-40

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Abstract

The first NASA Spacelab Life Sciences mission (SLS-1) flew 5 June to 14 June 1991 on the orbiter Columbia (STS-40). The purpose of the mission was to investigate the human body's adaptation to the low gravity conditions of space flight and the body's readjustment after the mission to the 1 g environment of earth. In addition to the life sciences experiments manifested for the Spacelab module, a variety of experiments in other scientific disciplines flew in the Spacelab and in Get Away Special (GAS) Canisters on the GAS Bridge Assembly. Several principal investigators designed and flew specialized accelerometer systems to characterize the low gravity environment. This was done to better assess the results of their experiments. This was also the first flight of the NASA Microgravity Science and Applications Division (MSAD) sponsored Space Acceleration Measurement System (SAMS) and the first flight of the NASA Orbiter Experiments Office (OEX) sponsored Orbital Acceleration Research Experiment accelerometer (OARE). We present a brief introduction to seven STS-40 accelerometer systems and discuss and compare the resulting data.

1. Introduction

The first NASA Spacelab Life Sciences mission (SLS-1) flew 5 June to 14 June 1991 on the orbiter Columbia (mission STS-40). The purpose of the mission was to investigate the human body's adaptation to the low gravity conditions of space flight and the body's readjustment after the mission to the 1 g environment of earth. In addition to the life sciences experiments manifested for the Spacelab module, a variety of experiments in other scientific disciplines flew in the Spacelab and in Get Away Special (GAS) Canisters on the GAS Bridge Assembly. To better assess the results of the various experiments, several principal investigators designed and flew accelerometer systems. This was also the first flight of the MSAD-sponsored SAMS and the first flight of the OEX-sponsored OARE. In the following section, we introduce seven accelerometer systems which measured and recorded acceleration levels during STS-40 and discuss the resulting data.

2. Accelerometer Systems, Data, and Results

The STS-40 accelerometer systems to be discussed are listed in Table 1.

Table 1. STS-40 Accelerometer Systems

Accelerometer System/Experiment	Investigator / Contact Person	Organization/ Affiliation
Fluid Behavior and Zeolite Crystal Growth Experiments	William W. Durgin	Worcester Polytechnic Institute
Gallium Arsenide Crystal Growth	David H. Matthiesen	Case Western Reserve Univ.
Orbiter Stability Experiment	Werner Neupert	NASA GSFC
OARE	Robert C. Blanchard	NASA LaRC
HiRAP	Robert C. Blanchard	NASA LaRC
Solid State Micro-Accelerometer	Philippe Roussel	ESA
SAMS	Richard DeLombard	NASA LeRC

2.1 GTE Gallium Arsenide Crystal Growth Experiment

The GTE experiment was designed to study the effect of reduced gravity on the growth of gallium arsenide semiconductor material.[1] The experiment was located in GAS Canister G-052 and was oriented with the accelerometer x- and y-axes parallel to those of the Orbiter and with the z-axes anti-parallel. A Sundstrand QA-2000 sensor was aligned with the crystal growth axis (x-axis) and QA-1400 sensors were used in the y- and z-directions. The measurement range for the system was 1×10^{-5}

clear to what extent the smooth reversal of attitude is the result of a sequence of thruster firings or reflects a low frequency response by the Orbiter to a single firing. In any case, no angular vibration at frequencies above about 1 Hz attributable to a vernier thruster firing is detectable with the present instrument.

2.4 ESA Solid State Micro-Accelerometer

The primary objective of the Solid State Micro-Accelerometer experiment (SSMA) was to test a new type of highly sensitive accelerometer in low-g to characterize the instrument performance. The system was designed to provide an engineering test demonstration of the sensors to prove suitability for applications on future flights. The SSMA was located in GAS Canister G-021. Twelve accelerometers (including two dummy units) were mounted in a three axis array on a one axis vibrating table designed to provide variable calibration signals during flight. Four accelerometers were oriented with their sensitive axis parallel to the vibration axis of the table and to the Orbiter y-axis, three parallel to the Orbiter x-axis, and three parallel to the Orbiter z-axis. Each accelerometer unit included a small proof mass (15 micro-gram) and supporting silicon springs fabricated from mono-crystalline silicon and combined on a hybrid substrate with analog readout electronics. The micro-structure and associated micro-electronics were sealed and mounted in a standard, 14 pin dual-in-line electronics package as an integral unit.

The SSMA was designed to operate in the range ±8 milli-g with a sensitivity of 125 volts/g and a frequency range of d.c. to

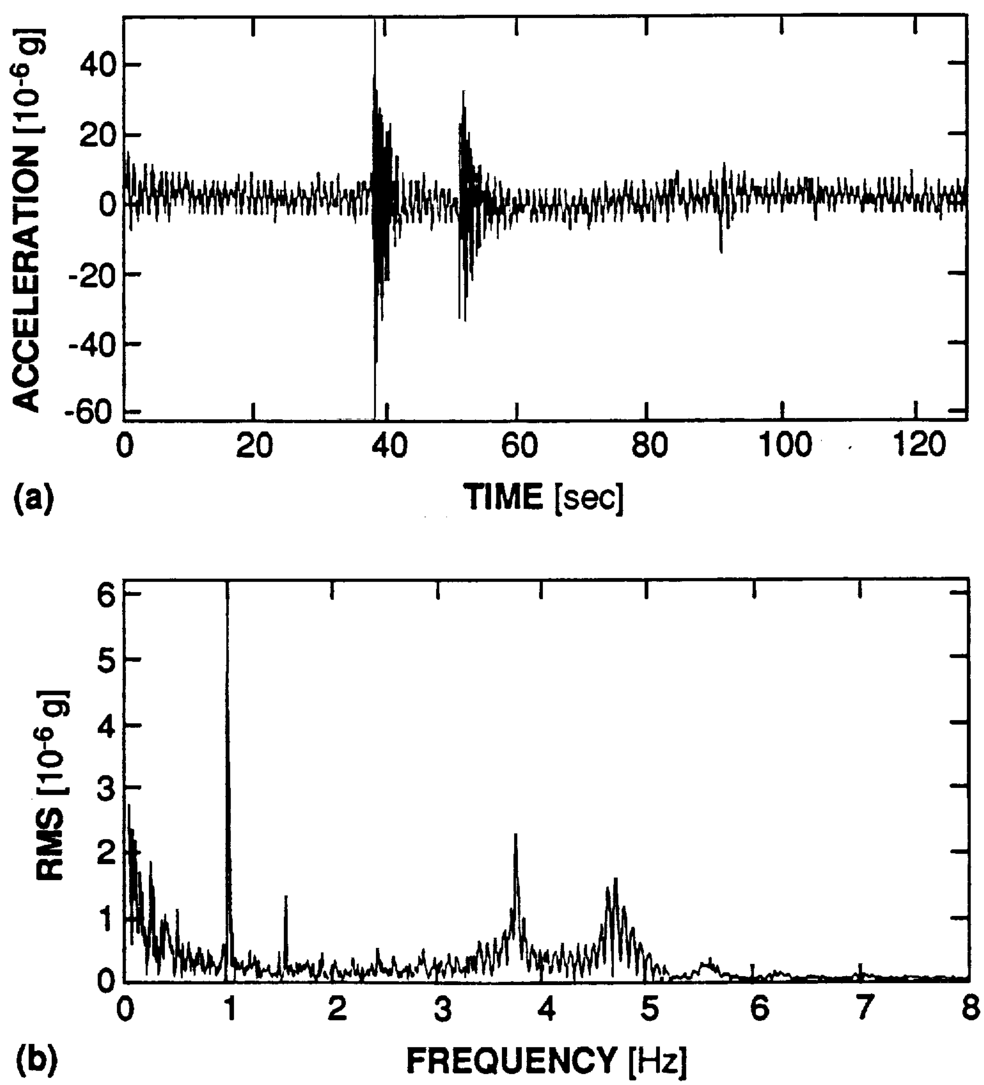

Fig. 1. Time history (a) and frequency domain representation (b) of SSMA y-axis data during Experiment Sequence 5. Note the 1 Hz/6 μg calibration signal and structural frequency modes of 3.7 and 4.7 Hz. Data were sampled at 16 Hz and a 4 Hz cutoff was applied in processing.

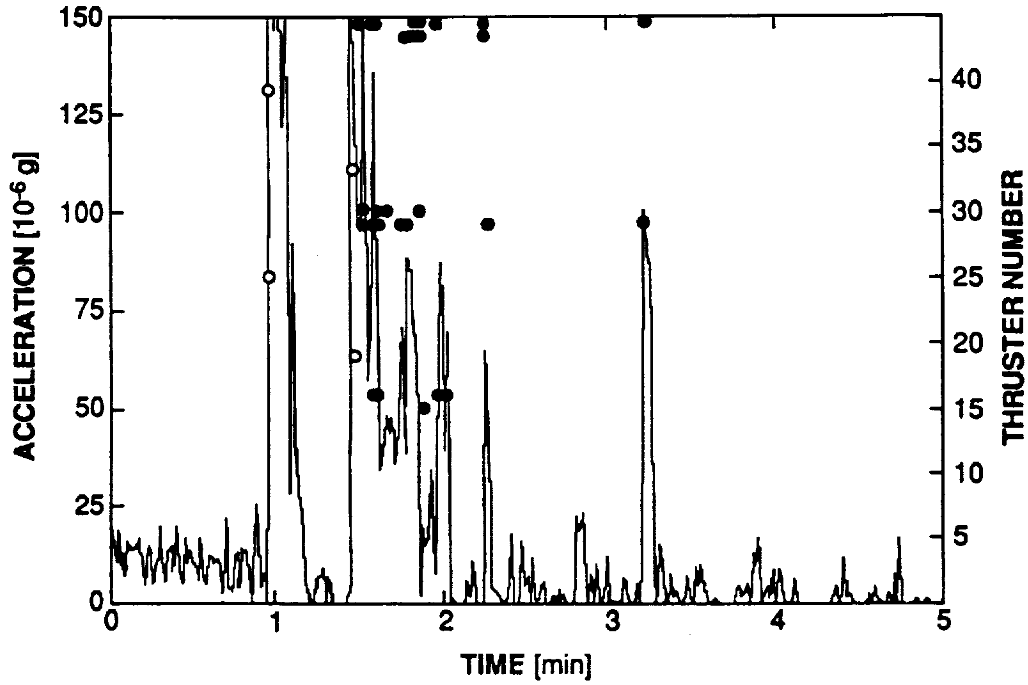

Fig. 3. Overlay of thruster firing occurrences and 1-second mean SAMS data. Solid circles denote vernier thruster firings, open circles denote primary thruster firings.

Variation of atmospheric drag among orbits was on the order of $\pm 2\times10^{-7}$ g. Some erratic instrument bias persists in the x- and z-axes. In these axes, the OARE data can be made to match a comprehensive atmospheric-aerodynamic model by making arbitrary bias adjustments.

2.6 High Resolution Acceleration Package

The High Resolution Acceleration Package (HiRAP) consists of a set of three orthogonal, pendulous, gas-damped accelerometers, each with a resolution of 1 μg and a measurement range of approximately ±8000 μg. HiRAP is designed to measure high-altitude aerodynamic acceleration on the Orbiter vehicle during atmospheric re-entry. The HiRAP is mounted in a wing box of the cargo bay, such that the orthogonal HiRAP axes are aligned with the Orbiter body axes. Data are collected at 112 Hz, and two lowpass filters at 20 Hz and 2 Hz are applied. HiRAP absolute accuracy over its twelve flights since 1983, after in-flight calibration, is in the range 3 to 7 μg.[4-13]

During re-entry, aerodynamic control surfaces used for Orbiter attitude and control require hydraulic power. This power is provided by a set of three auxiliary power units (APU). The exhaust gas ports for these pulsed turbines are located on the top of the Orbiter just in front and to the sides of the vertical tail. The exhaust jets of gas produce accelerations in the Orbiter negative z-direction. These APU accelerations were measured and recorded by HiRAP.

The APU signals become evident at two times during Orbiter descent: just before the deorbit burn and just before the onset of atmospheric drag. The 112 Hz HiRAP data were averaged over one second intervals to permit characterization of the acceleration changes. A time history of this period shows a shift at the ignition of the first APU, a sensor saturation during deorbit burn, a second shift at the ignition of the second and third APU, and the onset of dominant atmospheric drag.

Around the first APU transition, a measurement of the data shift shows a bias of about 15 μg. Data from the second and third APU transitions show a shift of about 32 μg. It is at the second APU transition region that an in-flight HiRAP calibration is performed. This 32 μg shift is incorporated in the calibration aerodynamic signal. The shifts in the z-axis acceleration signal are consistent with the shifts found in prior HiRAP missions.

2.7 Space Acceleration Measurement System

The Space Acceleration Measurement System was developed to monitor and measure the low-g environment of MSAD-sponsored science payloads on the Orbiter.[14,15] SAMS consists of three remote triaxial sensor heads, connecting cables, and a controlling data acquisition unit with a digital data recording system using optical disks with 200 megabyte storage capacity per side. With crew access to change the disks, the data storage capacity is essentially unlimited. On STS-40, three triaxial sets of Sundstrand QA-2000 sensors recorded data at 25 samples per second with a 5 Hz lowpass filter applied (140 dB/decade rolloff). The SAMS control electronics and data recording package was mounted in the Spacelab in SMIDEX Rack 5; SAMS was manifested to support the Solid Surface Combus-

SAMS, and SSMA data. The SAMS and SSMA data show typical excitation of Orbiter and Spacelab structural modes. The most common of these modes in the STS-40 data are those at 3.5, 4.7, 5.2, 6.2, and 7 Hz. The SSMA, recording data at a higher sampling rate than other instruments on STS-40, also measured the 17 Hz Ku-band antenna dither and Orbiter structural mode. The fact that the 4.7 Hz Spacelab mode was recorded by the SSMA on the GAS Bridge Assembly leads us to reevaluate our understanding of how vibrations propagate across loosely coupled structures. Further analysis of this phenomenon is required.

The flight of the seven accelerometer systems discussed here made STS-40 the best instrumented low-g Orbiter flight to date. The analysis has increased our knowledge of the typical acceleration environment of a manned Orbiter in low-Earth orbit. Further work, specifically additional frequency domain analysis, comparisons of thruster firing times with accelerometer data, and comparisons of data from accelerometers in the Spacelab and on the Gas Bridge Assembly, will greatly enhance our understanding of the propagation of accelerations throughout and across structures of the Spacelab and Orbiter.

4. References

[1]Matthiesen, D. H. and A. H. Bellows, Microgravity Acceleration Measurements Aboard the Get Away Special Bridge During STS-40, AIAA Paper 92-0355, AIAA 30th Aerospace Sciences Meeting, January 1992, Reno, Nevada.

[2]Blanchard, R. C., M. K. Hendrix, J. C. Fox, D. J. Thomas, and J. Nicholson, The Orbital Acceleration Research Experiment, AIAA Paper 86-1195, June 1986.

[3]Blanchard, R. C., J. Y. Nicholson, and J. R. Ritter, STS-40 Orbital Acceleration Research Experiment Flight Results During a Typical Sleep Period, NASA Technical Memorandum 104209, January 1992.

[4]Blanchard, R. C., Rarefied Flow Lift-to-Drag Measurements of the Shuttle Orbiter, ICAS Proceedings 1986 - 15th Congress of the International Council of the Aeronautical Sciences, Volume 2, P. Santini and R. Staufenbiel, eds., 1986, pp. 1421-1430.

[5]Blanchard, R. C. and G. M. Buck, Rarefied-flow Aerodynamics and Thermosphere Structure from Shuttle Flight Measurements, J. Spacecraft and Rockets 23 (1986) 18-24.

[6]Blanchard, R. C., E. W. Hinson, and J. Y. Nicholson, Shuttle High Resolution Accelerometer Package Experiment Results: Atmospheric Density Measurements Between 60 and 160 km, J. Spacecraft and Rockets 26 (1989) 173-180.

[7]Blanchard, R. C. and K. T. Larman, Rarefied Aerodynamics and Upper Atmospheric Flight Results from the Orbiter High Resolution Accelerometer Package Experiment, AIAA Paper 87-2366, AIAA Atmospheric Flight Mechanics Conference, August 1987.

[8]Blanchard, R. C. and J. F. Rutherford, Shuttle Orbiter High Resolution Accelerometer Package Experiment: Preliminary Flight Results, J. Spacecraft and Rockets 22 (1985) 474-480.

[9]Buck, G. M. and R. C. Blanchard, Rarefied Aerodynamics and Upper Atmosphere Density from Multiple Orbiter Flight Measurements, AIAA Paper 86-0269, January 1986.

[10]Thompson, J. M., J. W. Russell, and R. C. Blanchard, Methods for Extracting Aerodynamic Accelerations from Orbiter High Resolution Accelerometer Package Flight Data, A Collection of Technical Papers - AIAA Atmospheric Flight Mechanics Conference, AIAA, 1987, pp. 130-138.

[11]Blanchard, R. C. and E. W. Hinson, Flight Measurements of Shuttle Orbiter Pitching-moment Coefficient and Elevon Effectiveness in the Rarefied-flow Regime, NASA Technical Paper 2889, March 1989.

[12]Blanchard, R. C. and E. W. Hinson, Hypersonic Rarefied-flow Aerodynamics Inferred From Shuttle Orbiter Acceleration Measurements, Paper N.7.0, International Conference on Hypersonic Aerodynamics, University of Manchester, England, September 1989.

[13]Blanchard, R. C., K. T. Larman, and M. Barrett, The High Resolution Accelerometer Package (HiRAP) Flight Experiment Summary for the First 10 Flights, NASA Reference Publication 1267, April 1992.

[14]DeLombard, R. and B. D. Finley, Space Acceleration Measurement System Description and Operations on the First Spacelab Life Sciences Mission, NASA Technical Memorandum 105301, November 1991.

[15]DeLombard, R., B. D. Finley, and C. R. Baugher, Development of and Flight Results from the Space Acceleration Measurement System (SAMS), AIAA Paper 92-0354, AIAA 30th Aerospace Sciences Meeting, January 1992, Reno, Nevada (NASA Technical Memorandum 105652, January 1992).

[16]Baugher, C. R., Early Summary Report of Mission Acceleration Measurements from STS-40 (1991).

[17]Hamacher, H. and U. Merbold, Microgravity Environment of the Material Science Double Rack on Spacelab-1, J. Spacecraft 24 (1987) 264-269.

[18]Hamacher, H., U. Merbold, and R. Jilg, Analysis of Microgravity Measurements Performed During D1, in Proceedings of the Norderney Symposium on Scientific Results of the German Spacelab Mission D1, Norderney, Germany, August 1986, pp. 48-56.

[19]Rogers, M. J. B. and J. I. D. Alexander, Analysis of Spacelab 3 Residual Acceleration Data, J. Spacecraft and Rockets 28 (1991) 707-712.