NASA Technical Memorandum 105652
AIAA 92–0354

Development of and Flight Results From the Space Acceleration Measurement System (SAMS)

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Prepared for the
30th Aerospace Sciences Meeting and Exhibit
sponsored by the American Institute of Aeronautics
and Astronautics
Reno, Nevada, January 6–9, 1992

NASA

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Abstract

This paper describes the development of and flight results from the Space Acceleration Measurement System (SAMS) flight units used in the Orbiter middeck, Spacelab module and the Orbiter cargo bay. The SAMS units are general purpose microgravity accelerometers designed to support a variety of science experiments with microgravity acceleration measurements. A total of six flight units have been fabricated; four for use in the Orbiter middeck and Spacelab module, and two for use in the Orbiter cargo bay. The design of the units is briefly described. The initial two flights of SAMS units on STS-40 (June 1991) and STS-43 (August 1991) resulted in 371 megabytes and 2.6 gigabytes of data, respectively. Analytical techniques developed to examine this quantity of acceleration data are described and sample plots of analyzed data are illustrated. Future missions for the SAMS units are listed.

Acronyms

ACAP	Acceleration Characterization and Analysis Project
BIMDA	Bioserve ITA Materials Dispersion Apparatus
BRS	Body Restraint System
I/O	Input/output
IML	International Microgravity Laboratory mission series
KSC	NASA Kennedy Space Center
LeRC	NASA Lewis Research Center
MPESS	Mission Peculiar Equipment Support Structure
MSAD	Microgravity Sciences and Applications Division
MSFC	NASA Marshall Space Flight Center
PCG	Protein Crystal Growth
POCC	Payload Operations Control Center
RMS	Root Mean Square
SAMS	Space Acceleration Measurement System
SH	Spacehab mission series
SL-J	Spacelab J Mission
SLS-1	First Spacelab Life Science Mission
SSCE	Solid Surface Combustion Experiment
STS	Space Transportation System
USML	United States Microgravity Laboratory mission series
USMP	United States Microgravity Payload mission series

Introduction

The mission of NASA's microgravity science program is to utilize the unique characteristics of the space environment, primarily the near absence of accelerations, to expand man's knowledge of physics, chemistry, materials and fluid sciences, and biotechnology; to understand the role of gravity in materials processing; and, where possible, to demonstrate the feasibility of space production of improved materials that have high technological, and possible commercial, utility. [1]

Environmental factors (e.g., temperature, pressure, acceleration level) are typically measured during microgravity science missions to characterize the conditions to which the experiments were exposed. Many science experiments which are particularly sensitive to acceleration levels incorporate an accelerometer within the experiment package. The need for a general purpose acceleration measurement system arose from these numerous special purpose accelerometers. A general purpose system was desired which could be utilized as a standard to measure the microgravity environment for many diverse experiments in different locations on the Orbiter. Such a system should also be capable of multiple flights and configurations for the support of different experiments on successive missions.

The SAMS project was conceived in 1986 to develop such a general purpose instrument to measure low-levels of acceleration at experiment locations on the space shuttle Orbiter. The SAMS project was assigned to the NASA Lewis Research Center (LeRC) by the NASA Headquarters Office of Space Science and Applications, Microgravity Science and Applications Division (MSAD). The primary experiments to be supported are those funded by the MSAD, although other experiments are occasionally supported through arrangements with MSAD.

A SAMS flight unit measures, conditions and records the microgravity acceleration levels at as many as three experiment locations simultaneously. Each triaxial sensor head can be mounted on or near an experiment to detect accelerations with three single-axis acceleration sensors. The data is filtered and converted to digital data and stored on optical disks for access after the mission. One SAMS configuration allows data to be downlinked to ground facilities for access during the mission.

The Acceleration Characterization and Analysis Project (ACAP) was conceived in 1990 to provide a description of the microgravity acceleration environment of space flight carriers and informed recommendations for the management of available microgravity flight resources. The ACAP was assigned to the NASA Marshall Space Flight Center (MSFC) by MSAD.

Acceleration disturbances on earth are composed of a constant component (earth's gravity, referred to as 1 g) and oscillatory accelerations, such as, earth tremors, mechanical systems (e.g., air conditioners, fans), etc. Acceleration disturbances are vector quantities and can be characterized by their magnitude, direction, duration and frequency content.

Acceleration disturbances affect different processes in different ways. For example, in fluid flow experiments, the direction and speed of the fluid flow may be affected by low frequency accelerations. In contrast, fundamental physics experiments may be affected by energy input from accelerations over a broad-band of frequencies. These acceleration disturbances may be reduced by performing the experiment in a low residual acceleration environment on-board the Orbiter, although other time dependent sources unique to a spacecraft vehicle (such as firing of thrusters) may be introduced at the same time.

The operation and data from an experiment may be correlated with the experiment's local acceleration environment by utilizing the SAMS data. Experiments are typically installed in the Orbiter middeck, Spacelab module and Orbiter cargo bay.

The SAMS development process has resulted in flight units for the Orbiter middeck, Spacelab module and Spacelab MPESS-B carrier in the Orbiter cargo bay. The first two SAMS units to fly have successfully operated and acquired data on the first Spacelab Life Sciences (SLS-1) mission, STS-40, in June 1991 and on the STS-43 mission in August 1991.

This paper presents a description of the SAMS flight unit development process, the flight unit technical aspects, and the operation during the missions. The analysis process used for characterizing this microgravity acceleration data is described and some of the more interesting data are illustrated.

Design & Development

A major goal for the SAMS project has been to provide a versatile unit capable of supporting a variety of microgravity science experiments in various locations in the Orbiter. This will provide multiple missions with a consistent microgravity acceleration measurement system. A secondary goal has been to include sufficient flexibility to readily incorporate additional features or new technology. To meet these goals, two configurations of flight units were designed; one for habitable areas of the Orbiter (middeck and Spacelab module) and one for the space environment in the Orbiter cargo bay. Figure 1 illustrates the configuration for the Spacelab module center aisle with one of three triaxial sensor heads connected to a sensor head cable. The optical disks are accessed by the crew through front panel doors. The configuration for the Spacelab MPESS-B carrier is shown in figure 2 during preparation for a thermal-vacuum test. The two enclosures containing the electronics and optical disk drives are mounted to an adaptor plate which is in turn mounted to a carrier cold plate for thermal control.

Both configurations have the same basic acceleration measurement capability and data processing electronics. Block diagrams showing the data flow through the middeck/Spacelab and cargo bay configuration units are shown in figures 3 and 4, respectively. In both configurations, the sensors produce signals in response to acceleration inputs. These signals are then amplified, filtered, and converted into digital data, which are then stored on optical disks. Time tags for the data are obtained from an Orbiter timing signal. The configuration for the cargo bay (figure 4) may transmit data to ground facilities for data access during the mission.

One main unit may have one, two or three triaxial sensor heads associated with it. Each triaxial sensor head (A, B, or C) contains three orthogonal accelerometers (x, y, and z). Each of these nine accelerometers have an acceleration sensor and a temperature sensor. In the sensor head, the acceleration signals are filtered by one-pole low-pass filters and amplified by four-decade preamplifiers. The three processed signals and the three temperature signals from each sensor head are carried to the main unit by a sensor head cable. The acceleration signals are further filtered by seven-pole filters in the signal conditioning card or the analog filter card. There are six low-pass filter cutoff frequencies available to users (2.5, 5, 10, 25, 50, and 100 Hertz) to support requirements from different types of experiments.

During operation of the unit, the microprocessor controls the acquisition of data from the analog to digital converters and the storage of that data on the optical disks. When the SAMS unit is located in the middeck and/or Spacelab module, the crew members are able to change disks as needed, allowing for essentially an unlimited amount of data storage. Two disk drives are employed in these units, allowing uninterrupted data recording during the mission. When the SAMS unit is located in the Orbiter cargo bay, sealed containers are utilized and therefore the disk drives (a maximum of four) are inaccessible to the crew.

The cargo bay configuration unit utilizes the post-processor to communicate data and commands with the MPESS (Mission Peculiar Equipment Support Structure) carrier data system. Data from sensor heads may be sent via downlink to the Payload Operations Control Center (POCC) to facilitate near-real-time data analysis during the mission. Commands (e.g., data record on and off) are sent via uplink from the POCC.

The SAMS design utilizes commercial parts in many areas to keep costs down and to increase availability of parts. The SAMS team has worked with vendors of the timing interface board, microprocessor boards (two vendors), small computer serial interface adaptor boards (two vendors), memory board, and the optical disk drives to modify the commercial parts for spaceflight use. Furthermore, a thermal testing program was utilized to ensure that the commercial boards and subsequent modifications were satisfactory for space applications. A report describes this thermal testing program. [2]

Early in the development process, a contract was awarded to develop an analog-to-digital converter for the special requirements of the SAMS units. The main features of this converter are three phase-coherent bipolar analog inputs, eight single-ended analog inputs, and 16-bit resolution. [3, 4] The SAMS project engineers worked closely with the contractor during the development of this converter. A commercial quality version of this converter is now available.

In some cases, special parts were required which were not commercially available. For example, the sensor head preamplifier boards, the signal conditioning boards, analog filter cards, the input/output (I/O) interface board, the control unit interface board were all designed and fabricated at LeRC by the SAMS project.

The two SAMS configurations, while similar in function, are packaged differently. The middeck/Spacelab configuration was designed to replace a locker in the Orbiter middeck. The basic mechanical structure was machined from a single block of aluminum to reduce the mass and eliminate welds, but yet maintain a high strength. Side, top and bottom panels add rigidity and enclose the volume for crew safety.

The cargo bay configuration unit was designed as two sealed container enclosures, one housing the electronic card cage and the other four optical disk drives. These two containers are mounted on an adaptor plate, which in turn is mounted to the MPESS carrier cold plate to maintain an even thermal environment. A multi-layer insulation blanket and frame covers the two sealed containers and the cold plate to insulate them from the cargo bay thermal environment.

Fabrication & Verification

To support the development and testing of the middeck/Spacelab module flight units, an engineering unit, two electrical ground support equipment racks and three shipping containers were fabricated from August 1988 through December 1989. Four flight units for the Orbiter middeck and Spacelab module were fabricated between May 1989 and April 1990. The major components for a spare unit were also fabricated in this timeframe. Typically five sensor heads (three flight sensor heads and two spares) were fabricated with each main unit.

The flight acceptance verification process for these flight units was conducted from September 1989 through October 1990. A characterization procedure is accomplished on each sensor head just before delivery to the Kennedy Space Center (KSC) or to an experiment for integration. This procedure is accomplished under contract with Sundstrand Data Control, Inc. and maps each sensor head over temperature, four gain ranges and from plus to minus one-g in small increments.[5]

Mission integration activities for five missions were conducted during the fabrication and verification process. Currently, mission integration activities for seven missions in various stages of preparedness are being supported.

Two additional flight units of a different configuration were fabricated between December 1990 and October 1991 for use on the Spacelab MPESS-B carrier in the cargo bay. The verification process is continuing for these units with an expected delivery date to KSC of March 1992 for a planned launch in September 1992.

The four units for middeck/Spacelab were initially delivered to KSC in April 1990, August 1990, October 1990 and April 1991. The first unit was launched in June 1991 as part of the SLS-1 mission. A quick-look report of the first SAMS flight [6] describes the preparation of the flight unit, the operations during the mission and a cursory look at the data.

In December 1990, the Spacelab J (SL-J) launch date was delayed one year. The SAMS unit which had been delivered for that mission was retrieved from KSC, partially re-tested, and flown in the middeck on STS-43 in August 1991. Post-mission re-verification was performed on that unit and it was again turned over to KSC in October 1991 for the SL-J mission.

There are currently three middeck/ Spacelab SAMS units at KSC in preparation for the first International Microgravity Laboratory mission, the first United States Microgravity Laboratory mission and the SL-J mission. The two cargo bay configuration units will be delivered in March 1992 to support the first United States Microgravity Payload mission.

Science Experiments Supported by SAMS

STS-40 Mission

The primary experiment supported by the SAMS unit on SLS-1 was the Solid Surface Combustion Experiment (SSCE). The SSCE investigates the dynamics of solid surface combustion during microgravity conditions. This is being accomplished by burning a sample (ashless paper or polymethylmethacrylate) in a sealed chamber while measuring temperatures and record the combustion process on 16 mm film. A SAMS sensor head was mounted to the baseplate of the SSCE combustion chamber.

Another SAMS function on SLS-1 was the initial acquisition of acceleration data to enable a future characterization of the Orbiter and Spacelab module structure. Disturbances introduced by the body restraint system rotating chair and the bicycle ergometer were utilized as sources of acceleration disturbances. Accelerations produced by these sources were measured with a sensor head mounted in the center aisle and in the base of a rack. These measurements, along with the corresponding measurements of the sensor head mounted on the SSCE, will enable observations of acceleration transfer from major sources to experiments in racks. This effort to acquire data for characterization is a factor in the placement of the sensor heads for all missions.

STS-43 Mission

The primary experiments supported by the SAMS unit in the middeck on STS-43 was the SSCE and the Protein Crystal Growth (PCG) experiment. PCG investigates the growth of protein crystals during microgravity conditions. Other areas supported were the crew exercise treadmill and the multitude of experiments associated with the Bioserve ITA Materials Dispersion Apparatus (BIMDA). The accelerations produced by the crew exercise treadmill are of interest to the NASA effort aimed at understanding and reducing the crew induced disturbances on microgravity science missions. The objective of BIMDA is to obtain scientific and technical knowledge regarding the commercial potential of biomedical manufacturing processes and fluid science processing in the microgravity environment of space.

Again, the data acquired from the sensor heads in the middeck on STS-43 will enable future characterization of the acceleration transfer from a major disturbance source (treadmill) to middeck experiments.

Other Missions

On future missions, various types of science experiments will also be supported, such as fluid physics, combustion, crystal growth, glovebox experiments, and fundamental sciences.

Data Analysis

The data from STS-40 and STS-43 were briefly examined by the SAMS project team, while the in-depth analysis of the data was accomplished by ACAP personnel. After each SAMS mission, ACAP will prepare an early summary report which will provide a preliminary assessment of the acceleration environment on that mission. Such a report covering the data for STS-40 was issued [7] and the report for STS-43 is in preparation at this time.

The objective of the early summary reports is to provide a reference document to microgravity scientists and other interested investigators that create a gateway into the content of the very large amount of information returned by the SAMS units on a typical mission. There were two significant challenges which required the development of innovative analytical and data presentation techniques due to the nature and quantity of the SAMS data.

The first was to condense a significant time frame of data into a format which maintained the highest level of detail. When properly implemented, such an analysis will emphasize correlations in the data and provide insight which would normally be obscured by the sheer volume of numbers. The STS-40 and STS-43 missions resulted in 371 megabytes and 2.6 gigabytes of data, respectively. Color spectrographs were prepared from approximately one megabyte of data to satisfy this requirement. These three dimensional plots (frequency versus time with amplitude shown in color) clearly show the dominate role played by structural resonance modes in the overall microgravity environment of the vehicle. For the 5 Hertz low frequency cutoff of the sensor heads on STS-40, the resonance modes at approximately 3.5, 4.7, 5.2, 6.2 and 7 Hertz are clearly observable in even the most quiet intervals. Any vehicle disturbances, such as thruster firings and crew exercise, are seen to interact and excite oscillations at these characteristic vehicle frequencies.

The second challenge was the problem of providing a meaningful presentation of a very long stretch of seemingly random time domain data in a manner which emphasized the properties of interest. To achieve this goal, an approach was chosen to provide derived parameters rather than presenting the direct accelerometer data. The simple statistics of the mean and root mean square (RMS) were utilized to separate events with a net acceleration from those which were primarily oscillatory in nature.

The resulting survey plots of a mission provide an effective tool for developing an early estimate of the relative magnitude of disturbances present on the vehicle. They also provide a means of scanning the entire time frame of the mission to begin the task of assessing the various microgravity conditions during the mission. An example (explained in the following section) for a two hour period is shown in figure 5. The upper plot is the acceleration mean, calculated "... as the vector magnitude of the arithmetic mean of the acceleration on each axis over a ten second period."[7] The lower plot is the peak root mean square (RMS) incorporating all three axes of a sensor head. For each one second period, the RMS was calculated for each axis and these three quantities were combined as a root sum square. The peak value for each ten second period was selected for the peak RMS plot. The approach provides point-for-point correspondence between the acceleration mean and peak RMS plots. This will be described further below.

STS-40

Various types of activities investigated in the STS-40 data included attitude maneuvers, middeck treadmill crew exercise, bicycle ergometer crew exercise, combination ergometer and treadmill, rotating chair operation, various levels of crew activity, and periods of crew sleep.

The data in figure 5 is an example of crew activity on the middeck treadmill (starting at 06:30 on day five) and the bicycle ergometer (starting at 07:15 on day five). This data shows a strong component of peak RMS activity with little corresponding average activity, since the treadmill and ergometer are primarily oscillatory devices.

Figure 6 includes the roll, pitch, and yaw attitude maneuvers of the Orbiter which start at 23:00 hours on day five. This data shows a strong component in the average plot due to the centripetal acceleration during the rotations. The corresponding peak RMS data illustrates the various thruster firings necessary to accomplish such a suite of maneuvers.

Data from one axis of a sensor head during an operating session of the Body Restraint System rotating chair is shown in figures 7 and 8. The time plot in figure 7 shows the cyclical nature of this disturbance while the frequency plot in figure 8 shows a significant peak at 0.37 Hertz. This represents a chair rotation rate of approximately once every three seconds. The acceleration peaks at 3.7 and 5.6 Hertz are vehicle structural modes.

A significant result from analyzing the SAMS data on STS-40 was the extraction of Orbiter drag acceleration measurements from data acquired during a very quiet time in a crew sleep period. These low-level, very low-frequency (0.00018 Hertz) accelerations were extracted by compensating the data for the accelerometer sensor bias and thermal coefficients and digitally filtering the data. An effort to correlate these SAMS/ACAP drag measurements with drag measurements of the Orbital Acceleration Research Experiment (a low frequency, low magnitude aerodynamic accelerometer) is currently underway.

STS-43

Various types of activities investigated in analyzing the STS-43 data included middeck treadmill crew exercise, a satellite deployment, Ku-band antenna disturbances, various levels of crew activity, and periods of crew sleep. A reasonably strong 51 Hertz signal was found to be present in much of the data. The origin of this disturbance is currently unknown. The disturbance is above one milli-g in level and is spectrally sharp. Initial analyses indicate that it is a mode of the Orbiter which is excited by the 17 Hertz Ku-band antenna dither. This has been seen in other data from previous missions and was assumed to have originated from a payload.

The automatic gain change algorithm for the low frequency (2.5 Hertz) sensor head was more active than expected during a major part of the mission. The cause of this is being investigated.

Future Applications for SAMS

In addition to these two missions, SAMS units are currently manifested on the International Microgravity Laboratory mission series, the United States Microgravity Laboratory mission series, the United States Microgravity Payload mission series, the SL-J mission, the first Spacehab mission, and, in general, two middeck missions per year. This will result in approximately four flights per year for the foreseeable future. On the majority of these missions, SAMS data is required to satisfy the science objectives of the experiments. The planned flight activity for SAMS is shown in figure 9.

Upgrading the SAMS flight units has recently been initiated with technical areas such as data mass storage, crew display, and Spacelab data access to be addressed. The long-term planning for SAMS includes an improved version for the support of the early microgravity payloads aboard the Space Station Freedom.

SAMS units are also being considered for characterizing the NASA KC-135 microgravity simulator and the drop towers at NASA LeRC.

Concluding Remarks

The first two flights of SAMS units appear to be successful in accomplishing the intended goal of acquiring microgravity acceleration data. The data gathered on STS-40 exceeded expectations shown by the extraction of Orbiter drag accelerations from the data. The STS-43 data will be of interest to the supported experiments and those concerned with treadmill disturbances in the Orbiter and Spacelab module. More definitive conclusions will be drawn as the vast quantity of data is analyzed further by ACAP and principal investigators.

Acknowledgements

The authors would like to acknowledge and thank the members of the SAMS project team at NASA Lewis Research Center and Sverdrup Technology, Inc. for their development, fabrication, verification, delivery, and integration of the SAMS flight units. Many additional support organizations who participate in the SAMS project are also recognized for their effort and dedication over the years.

The authors would also like to acknowledge and thank the members of the ACAP project team at NASA Marshall Space Flight Center, Teledyne Brown Engineering and Sverdrup Technology, Inc. for their analysis of the SAMS flight data.

The effort of many SAMS and ACAP team members is also recognized for their support of SAMS flight operations in the Payload Operations Control Center. Their work resulted in significant correlation between the recorded acceleration data and mission events, which otherwise would not have been possible.

Finally, the authors would like to acknowledge the long-standing support of the Microgravity Sciences and Applications Division at NASA Headquarters.

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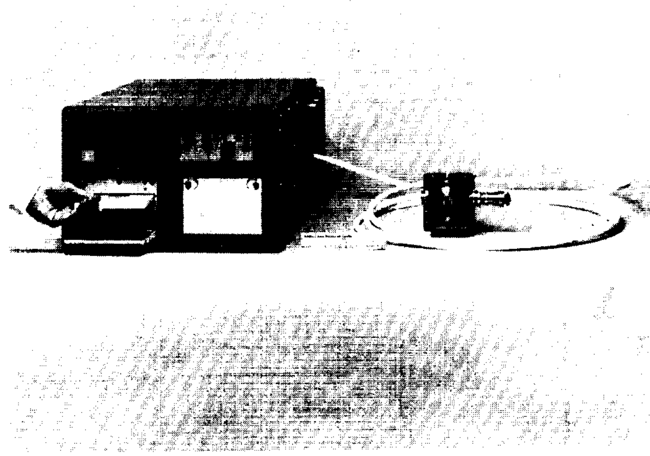

Figure 1: SAMS Configuration for Orbiter Middeck and Spacelab Module

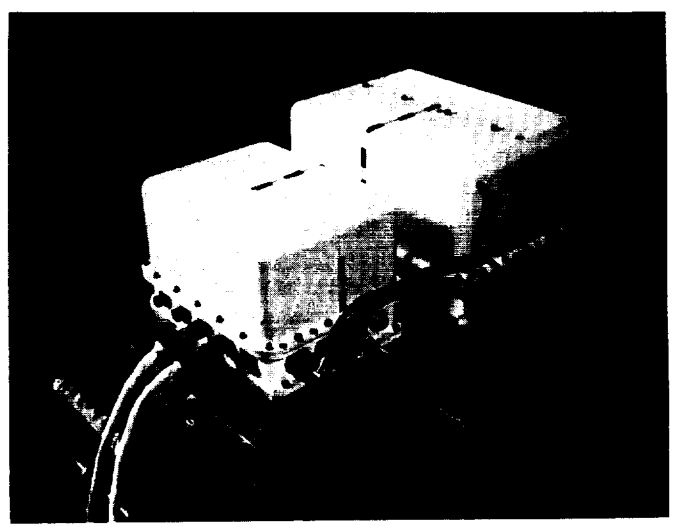

Figure 2: SAMS Configuration for Spacelab MPESS-B Carrier

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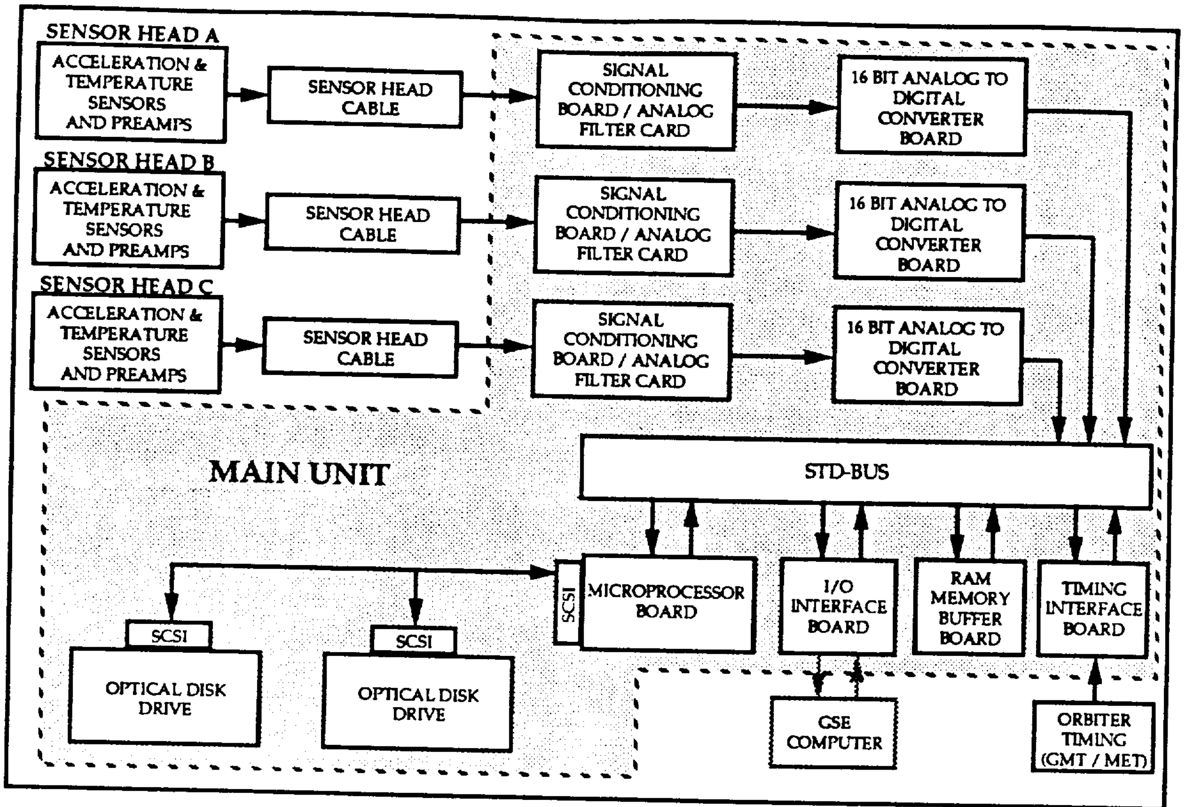

Figure 3: SAMS Data Flow - Middeck, Smidex & Center Aisle Configurations

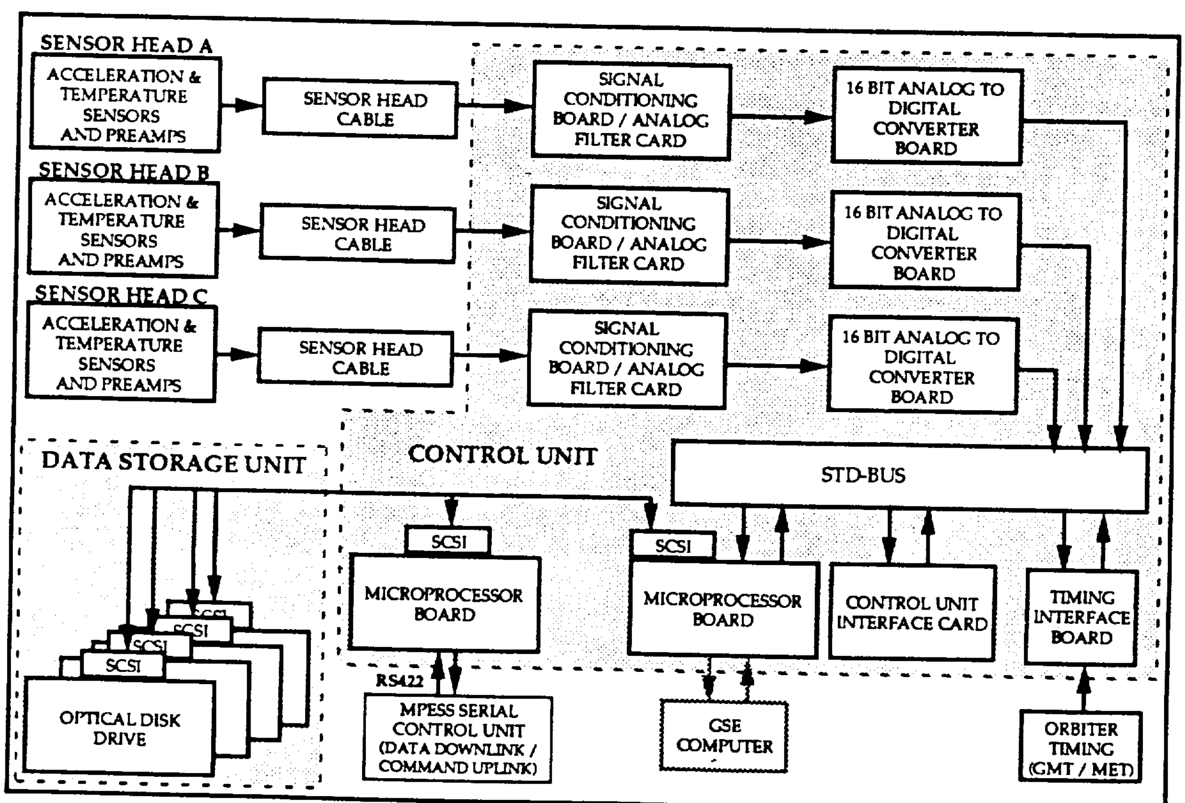

Figure 4: SAMS Data Flow - MPESS Carrier Configuration

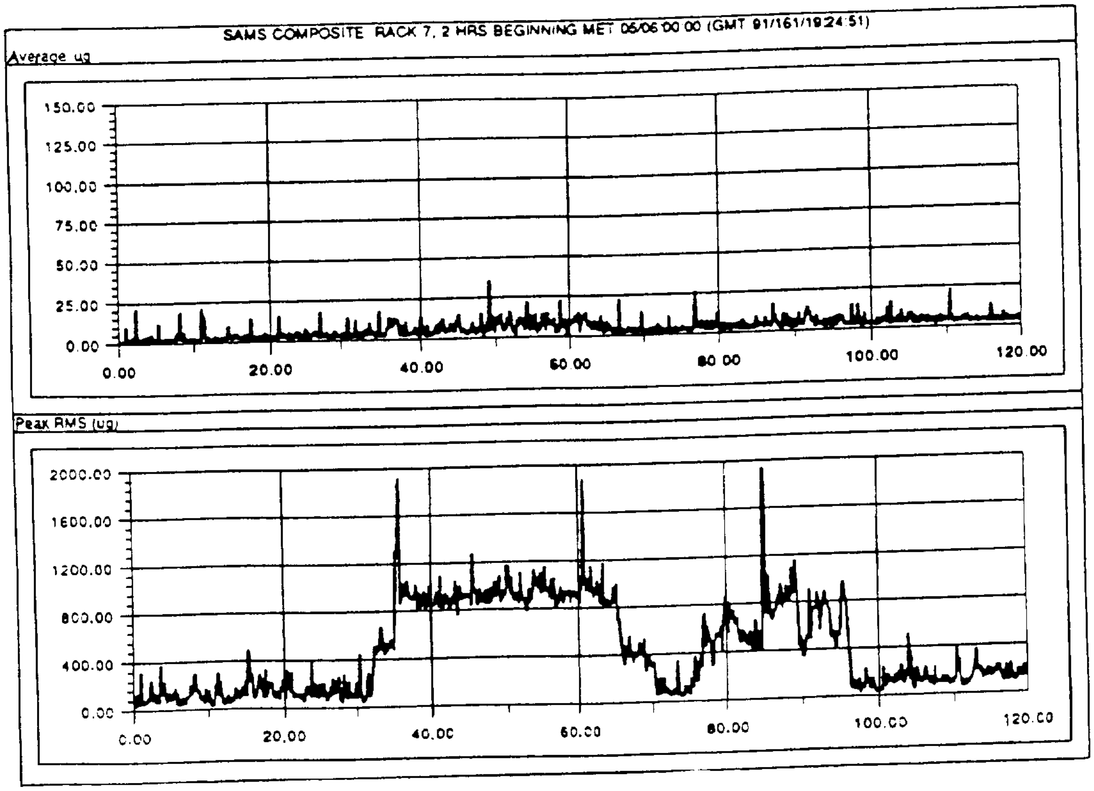

Figure 5: Two Hours of Data Including Crew Treadmill and Ergometer Exercise (MET: 005/06:00) [Ref. 7]

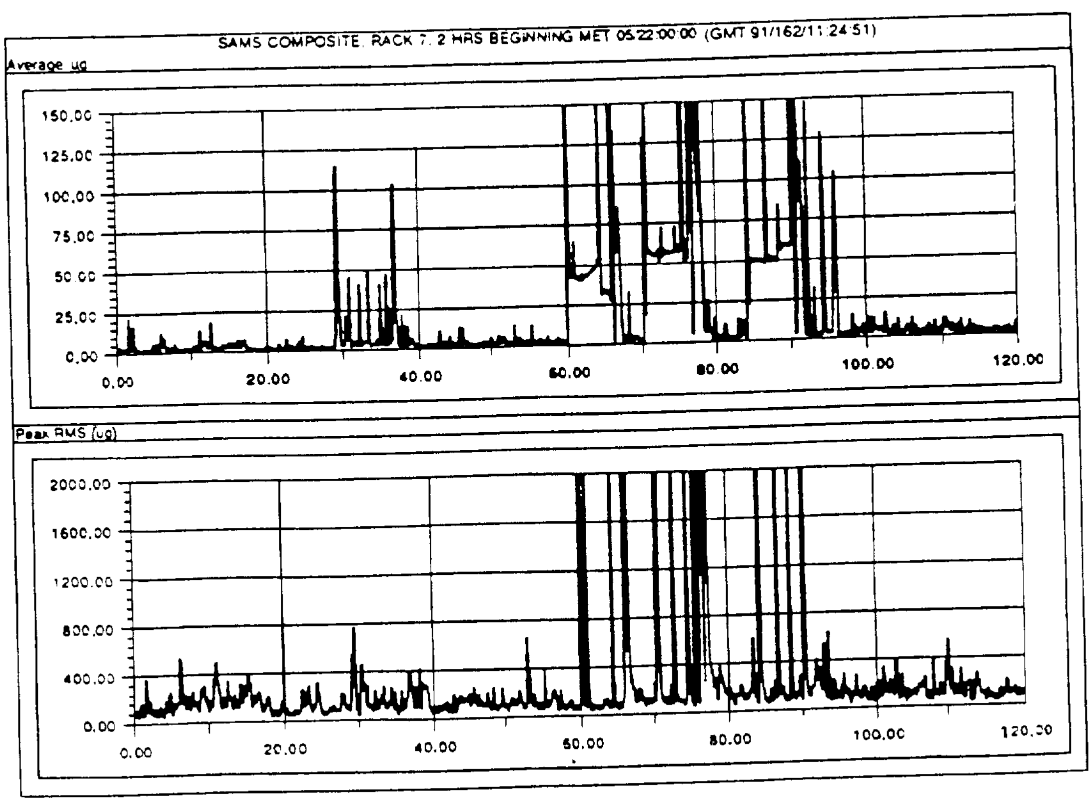

Figure 6: Two Hours of Data Including Roll, Pitch and Yaw Orbiter Maneuvers (MET: 005/22:00) [Ref. 7]

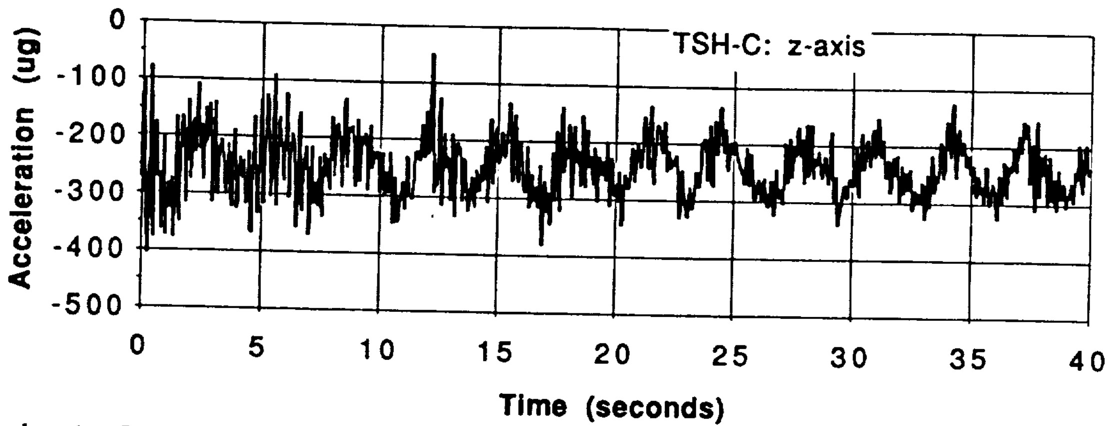

Figure 7: Acceleration Levels vs. Time during Body Restraint System Rotating Chair Operation [Ref. 6]

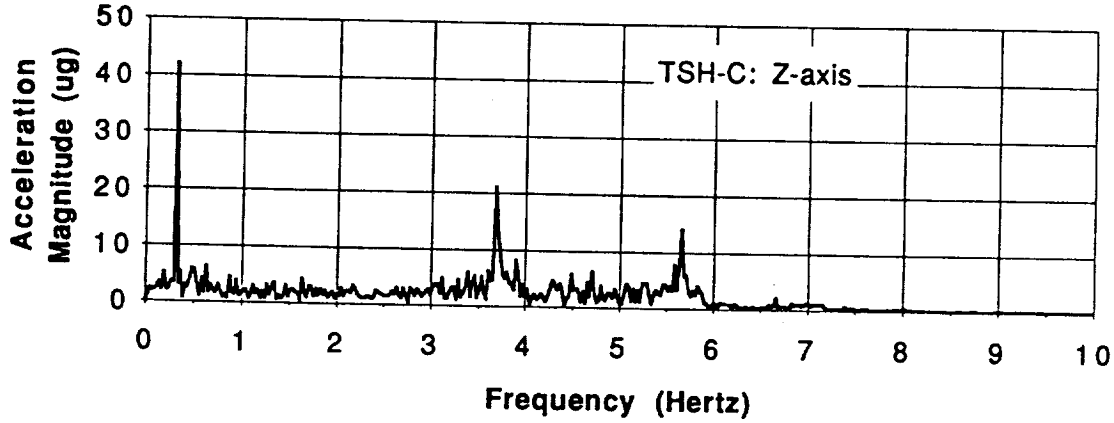

Figure 8: Acceleration Levels vs. Frequency during Body Restraint System Rotating Chair Operation [Ref. 6]

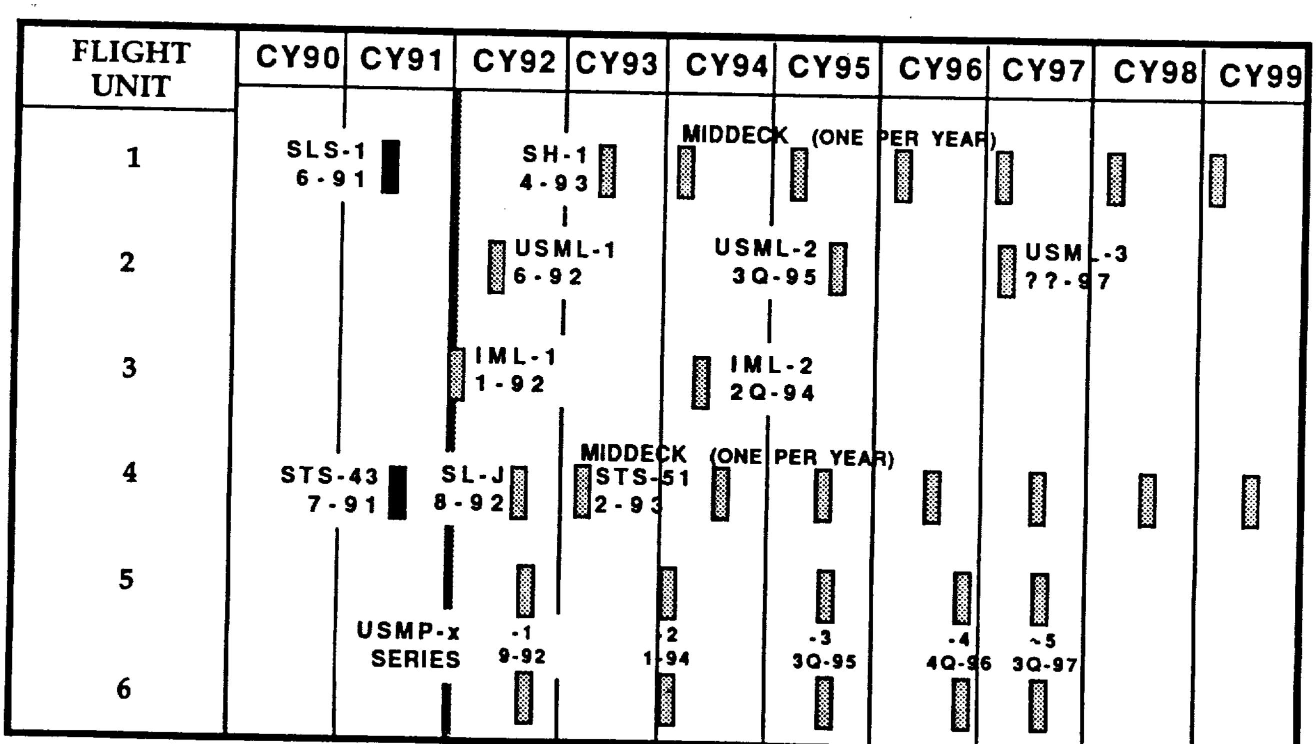

Figure 9: SAMS Flight Schedule

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
January 1992

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Development of and Flight Results From the Space Acceleration Measurement System (SAMS)

5. FUNDING NUMBERS
WU-694-03-0H

6. AUTHOR(S)
Richard DeLombard, Brian D. Finley, and Charles R. Baugher

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-7018

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-105652
AIAA 92-0354

11. SUPPLEMENTARY NOTES
Prepared for the 30th Aerospace Science Meeting and Exhibit sponsored by the American Institute of Aeronautics and Astronautics, Reno, Nevada, January 6-9, 1992. Richard DeLombard, NASA Lewis Research Center, Cleveland, Ohio 44135, Brian D. Finley, Sverdrup Technology, Inc., Lewis Research Center Group, 2001 Aerospace Parkway, Brook Park, Ohio 44142, and Charles R. Baugher, Marshall Space Flight Center, Huntsville, Alabama. Responsible person, Richard DeLombard, (216) 433-5285.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 19

12b. DISTRIBUTION CODE

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

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14. SUBJECT TERMS
Microgravity applications; Optical disks; Accelerometer; Vibration meters; Optical memory (Data Storage)

15. NUMBER OF PAGES
12

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	

National Aeronautics and
Space Administration

Lewis Research Center
Cleveland, Ohio 44135

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