Further Analysis of the Microgravity Environment on Mir Space Station during Mir-16

April 18, 1996

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Abstract

The NASA Microgravity Science and Applications Division (MSAD) sponsors the Space Acceleration Measurement System (SAMS) to support microgravity science experiments with microgravity acceleration measurements. In the past, SAMS was flown exclusively on the NASA Orbiters. MSAD is currently sponsoring science experiments participating in the Shuttle-Mir Science Program in cooperation with the Russians on the Mir space station. Included in the complement of MSAD experiments and equipment is a SAMS unit installed on the Mir space station.

On 25 August 1994, the SAMS unit was launched on a Russia Progress vehicle to the Mir space station. The SAMS unit will support science experiments from the U.S. and Russia in a manner similar to the Orbiter missions by measuring the microgravity environment during the experiment operations.

In October 1994, the SAMS unit recorded data on Mir for over fifty-three hours in seven different time periods to survey possible locations for future experiments. The Mir acceleration data were examined by PIMS to develop characteristics of the data. A report was previously written to quickly summarize the characteristics of the SAMS data from Mir [1]. That report contained an overview of data from the 100 Hertz (Hz) SAMS sensor head. This report presents an overview of the data from the 10 Hz SAMS sensor head and additional information about crew and vehicle activities. Some additional observations are also made concerning the 100 Hz sensor head data.

Appendix A describes the procedures to access SAMS data by file transfer protocol (ftp) utilizing the internet. Appendices B and C provide plots of the SAMS 10 Hz data for an overview of the microgravity environment at the times that data were recorded. Appendix D contains a user comment sheet.

Acronyms and abbreviations

ECK	inertial coordinate system (Russian acronym)
ftp	file transfer protocol
Hz	Hertz
LeRC	NASA Lewis Research Center
MSAD	Microgravity Science and Applications Division
PCG	Protein Crystal Growth
PGO	(Russian acronym)
PIMS	Principal Investigator Microgravity Services
PNO	(Russian acronym)
PSC	principal spectral component
PSD	Power Spectral Density
PSO	Mir module transfer/docking compartment (Russian acronym)
SAMS	Space Acceleration Measurement System
SMSP	Shuttle-Mir Science Program
TSH	triaxial sensor head
VM	vector magnitude
WWW	World Wide Web

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Introduction and Purpose

The NASA Microgravity Science and Applications Division (MSAD) sponsors science experiments on a variety of microgravity carriers, including sounding rockets, drop towers, parabolic aircraft, and space shuttle Orbiters. The MSAD sponsors the Space Acceleration Measurement System (SAMS) to support microgravity science experiments with microgravity acceleration measurements. The purpose of SAMS is to characterize the microgravity environment to which the experiments were exposed on such missions. Between June 1991 and March 1996, the SAMS project participated in fourteen NASA Orbiter missions with six SAMS flight units. The Principal Investigator Microgravity Services (PIMS) project at the NASA Lewis Research Center (LeRC) supports principal investigators of microgravity experiments as they evaluate the effects of varying acceleration levels on their experiments.

In 1993, a cooperative effort was started between the United States and Russia involving science utilization of the Russian Mir space station (figure 1) by scientists from the United States and Russia. MSAD is currently sponsoring science experiments participating in the Shuttle-Mir Science Program (SMSP) in cooperation with the Russians on the Mir space station. The initial U.S. experiments were planned to be a Protein Crystal Growth (PCG) experiment and a material sample for the Russian GALLAR furnace. Included in the complement of MSAD experiments and equipment is a SAMS unit.

On 25 August 1994, the SAMS unit was launched on a Russian Progress vehicle to the Mir space station. The SAMS unit will support science experiments from the U.S. and Russia in a manner similar to the Orbiter missions by measuring the microgravity environment during the experiment operations.

The SAMS unit recorded data on Mir for over fifty-three hours in seven different time periods (figure 2) from September 28 to October 28, 1994 to survey possible locations for future experiments.

The Mir acceleration data were examined by PIMS to determine characteristics of the data. A report was previously written which quickly summarized the characteristics of the SAMS data from Mir [1]. That report contained an overview of data from the 100 Hertz (Hz) SAMS sensor head. This report presents an overview of the data from the 10 Hz SAMS sensor head and additional information about crew and vehicle activities. Some additional observations are also made concerning the 100 Hz sensor head data.

Appendix A describes the procedures to access additional information about SAMS and PIMS utilizing the internet. Appendices B and C provide plots of the SAMS 10 Hz sensor head data for an overview of the microgravity environment at the times that data were recorded. Appendix D contains a user comment sheet. Users are encouraged to complete this form and return it to the authors.

Mission Configuration

Mir Configuration

The Mir space station was launched in 1984 as a base module and has been expanded since that time to include five modules in 1995. The overall space complex length along the longitudinal axis is about 33 meters and the length along the lateral axis is about 27 meters.

Figure 1 shows the configuration of the Mir space station during Mir-16. The four major components are the Mir core module, the Kvant-1 astrophysics module, the Kvant-2 scientific and airlock module, and the Kristall technological module. The Mir modules are occasionally re-oriented.

The Spektr module was added to Mir in May 1995. In early 1996, the Priroda module will be launched to and installed on the Mir.

Mir Coordinate System

The Mir basic coordinate system is the base module coordinate system. In the Mir configuration during Mir-16, this coordinate system was defined as shown in figure 1.

Mir Attitudes

For the majority of time during Mir-16, the Mir space station orbited the Earth in one of two solar-inertial attitudes. The first inertial system coordinates (ECK1) attitude is defined by the -Y axis of the base module pointing toward the sun. The base module X & Z axes define the orbit plane. The ECK2 attitude is defined by the +X axis of the base module pointing toward the sun. This attitude puts the Kvant-1 module closest to the sun. The base module Y & Z axes define the orbit plane.

The Mir space station periodically re-establishes its attitude. This is accomplished by turning station-keeping gyrodynes off and using thrusters to establish the new attitude. When the new attitude is established, the gyrodynes are turned on again.

Triaxial Sensor Head Orientation and Location

The SAMS triaxial sensor heads (TSHs) are mounted to structures and/or experiments. The orientation of the TSH axes to the vehicle is measured and recorded for later use in understanding the acceleration data. Using this information, the measured acceleration levels may be transformed to other orientations, such as an experiment based coordinate system or the Mir coordinate system. Tables 1 and 2 list the location and orientation of the three SAMS TSH's during Mir-16. The TSH locations and orientations are shown in figures 3 and 4 for the Ksenia and Gallar furnace locations, respectively. The Ksenia equipment is identified in reference 4 as item #15 in figure E-9.

Mission Activities

The information presented in reference 1 was primarily from the crew logbooks. Additional information concerning the crew and vehicle activities has since been obtained by Mr. Stanislav Ryaboukha [2, 3]. This new information complements the logbook information recorded by the crew.

The section headers below refer to the days in the crew log-book and in figure 2 of reference 1. The SAMS data (as noted in reference 1) contain time stamps with a two day offset from the crew members' notations in the logbook. That difference has not been resolved nor explained. In this report, the data plots produced from the SAMS data have not been corrected for this time differential. The time of an event in the data plots is two days less than the time cited in the logbook, table 3. The times shown are in hour:minute:second format and are based on Moscow local time.

Day 277

(4 Oct 94) 19:10:00 to 19:56:30

The Mir station was in the solar inertial attitude ECK2.

During this time period, there were crew members exercising on the treadmill and bicycle at the same time in the core module.

Day 289

(16 Oct 1994) 12:08:40 to 16:01:30

The TSH orientation and the Mir attitude remained the same as the previous day.

From 12:08:40 to 14:00:00, crew exercise was conducted in sequence on the core module treadmill, the core module bicycle and the Kristall module treadmill.

Between 12:45:00 and 13:15:00, the Mir station attitude was adjusted. The gyrodynes were turned off, the attitude was adjusted with thrusters, and then the gyrodynes were turned on. This was described as a correction for a gradual shift in attitude of the Mir station. The exact meaning of turning gyrodynes on and off are unclear at the present time to the authors.

Day 289 - 290

(16-17 Oct 1994) 23:13:30 to 10:02:30

The Mir station was in the ECK2 attitude.

This time period was basically a quiet time with the crew sleeping. Normally, equipment is turned off during the crew rest time.

Day 291

(18 Oct 1994) 10:57:55 to 20:47:30

The SAMS TSHs were moved to the Gallar furnace location as specified in the plan. The Gallar furnace was not operated during this recording period.

From 10:57 to 11:25, the Mir station attitude was adjusted back to the previous solar inertial attitude. The attitude modification was started before SAMS began data recording.

From 11:25 to 11:58, the Mir station was in the solar inertial attitude ECK2.

From 11:58 to 12:40, the Mir station was in a different solar inertial attitude with the core module -Y axis toward the sun (ECK1).

From 12:00 to 14:00, there was crew exercise in both the core and Kristall modules.

From 12:40 to 13:30, the Mir station was in the ECK1 attitude.

From 13:30 to 14:00, the Mir station was in the ECK2 attitude.

From 15:00 to 16:00, there was crew exercise on the core module treadmill, but not on the Kristall module treadmill.

From 17:30 to 19:30, there was crew exercise on the core module treadmill and bicycle, but not on the Kristall module treadmill.

Day 291 - 292

(18-19 Oct 1994) 22:45:00 to 08:43:00

From 23:15 to 23:45, there was a correction to the attitude. The rest of this time period was quiet with crew rest.

The Gallar furnace was not operated during this recording period.

Day 300

(27 Oct 1994) 14:58:30 to 23:47:00

The Mir was in the ECK2 attitude. The TSHs were in the same position at the Gallar furnace. The Gallar furnace was turned on in this interval.

From 17:30 to 19:30 there was crew exercise in the core and Kristall modules at the same time.

From 18:40 to 19:20, there was a correction to the attitude.

Day 301

(28 Oct 1994) 11:50:00 to 21:00:00

The Mir was in the ECK2 attitude. The TSHs were in the same position at the Gallar furnace. The Gallar furnace was turned on in this interval.

From 12:30 to 14:30 and from 17:40 to 19:40, there was crew exercise in the core (treadmill and bicycle) module and on the Kristall module treadmill at the same time.

From 12:50 to 13:30, there was a correction to the attitude.

Analysis Techniques

A new analysis technique was used to examine the SAMS data in the frequency domain. This new technique resulted in the principal spectral component (PSC) plots illustrated in figure 5. This technique calculates a power spectral density (PSD) plot of a specified length of time (or number of data points) then calculates significant local peaks within the PSD data. A time sequence of such PSD plots are processed and combined into the single PSC plot.

The PSC plot has characteristics which illustrate additional information compared with a standard PSD plot. As seen in figure 5, there are characteristic groups of dots which indicate certain activities.

Some of the dot groups (referred to as clusters) have a slight magnitude and/or frequency distribution. These clusters appear to be indicative of equipment or activity which is loosely controlled in speed or operating frequency. The power level of the activity is not necessarily constant. Examples of this type of characteristic might be hydraulic fluid pumps or vehicle structural vibrations.

Some of the dot groups (referred to as columns) have little variation in the frequency distribution. The columns appear to be indicative of equipment or activity which is tightly controlled in speed or operating frequency. Two examples of this type of characteristic might be an air circulation pump and a centrifuge.

The appearance of a cluster or column in a PSC plot with no other dots below it indicates that the source was probably active for the entire time represented by the data. This is illustrated by the two columns in figure 5 at about 19 and 22 Hz.

Conversely, the appearance of a cluster or column in a PSC plot with other dots below it indicates that the source was probably not active during the entire time represented by the data. This is illustrated by the cluster in figure 5 at 24 Hz.

Mir Structural Modes

The PSC plot in figure 6 illustrates the structural modes of the Mir space station during the time (October 1994) that these data were gathered.

The PSD plot shown in figure 7 is a combination of 175 successive PSD plots, each of which represents 21 seconds (Welch's method). The data contained in each of the discrete frequency bins were averaged among all of the PSD plots.

Equipment Operation

Air Compressor

The 24 Hz vibration from the air compressor was previously mentioned in the literature [5, 6]. This vibration appears distinctly in both PSC and PSD plots (figure 5 and figure 7, respectively). Note that from the PSC plot, it appears that the compressor was turned off for some of the time in which these SAMS data were acquired.

Gyrodynes

To adjust the Mir attitude, the gyrodynes are turned off, the attitude is adjusted with thrusters and then the gyrodynes are turned on again. Known times in which the gyrodynes were turned on and off are listed in *Mission Activities*.

The gyrodyne being turned off does not (apparently) mean spinning down to a stop. It apparently means that the attitude control is disengaged from the gyrodyne. The nominal speed of the Mir gyrodynes is 10,000 revolutions per minute (rpm) which translates to a vibration frequency of 166. 67 Hz. As the gyrodynes are used for control of the attitude, the speed changes as energy is absorbed and released from the gyrodyne. Each of the major modules of the Mir space station has six gyrodynes for attitude control [4].

In figure 8, six frequency traces may be seen around 170 Hz. These are believed to be from the six gyrodynes of the module. This spectrogram was calculated out to the Nyquist frequency (250 Hz) corresponding to the sample rate of the data (500 samples per second). The filter for this TSH, however, had a corner frequency of 100 Hz. Despite attenuation, the peak at 166.67 Hz may be easily seen.

Exercise Devices Characteristics

The Russian crew typically exercise in five minute intervals. An example may be seen in the figures of Appendix B at day 289, 13:05. A PSD of this period (figure 9) shows the higher level of accelerations around the 1 to 3 Hz region. The variable frequencies observed in much of the exercise data are due to the different exercise exertion levels by the particular crew member.

The Mir treadmill can be used without motorized assistance, but it is usually used at 5 different motorized speeds including 5, 8 and 13 km / hr. There are substantial, noticeable vibrations all over the spacecraft when the treadmill is used on the 13 km / hr (8 mph or about 3.8 Hz) setting.

The treadmills are permanent features of the Base and Kristall modules and are flush with the adjacent floors. The Base module bicycle is a permanent feature of the Base module and is stowed by folding the bicycle apparatus into a floor well.

Summary

This report is a further explanation of the SAMS data acquired in October 1994 during the Mir-16 mission on the Mir space station.

The SAMS unit on-board Mir was installed to support the U.S. experiments to be flown on Mir under the SMSP. Three SAMS TSHs were mounted at various locations in Mir. There were two primary payload locations measured during the Mir-16 mission: the PCG Dewar and the GALLAR furnace.

A summary of the vector magnitude RMS and average accelerations for the entire data set was produced for the SAMS 10 Hz TSH. Spectrograms were also produced to give a frequency domain summary for the entire mission. These plots are presented in the Appendices. Some characteristics of the SAMS data are outlined in relation to known activities occurring on Mir at those times.

Future work will continue this initial effort to correlate activities and operations with the microgravity environment. Additional work will also be performed to compare the Mir environment with that of the NASA Orbiters. As additional data are acquired from SAMS operations on Mir, further analyses will be performed.

References

[1] DeLombard, R. and M. J. B. Rogers: Quick Look Report of Acceleration Measurements on Mir Space Station during Mir-16. TM-106835, 1995.

[2] Discussions with Mr. Stanislav Ryaboukha, NPO Energia, Moscow during his visit to NASA LeRC on March 13 - 17, 1995.

[3] Nikitski, V. P., S. V. Ryaboukha, S. V. Kiselev, and E. D. Bogdanova: Evaluation of Microgravity Environment on-Board Mir Orbital Station. Microgravity Measurement Group meeting #14, NASA JSC, 21 - 23 March 1995

[4] Bockman, M. W., S. Kelly, et al. (1994). A Russian Space Station: The Mir Complex. Houston, Texas, NASA Johnson Space Center. Document TD501

[5] Granier, J.-P., P. Faucher, S. Riaboukha: Mir Microgravity Environment, “microaccelerometre” Experiment. 24th International Conference on Environmental Systems, Friedrichshafen, Germany, June 20-23, 1994.

[6] Belyaev, M. Yu., S. G. Zykov, S. B. Ryabukha, V. V. Sazonov, V. A. Sarychev, and V. M. Stazhkov: Computer Simulation and Measurement of Microaccelerations on the “Mir” Orbital Station. Journal of Fluid Dynamics, Vol. 29, No. 5, pp. 594-601, 1994. (Translated from Russian.)

Tables

Table 1: SAMS TSH Orientation at Ksenia Apparatus

TSH	Location	TSH Axis	Mir Axis
A	near Ksenia	X_h	X_B
		Y_h	$- Y_B$
		Z_h	$- Z_B$
B	on Ksenia	X_h	X_B
		Y_h	Y_B
		Z_h	Z_B
C	on Ksenia	X_h	Z_B
		Y_h	Y_B
		Z_h	$- X_B$

Table 2: SAMS TSH Orientation at Gallar Furnace

TSH	Location	TSH Axis	Mir Axis
A	near Gallar	X_h	Z_B
		Y_h	X_B
		Z_h	Y_B
B	near Gallar	X_h	$- Z_B$
		Y_h	X_B
		Z_h	$- Y_B$
C	on Gallar	X_h	$- Z_B$
		Y_h	$- X_B$
		Z_h	$- Y_B$

Figures

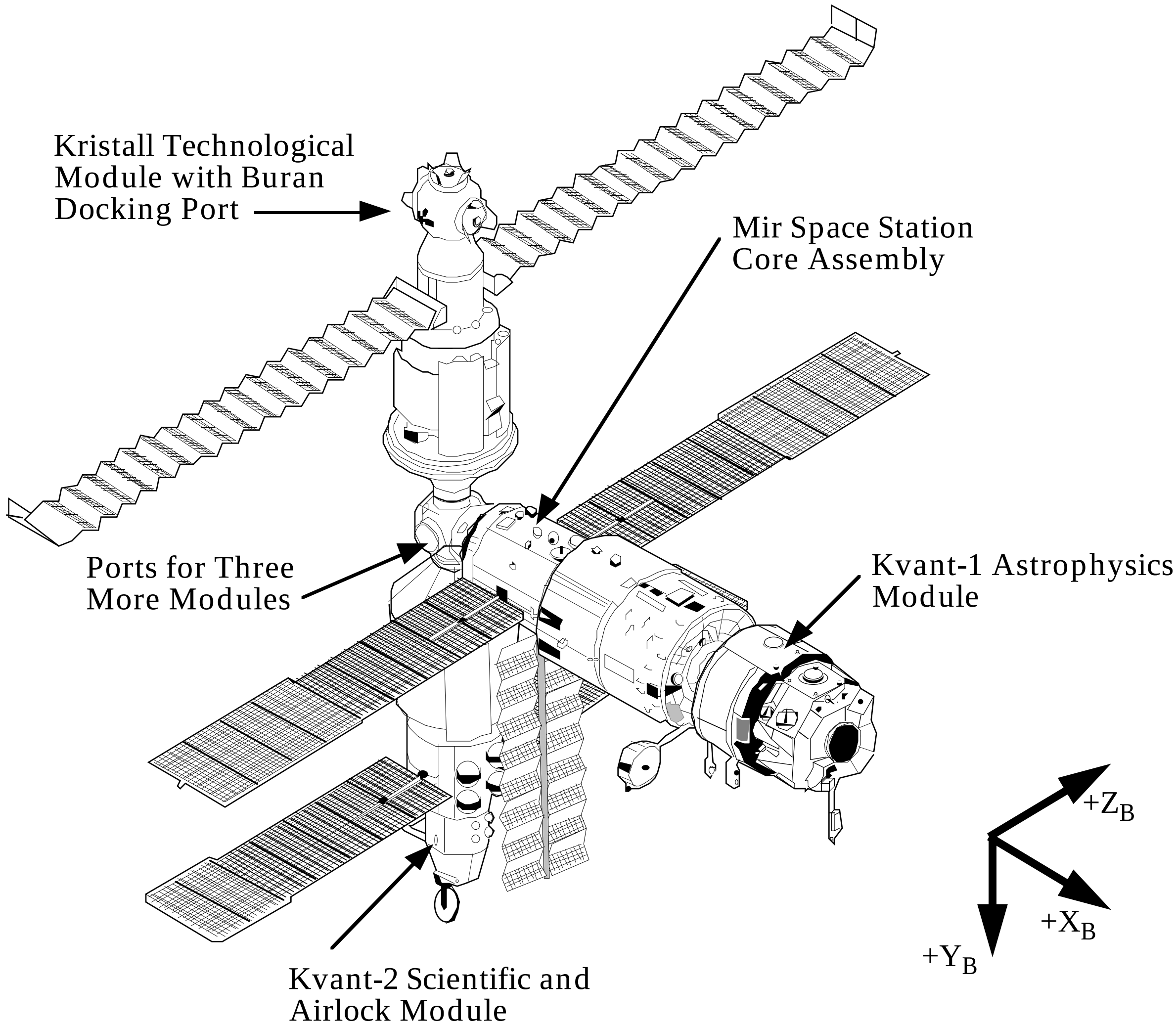


Figure 1: Mir base module coordinate system and module orientation

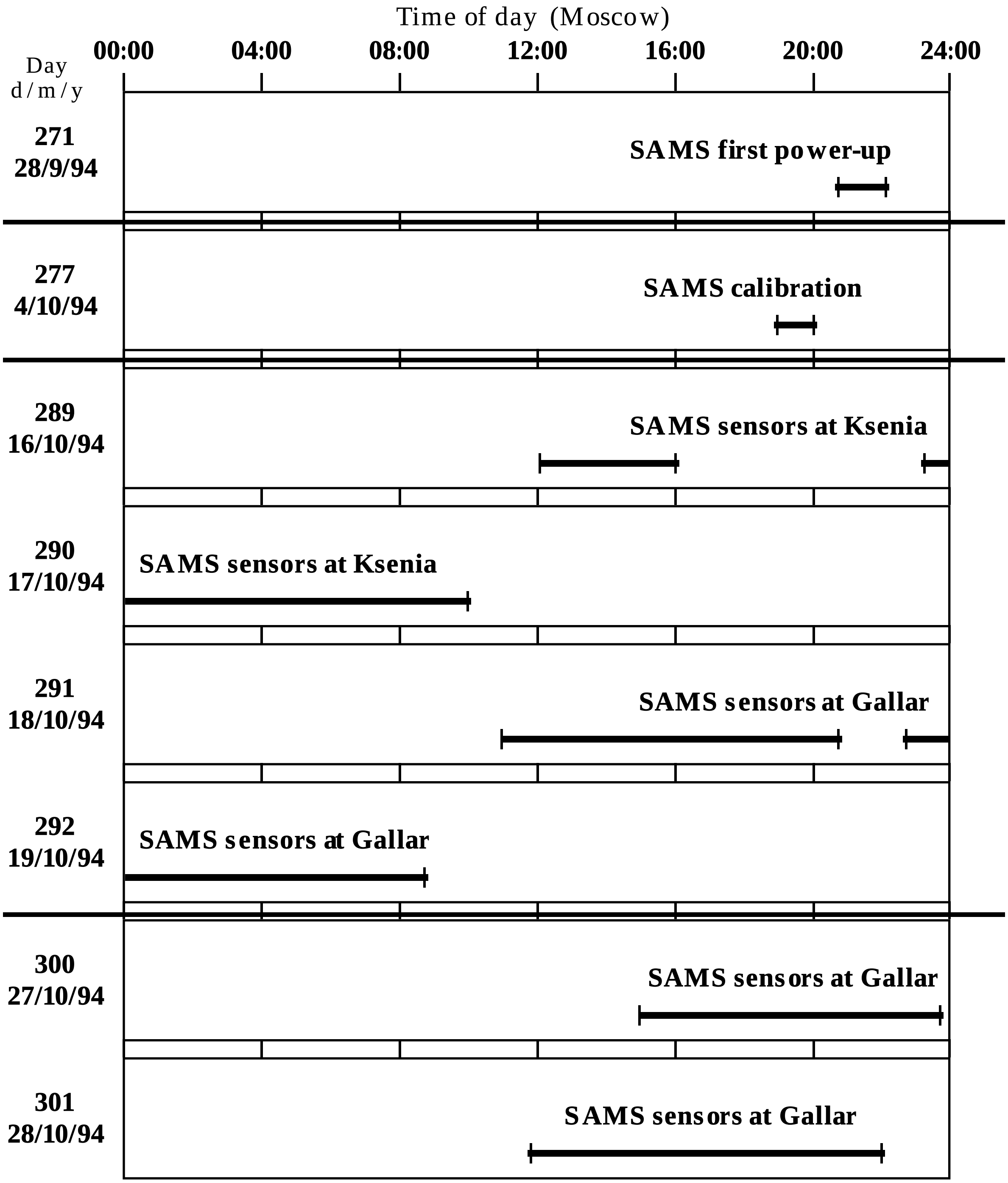


Figure 2: SAMS recording times during Mir-16

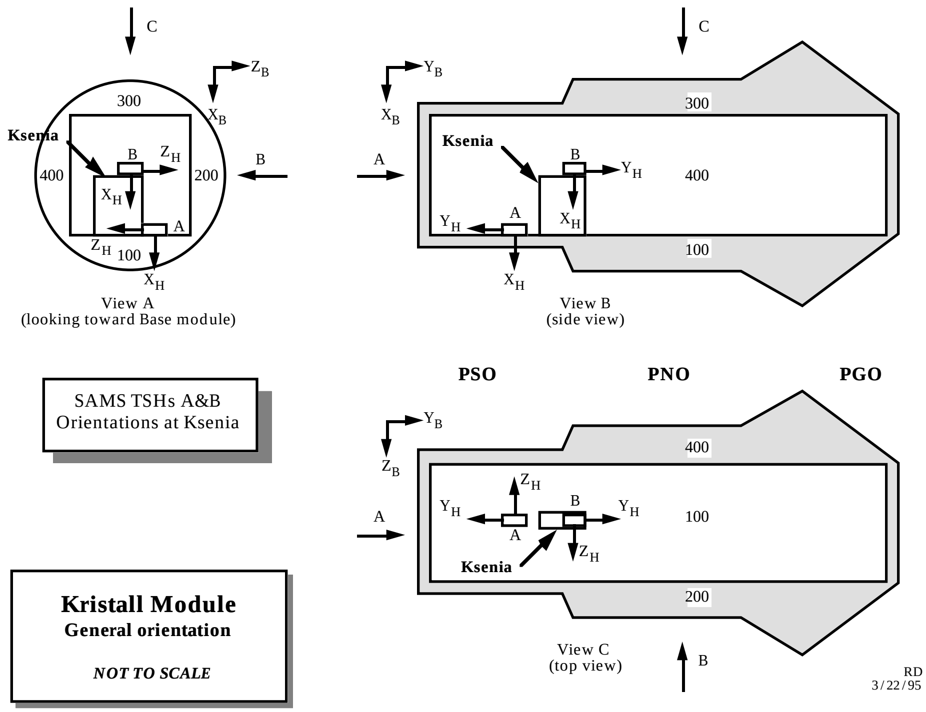


Figure 3: SAMS TSH Orientation at Ksenia apparatus in Kristall module

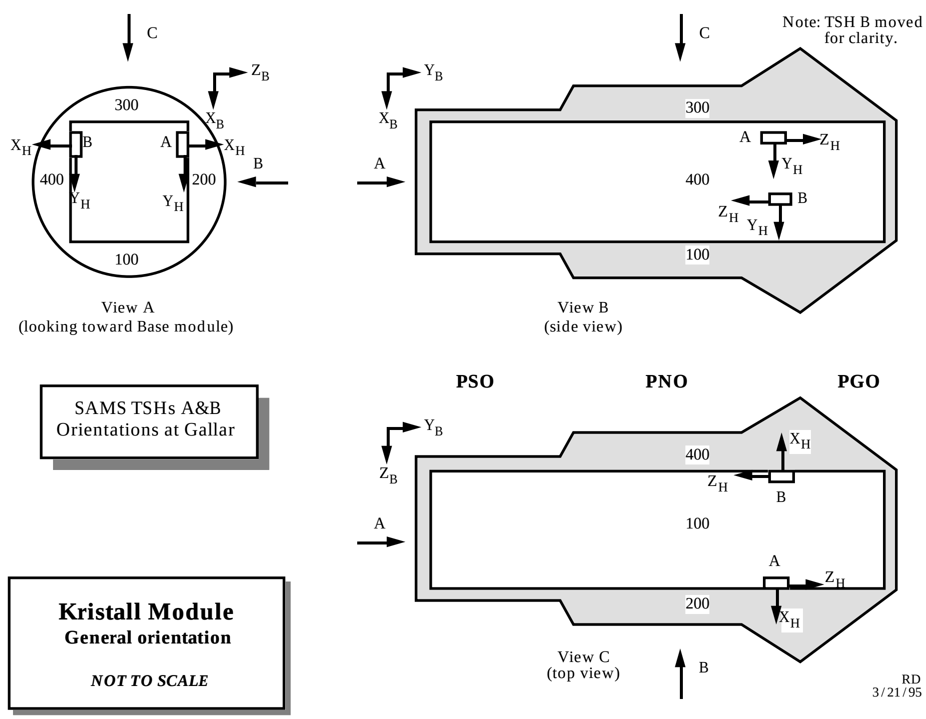


Figure 4: SAMS TSH Orientation at Gallar furnace in Kristall module

Figure 5: PSC plot for illustration of concept

Figure 6: PSC plots for structural modes

Figure 7: PSD plot showing structural modes

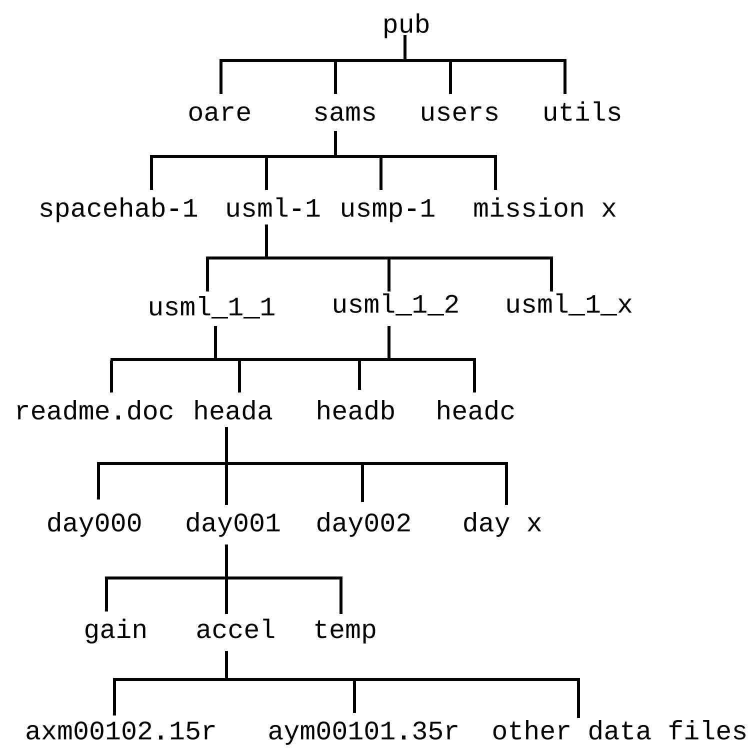
Figure 8: Spectrogram showing gyrodyne disturbance

Figure 9: PSD for crew exercise (MLT 289/13:02:30 TO 13:07:30)

Appendix A

ACCESSING SAMS DATA VIA INTERNET

SAMS data are distributed on CD-ROM media and are available on a computer file server. In both cases, files of SAMS data are organized in a tree-like structure as illustrated in the figure. Data acquired from a mission are categorized based upon sensor head, mission day, and type of data. Data files are stored at the lowest level in the tree and the file name reflects the contents of the file. For example, the file named axm00102.15r contains data for sensor head A, the X axis, the time base was Mission Elapsed Time, day 001, hour 02, 1 of 5 files for that hour, and it contains reduced data. The file readme.doc provides a comprehensive description and guide to the data.



SAMS Data File Structure

Also available from the file server are some data access tools for different computer platforms.

SAMS data files may be accessed from a file server at NASA LeRC. The NASA LeRC file server `beech.lerc.nasa.gov` can be accessed via anonymous file transfer protocol (ftp), as follows:

[1] Establish ftp connection to the file server named `beech.lerc.nasa.gov`.

[2] Login: *anonymous*

[3] Password: *guest*

[4] Change the directory to: *pub*

[5] List the files and directories in the pub directory.

[6] Change the directory to the mission of interest, for example: *usml-1*

[7] List files and directories for the specific mission chosen in previous step.

[8] Use the data file structure shown in the figure to find the files of interest.

[9] Transfer the data files of interest.

If you encounter difficulty in accessing the data using the file server, please send an electronic mail message to the internet address below. Please describe the nature of the difficulty and a description of the hardware and software you are using to access the file server.

`pims@lerc.nasa.gov`

Additional information about SAMS and PIMS may be obtained at the following World Wide Web (WWW) location:

`http://www.lerc.nasa.gov/Other_Groups/MMAP/index.html`

Appendix B

ACCELERATION DATA TIME HISTORY

The Principal Investigator Microgravity Services (PIMS) group has further processed SAMS data from Mir-16, Head B to produce the plots shown here. Two time history representations of the data are provided: ten second average and ten second root mean square (RMS) plots. These calculations are presented in two hour plots, with the corresponding average and RMS plots on one page. The ten-second interval average plots give an indication of net accelerations which last for a period of 10 seconds or more. Shorter duration, high amplitude accelerations may be seen with this type of plot, however their exact timing and magnitude cannot be extracted. The ten-second interval RMS plots give a measure of the oscillatory content in the acceleration data. Plots of this type may be used to identify times when oscillatory and/or transient deviations from the background acceleration levels occurred.

These average and RMS plots differ from similar plots produced in PIMS mission summary reports prior to January 1996. Previous plots tended to show an artificial spike when a gain change occurred within the SAMS unit. This artifact has been suppressed using gain change compensation routines.

Interval Average and Root Mean Square Calculations

This data were collected at 50 samples per second, and a 10 Hz low pass filter was applied to the data by the SAMS unit prior to digitization.

Prior to the production of the interval average and RMS plots, the data were demeaned. This was accomplished by demeaning individual sections with a nominal length of 14 minutes. The average plots were produced by calculating the average of ten second intervals of data for each axis. This operation is described as:

$$x_{avg_k} = \frac{1}{M}\sum_{i=1}^{M} x_{(k-1)M+i}$$

where x represents the x, y, or z axis data, M is the number of points analyzed in an interval, and k refers to the kth interval analyzed. The resulting data streams (x_{avg}, y_{avg}, z_{avg}) are then combined by a vector-magnitude operation. This computation is expressed mathematically as: .

$$accel_{avg_k} = \sqrt{x_{avg_k}^2 + y_{avg_k}^2 + z_{avg_k}^2}$$

The RMS plots were produced by taking the root-mean-square of ten second intervals of data for each axis and forming a vector magnitude of the resulting data stream. The interval RMS operation is expressed mathematically as: .

$$x_{RMS_k} = \sqrt{\frac{1}{M}\sum_{i=1}^{M}(x_{(k-1)M+i})^2}$$

The same definitions apply for x, M, and k as in the interval average computation. The resulting data streams are combined by a vector-magnitude operation.

Appendix C

SAMS COLOR SPECTROGRAMS

The SAMS data have been further processed to produce the plots shown here. Color spectrograms are used to show how the microgravity environment varies in intensity with respect to both the time and frequency domains. These spectrograms are provided as an overview of the frequency characteristics of the SAMS data during the Mir-16 time period. Each spectrogram is a composite of two-hour's worth of data. The time resolution used to compute the spectrograms seen here is 40.960 seconds. This corresponds to a frequency resolution of 0.0244 Hz.

The spectrograms contained herein differ from those spectrograms produced for PIMS mission summary reports prior to January 1996. Previous spectrograms utilized a colormap which had 8 colors. The new spectrograms contain 64 colors. Thus, the magnitude resolution (as represented by the color) shows a significant improvement. Care should be taken to not confuse the current colormap system with that used in reports prior to January 1996. For example, in previous spectrograms, yellow represented a higher magnitude than did red. The new colormap system is opposite when it comes to the yellow-red relation. The user is advised to refer to the colormap key located next to each spectrogram plot.

In order to produce the spectrogram image, Power Spectral Densities (PSDs) were computed for successive time intervals (the length of the interval is equal to the time resolution). For the PSD computation, a boxcar window was applied. In order to combine all three axes into a single plot to show an overall level, a vector-magnitude (VM) operation was performed. Stated mathematically: .

$$PSD_{VM_k} = \sqrt{PSD_{x_k}^2 + PSD_{y_k}^2 + PSD_{z_k}^2}$$

By imaging the base 10 logarithm ($\log_{10}$) magnitude as a color and stacking successive PSDs from left to right, variations of acceleration magnitude and frequency are shown as a function of time. Colors are assigned to discrete magnitude ranges, so that there are 64 colors assigned to the entire range of magnitudes shown.

Plot gaps (if any exist) are shown by either white or dark blue areas on the page. Care should be taken to not mistake a plot gap (represented by a black vertical band) with a quiet period. If a plot gap exists for an entire plot (or series of successive plots), a comment is placed on the page to let the user know there is a gap in the data. These "no data available" comments will not show exact times for which the data are not available, but will only indicate missing plots.

Due to the nature of spectrograms, care should be taken to not merely read a color's numeric value as being the "amount" of acceleration that is present at a given frequency. In order to get this type of information, the PSDs must be integrated between two frequencies. These frequencies (lower and upper) form the "band" of interest. The result of this integration is the g_{RMS} acceleration level in the [f_{lower}, f_{upper}] band. The PIMS group is able to provide this type of analysis on a per-request basis. To request this additional analysis, send an e-mail to pims@lerc.nasa.gov, or FAX a request to (216) 433-8545.

Appendix D

USER COMMENT SHEET