

A Researcher's Guide to:

INTERNATIONAL SPACE STATION

Acceleration Environment



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Cover and back cover:

- a. Front cover: The International Space Station orbits the earth. (Image credit: NASA)
- b. Back cover (top): Spectrogram of SAMS measurements showing signature and features of crew exercise on the Velo device. (Image credit: NASA)
- c. Back cover (bottom): Two-dimensional histogram of SAMS measurements in Columbus showing power spectral density divide above 60 Hz created by European Physiology Modules rack being on versus off. (Image credit: NASA)

The Lab is Open

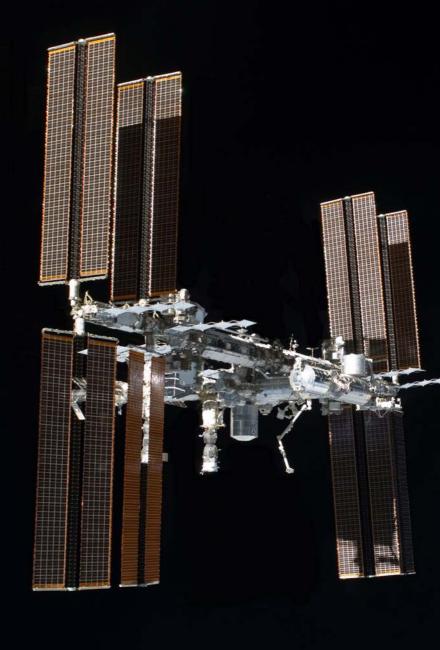
Full Speed Ahead

The International Space Station (ISS) has a mass of over 900,000 pounds (400,000 kg), but it's nearly weightless! This near weightlessness is due to its continuous state of free-fall around the Earth not considering a small amount of atmospheric drag. An accounting of precisely how weightless comes by virtue of the Microgravity Acceleration Measurement System (MAMS) which monitors the quasi-steady acceleration environment 24 hours a day, 7 days a week.

The ISS offers a microgravity research platform for those who need to leverage its unique environment. The space station is over 350 feet (109 m) wide and has 3 separate, main laboratory modules, each roughly the size of a school bus. Each laboratory has a multitude of equipment, some related to science operations and some related to life-support. Centrifuges, fans, pumps, compressors, structural bending, etc. all contribute to tiny vibrations over a wide range of frequencies that are monitored continuously by sensors distributed in locations designated for support by the Space Acceleration Measurement System (SAMS). These SAMS measurements along with those from MAMS give researchers, technology developers, and structural analysts the information they need to do their work, whether it is principal investigators studying fluid or combustion behavior in microgravity, or analysts tracking the structural integrity of the ISS.



SAMS Sensor (SE-F02) supporting science operations near the European Drawer Rack in the Columbus Module. (Image credit: NASA)



Unique Features of the ISS Research Environment

- 1. Microgravity, or weightlessness, alters many observable phenomena within the physical and life sciences. Systems and processes affected by microgravity include surface wetting and interfacial tension, multiphase flow and heat transfer, multiphase system dynamics, solidification, and fire phenomena and combustion. Microgravity induces a vast array of changes in organisms ranging from bacteria to humans, including global alterations in gene expression and 3-D aggregation of cells into tissue-like architecture.
- 2. Extreme conditions in the ISS environment include exposure to extreme heat and cold cycling, ultra-vacuum, atomic oxygen, and high-energy radiation. Testing and qualification of materials exposed to these extreme conditions have provided data to enable the manufacturing of long-life, reliable components used on Earth as well as in the world's most sophisticated satellite and spacecraft components.
- 3. Low-Earth orbit at 51 degrees inclination and at a 90-minute orbit affords ISS a unique vantage point with an altitude of approximately 240 miles (400 kilometers) and an orbital path over 90 percent of the Earth's population. This can provide improved spatial resolution and variable lighting conditions compared to the sun-synchronous orbits of typical Earth remote-sensing satellites.

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Components of ______ Microgravity Environment

The acceleration environment of any orbiting spacecraft such as the International Space Station (ISS) is not truly "zero G" as sometimes assumed. This popular idiom applies only to the vehicle's center of mass, a point that is not necessarily a physical part of the spacecraft's structure. All the rest of the mass that comprise the vehicle or are otherwise attached to it will experience accelerations from a variety of sources, such as pumps, fans, thrusters, atmospheric drag, rotational forces and others. These accelerations are often referred to as disturbances in that they can introduce undesired effects. These disturbances are mostly transmitted mechanically through the vehicle structure or acoustically through the air within the habitable modules.

A prismatic view of the ISS acceleration environment reveals a broad spectrum of vibrational frequencies, ranging from the relatively low-magnitude, low-frequency portion referred to as the quasi-steady regime up through the relatively high-frequency, high-magnitude vibratory regime. Without any additional payload vibration isolation, the ISS acceleration spectrum ranges from on the order of much less than a micro-g at the low-frequency end (< 0.1 Hz) to well over 10 milli-g at the high-frequency end of the spectrum. With available ISS payload vibration isolation systems, the acceleration environment can further be reduced by up to a factor of 100 so as to sometimes meet the ISS microgravity requirements.

Another aspect of the acceleration environment to consider is the transient regime, which is associated with relatively brief and relatively high-magnitude accelerations, such as those introduced by a vehicle docking, thruster firing, or even a crew push-off or crew landing. These impulsive events do not fall neatly into either the quasi-steady regime or the vibratory regime. When we consider its spectral decomposition, we see that this type of disturbance has impact over a wide portion of the acceleration spectrum.

Why use the label microgravity? Well, if we consider only the low-frequency, low-magnitude accelerations, then we note that those are approximately one-millionth of what would be experienced at the surface of the Earth—one-millionth, hence the prefix "micro." This label, of course, is oversimplified and not intended to completely characterize the dynamic acceleration environment of the ISS. See Figure 1 Microgravity Environment Components for an overview of microgravity environment acceleration components.

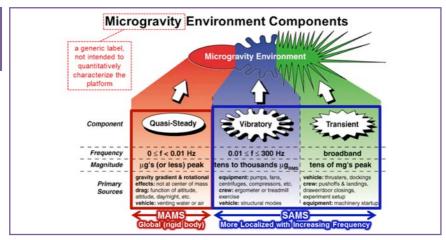


Figure 1. Microgravity Environment Components

The Quasi-Steady Regime

The quasi-steady regime is comprised of accelerations at the lower end of the spectrum (below 0.01 hertz) and with magnitudes on the order of less than a micro-g. These low-frequency disturbances are associated with phenomena related to the ISS orbital rate of about 90 minutes, and primarily are due to aerodynamic drag and vehicle rotation. The drag exerted on the space station comes from a thin atmosphere that exists even at a nominal altitude of about 200 miles. This drag varies as the ISS traverses a slightly elliptical orbit through the atmosphere with thermal variations throughout. Denser portions give rise to more drag and thus higher acceleration levels. In its nominal attitude (+XVV +ZLV), the aerodynamic drag exerted on the ISS is primarily manifested on the two axes aligned with its orbital trajectory. One axis is aligned with the local vertical axis (the Z-axis), and one axis is aligned with the velocity vector or direction of travel (the X-axis). See

Y_A

Velocity vector (direction of flight)

Z_A

nadir
(toward Earth)

Figure 2. Space Station Analysis (SSA) Coordinate System

Figure 2 Space Station Analysis (SSA) Coordinate System for a depiction of this attitude and a description of the SSA coordinate system.

Gravity gradient and rotational effects are key factors in shaping the quasi-steady regime. Both of these factors depend on the location of interest relative to the vehicle's center of mass. The gravity gradient component stems from the fact that

Earth's gravitational tug decreases according to the inverse-square law, whereby the lower part of the orbiting structure will get a slightly stronger tug from the Earth. Rotational effects come about from the attitude maintained by the ISS. In essence, the space station tumbles or rotates once per orbit.

The Vibratory Regime

The vibratory regime is comprised of vibrations in the acceleration spectrum above 0.01 hertz. These vibrations result from motion of the vehicle, crew or experiment-related equipment. The omnipresent flexing and bending of vehicle structure, crew sleep/wake cycles, crew exercise, turbulent airflow, and rotating/reciprocating machinery are some of the disturbance sources that play a role in shaping this vibratory regime. In general, as the vibrational frequency under consideration increases, the more localized the effect of these disturbances tends to be. Vehicle subsystems such as those needed for life support, thermal control or communications produce significant disturbances here. The impact of these is primarily a function of proximity to the disturbance source. In a similar way, experiment-related equipment needed to support or conduct scientific investigations on the space station can play a major role, particularly as disturbances to other payloads in their vicinity.

Vehicle Structural Modes

Vehicle structural modes reside at the low-frequency end of the vibratory portion of the acceleration spectrum. These vibrations fall within the frequency range from about 0.1 hertz to about 5 hertz. These vibrations arise from the excitation of natural frequencies associated with large components of the space station structure, such as the main truss, and with fundamental appendage modes, such as solar arrays. These structures are typically excited by relatively large magnitude, relatively brief impulsive events like during a reboost or by crew locomotive events like push-offs. The driving excitation of such events results in response vibrations as structural ringing damps out. Also, relatively small magnitude vibrations at just the right frequency will give rise to structural resonance. Structural vibrations propagate via mechanical linkage. While the frequency of these disturbances may be registered the same throughout the space station, their amplitude is a function of location. Structural mode vibrations tend to be low amplitude during crew sleep periods relative to crew active periods owing to the absence of impulsive push-off and landing events by the crew on space station structure.

After assembly complete, the first such structural mode of the ISS, sometimes referred to as "mode one" is nominally at about 0.1 hertz. During quiet periods such

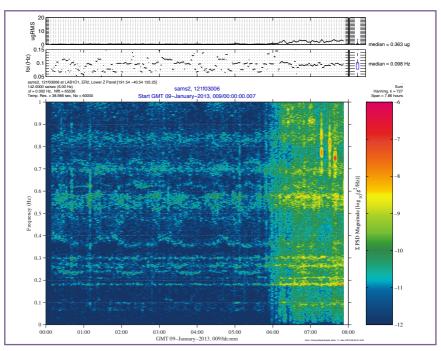


Figure 3. Spectrogram Showing Mode One with Crew Sudden Transition to Wake.

as crew sleep, the spectral amplitude of the narrowband peak at mode one is about an order of magnitude less than otherwise for measurement locations in the United States Laboratory (USL). The color spectrogram in Figure 3 Spectrogram Showing Mode One with Crew Sudden Transition to Wake shows mode one as the faint, yellow horizontal trace at about 0.1 hertz that becomes noticeable when the crew wakes with a sudden transition just after Greenwich Mean Time (GMT) 06:00. Conversely, the color spectrogram in Figure 4 Spectrogram Showing Mode One with Crew Slow Transition to Sleep for that same day shows mode one along with other structural vibrations tapering off after GMT 21:00 with transition toward weaker (blue) magnitudes.

In the Japanese Experiment Module (JEM) and in the Columbus Module (COL), mode one is about two orders of magnitude less during quiet periods. In addition to mode one, there is a cluster of modes below 5 hertz that further characterize the vibrations of large space station structures. These are noted along with the location

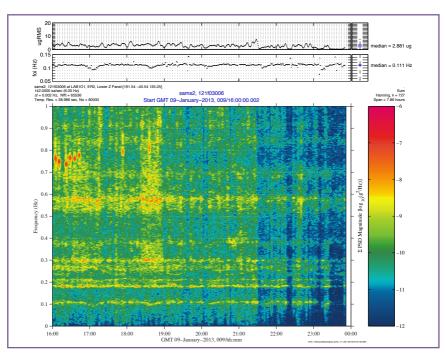


Figure 4. Spectrogram Showing Mode One with Crew Slow Transition to Sleep.

of the Space Acceleration Measurement System (SAMS) sensors that captured this persistent set of vibrations in Table 1 Partial List of Vehicle Structural Modes*.

When considering the concentration of structural modes between about 0.06 < f < 3 hertz in aggregate, it is important to note that SAMS sensors mounted in the USL register root mean square (RMS) acceleration levels between about 20 and 30 ug in this band, while SAMS sensors mounted in the JEM and the COL register RMS levels closer to 40 ug. Geometry, structural dynamics and sensor location account for this difference.

Crew Exercise

Next in the vibratory regime, we examine crew exercise. Exercise is an important part of the crew's daily routine. In addition to promoting fitness, this activity is geared to help prevent bone and muscle loss associated with prolonged exposure to microgravity. On average, each crew member is scheduled to exercise approximately

	SENSOR LOCATION			
f (hertz)*	ALL	LAB	COL	JEM
0.10	Х			
0.18	Х			
0.25			Х	
0.28		Х		Х
0.41		Х		Х
0.60		Х		Х
0.71		Х		Х
0.83		Х		
0.87			Х	Х
1.13		Х		
1.28		Х		
1.30			Х	Х
1.62		Х		
1.65			Х	Х
1.84		Х		Х
1.95		Х		
1.98		Х		Х
2.25		Х		
2.30				Х
2.50				Х

Table 1. Partial List of Vehicle Structural Modes*
* note that closely spaced modes can appear as
a single peak in a power spectral density (PSD)
for a given frequency resolution and that was not
accounted for in this analysis; therefore, closely
spaced modes may be represented as a single
value in the table above.

two hours per day and with multiple crew members; many of their scheduled periods overlap on the daily plan. There are three basic types of exercise equipment that the crew can use including a treadmill, a cycle ergometer and a resistive apparatus.

The space station has one treadmill in Node 3 referred to as "T2" and another one in the Service Module, which is called the Treadmill with Vibration Isolation and Stabilization (TVIS). The TVIS is suspended over an opening in the floor, which allows for movement of the treadmill into and back out of this opening. The vibration isolation system serves to minimize the transfer of exercise forces from the treadmill to the ISS structure. There are a couple of cycle ergometers on the ISS: the Cycle Ergometer with Vibration Isolation System (CEVIS) located in the USL, and the Veloergometer (Velo) located in the Service Module. These devices provide controlled workloads for the crew. The CEVIS is located in the USL where the astronauts strap themselves in. The CEVIS was designed to counteract crew motions in order to attenuate the transfer of its vibratory disturbances to the space station. The last type of exercise equipment comes in the form of the Advanced Resistive Exercise Device (ARED) located in Node 3. This is a resistive device that simulates gravity. The

ARED provides the capability to do both upper- and lower-body exercises including squats, dead lifts, heel raises, bicep curls and bench press. This equipment has built-in vibration isolation as well.

In general, these exercise equipment were designed to maintain the ISS microgravity environment. However, factors outside of their design envelope can play a role in this activity having an impact on the environment. As a result, this activity can excite vehicle structural modes depending on the frequency of exercise movement and on

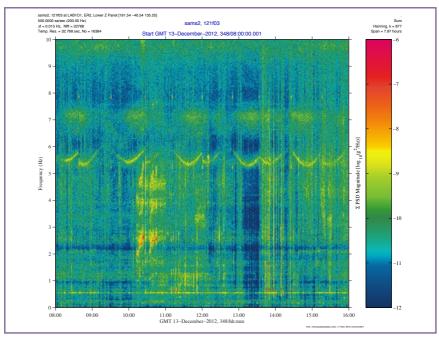


Figure 5. Spectrogram Showing Crew Exercise Periods and Relative Quiet Period.

the vigor of the crew. In addition, exercise will introduce its own, unique signature in the vibratory regime. Typically, these signatures are manifest below about 3 hertz. The color spectrogram of Figure 5 Spectrogram Showing Crew Exercise Periods and Relative Quiet Period shows a couple of bouts of exercise between about GMT 10:00 and 11:00 with the strongest impact (red horizontal streaks) seen below 3 hertz. Interesting to note in this figure also is the relative quiet crew period ending at about GMT 13:30 as indicated by the vertical dark blue region. This indicates most or all of the crew members were relatively still for the 15 minutes or so of the dark blue span.

Urine Processor Assembly (UPA)

Another noticeable, but weak, disturbance source in the vibratory regime is the UPA, which is part of the ISS water recovery system in Node 3. The UPA houses a distillation assembly centrifuge that was designed to spin at 220 rpm (3.67 hertz). Onboard acceleration measurements indicate that it often rotates closer to 221 rpm (3.68 hertz). This equipment routinely operates continuously for several hours

Sensor	RMS (ug)	LAB	Location
SAMS 121f08	210	COL	COL1A1, ER3, Seat Track near D1
MMA Obbd	204	JEM	JPM1A3 Upper Left
SAMS 121f05	108	JEM	JPM1F5, ER4, Drawer 2
SAMS 121f04	99	USL	LAB102, ER1, Lower Z Panel
SAMS 121f03	72	USL	LAB101, ER2, Lower Z Panel
SAMS 121f02	136	USL	LAB1S2, MSG, Upper Left Seat Track
SAMS TSH es06	109	USL	LAB1S4, FIR

Table 2. Ku-Band Antenna, RMS Values (5 < f < 20 hertz).

at a time and leaves a faint, yet distinct narrowband signature in the acceleration spectrum. The impact of this disturbance was measured by SAMS in the USL, and is also evident in SAMS measurements from the COL. The signature from this equipment, however, is much less clear in the JEM. To summarize, the UPA injects a weak narrowband signature at just over 3.6 hertz. This narrowband disturbance is most distinctive in the USL, with RMS levels of around 38 ug at the SAMS es06 sensor location; with RMS levels in the JEM of about 6 ug at the SAMS 121f05 sensor location. For more information on this disturbance source see http://pims.grc.nasa.gov/pimsdocs/public/ISS%20Handbook/hb vib vehicle uparev 2011 12 22.pdf. Also, use Table 2 as a reference for sensor locations on the ISS.

Ku-Band Antenna

The Ku-band antenna provides a link for payload communications between the ISS and ground stations throughout the world. The antenna is also referred to as the space-to-ground antenna and is mounted on a two-axis gimbal assembly to allow the dish to rotate for acquisition and line-of-sight tracking of data relay satellites. The vibratory signature of the Ku-band antenna is persistent and distributed mainly over the frequency range from about 5 hertz to about 20 hertz. Extended durations of auto-tracking while locked on current target satellite are punctuated by occasional, brief spatial acquisition iterations to lock on to the next target satellite and the vibratory motions associated with these functions are seen as twin spectral peaks at about 5.2 hertz and 7.8 hertz. Superimposed, there is a broad spectral hump between about 5 and 8 hertz, which gets registered to varying degrees throughout the ISS. The magnitude of this disturbance at any given sensor location is not a function of quiet versus nominal periods, like sleep versus wake, because this communications link is maintained around the clock; it does vary with

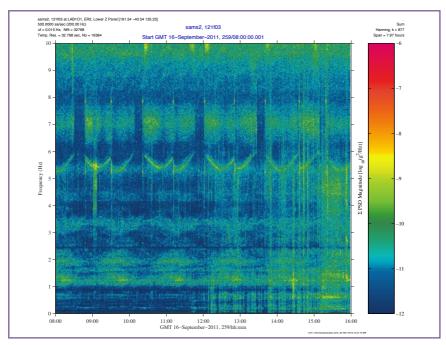


Figure 6. Spectrogram Showing Ku-Band Acquisition Signature.

time though. For the most part, its impact as a disturbance source is dependent on measurement location. Table 2 shows representative values.

For the narrowband nature of the brief acquisition handover periods, see the spectral peaks at 5.2 hertz, and 7.8 hertz in Figure 6 Spectrogram Showing Ku-Band Acquisition Signature; not seen in this figure are two more narrowband spectral peaks at 10.6 hertz and 13.1 hertz.

In summary, the Ku-band antenna described in this section is the dominant disturbance source from about 5 hertz to about 20 hertz at all acceleration sensor locations analyzed by the Principal Investigator Microgravity Services (PIMS) team. Its acceleration signature is characterized by a semi-regular pattern of frequency sweeps that are evident on a time scale of an orbital period. Measurements show this disturbance source registers loudest at the SAMS 121f08 location in the COL at about 210 ugRMS.

Russian SKV Air Conditioner

The Russian SKV air conditioner is part of the Environmental Control and Life Support System. This equipment gives rise to another common vibratory disturbance that shows up at all sensor measurement locations. It is tightly controlled in frequency producing narrowband vibrations at 23.5 hertz. These vibrations were measured as loudest in the USL at the 121f03 and 121f04 locations at about 29 ugRMS.

SAMS Fan

There is a SAMS fan that produces a narrowband vibration at 47 hertz. This disturbance is only detectable at sensor locations near ER1 in the USL. At the SAMS 121f04 location on LAB1O2, it is registered with an RMS level of about 174 ug.

General Laboratory Active Cryogenic International Space Station Experiment Refrigerator (GLACIER)

The GLACIER is a water-cooled freezer that provides cryogenic transportation and preservation of samples requiring temperatures as low as minus 160 degrees Celsius. Acceleration spectral analysis shows the vibratory impact of this equipment was focused primarily in three narrowband peaks at 60 hertz, 120 hertz, and 180 hertz. Since these are common operating frequencies, it is likely that some of the energy in these bands is attributable to other equipment as well. Acceleration measurements indicate the epicenter of this disturbance's 60 hertz component is in the USL near ER1 (the 121f04 location on LAB1O2 at about 1027 ugRMS), and it was also loud near ER2 (the 121f03 location on LAB1O1 at about 911 ugRMS) and to a much lesser extent near the MSG (the 121f02 location at about 97 ugRMS). The other components shake out as follows: the 120 hertz component was loudest at 121f03 location on LAB1O1 at about 369 ugRMS, next at 121f04 location on LAB1O2 at about 227 ugRMS, and least so at 121f02 location on the MSG at about 102 ugRMS. The 180 hertz component had the lowest impact with 194 ugRMS at 121f04 location on LAB1O2, 133 ugRMS at 121f03 location on LAB1O1, and 41 ugRMS at 121f02 location on the MSG, and it was not distinguishable at the JAXA MMA 0bbd sensor location on JPM1A3.

Common Cabin Air Assembly (CCAA)

The CCAA in the USL provides the capability to control the cabin air temperature, maintain the humidity level within desired limits and generate ventilation air flow.

During a normal shutdown operation of the CCAA, the inlet fan speed is reduced from about 5,700 RPM (about 95 hertz) to about 3,400 RPM (about 57 hertz). At that point, the water separator continues to operate at about 5,900 RPM (about 98 hertz) for approximately three hours to accomplish dry-out prior to final shutdown. Both fans are then shut down during the transition from the port side CCAA to the starboard CCAA. Operation of the water separator results in the primary impact of this system on the microgravity environment. The water separator has a narrowband signature at about 98 hertz and imparts RMS levels as follows (see Table 2 for sensor locations): about 557 ugRMS at the 121f03 location, 397 ugRMS at the 121f02 location, 232 ugRMS at the 121f04 location, and 39 ugRMS at the SAMS es06 location.

Control Moment Gyroscopes (CMGs)

There are four CMGs located on the Z1 truss structure of the ISS. These rotate at 6,600 RPM to provide angular momentum. The immutable laws of physics allow flight controllers to tap into inherent torque and use it as a non-propulsive means of attitude control for the space station. As seen by the narrow spectral peak at 110 hertz in the figure at this link http://pims.grc.nasa.gov/plots/batch/year2013/month01/day03/2013 01 03 00 00 00.000 121f03 pcss roadmaps500.pdf, these gyros are tightly controlled in frequency and register most distinctly in the USL with RMS levels of about 61, 65, and 111 ugRMS at the 121f02, 121f04, and 121f03 sensor locations, respectively.

The Transient Regime

The transient regime describes accelerations that are impulsive in nature. That is, brief yet relatively large amplitude accelerations that can often excite structural modes. These accelerations are associated with events like thruster firings for reboosts or attitude maneuvers, which are more globally felt and can include crew push-offs and landings, which tend to be more localized. An example of this type of disturbance is documented at this link http://pims.grc.nasa.gov/pimsdocs/public/ISS%20Handbook/hb vib vehicle progress50p docking.pdf.

Acceleration Environment_ Feedback Model

The microgravity acceleration environment of the ISS is quite dynamic. The user community is diverse with concerns ranging from structural integrity of the vehicle to experiment resonances and sensitivities. See Figure 7 Acceleration Environment Feedback Model for an overview of the PIMS team interaction with the user community. The PIMS project supports Microgravity Research Program Office principal investigators in the science disciplines of biotechnology, combustion science, fluid physics, materials science and fundamental physics. PIMS plays an active role throughout the experiment life cycle with involvement and support during experiment planning, performance and evaluation of results.

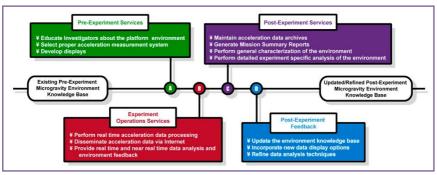


Figure 7. Acceleration Environment Feedback Model.

Pre-Experiment Services

PIMS contributes to experiment teams through acceleration data analysis specific to their particular science. This effort is augmented by more general efforts aimed at educating microgravity principal investigators about reduced-gravity experiment platforms' environments and about the accelerometer systems available to measure the environments of those platforms. This involvement with experiment teams during experiment planning stages results in the collection of acceleration data best suited for correlation with measured science data. A fundamental role of the PIMS project's acceleration data support efforts is to archive and disseminate acceleration data. The archival of acceleration data provides investigators the means to determine the environment under which their experiments were conducted and potentially help to plan their future work. PIMS utilizes the archived data to support users interested in the microgravity acceleration environment by providing

information about activities and sometimes about acceleration sources. The result of this accumulated knowledge base is an improved understanding of the expected environment of the various reduced gravity platforms that is passed on to investigator teams during the experiment planning process.

Experiment Operations

In addition to providing the proper microgravity environment education during experiment planning, PIMS works with investigators to design acceleration data displays and analysis techniques best suited for understanding potential relationships between measured acceleration data and the science results. A number of plot options, displays and analysis techniques are currently available to principal investigators. Distribution of the acceleration environment information is accomplished primarily through the Internet. The availability of the microgravity acceleration data in near real-time can also be employed by investigators as a tool for making decisions regarding when to initiate experiment operations and how to make adjustments from experiment run to experiment run in order to improve science results. This interaction during experiment operations can help lead to experimental success.

Post-Experiment Feedback

Post-experiment analysis and interpretation of acceleration data can be the missing puzzle piece for investigators trying to determine what factors either helped or hindered their results. Correlation with the acceleration record can help expand their existing knowledge base and in turn serve those who follow in their footsteps or toward future, follow-on investigations.

Acceleration System Description

NASA's Glenn Research Center (GRC) is home to many key components of the ISS acceleration measurement and analysis program. The GRC has the long-established goal to provide timely and readily accessible acceleration data and related information. Foremost in this pursuit is to capture, process and archive the acceleration measurements, which continuously stream from the space station. Furthermore, it offers analysis services for the microgravity community in general and with the capability to provide tailored products for scientific payloads, structural dynamics monitoring, and technology developers. As a means to fulfill its acceleration program goals, the GRC sponsors the SAMS, the Microgravity Acceleration Measurement System (MAMS), and the PIMS projects.

Space Acceleration Measurement System (SAMS)

SAMS has been a cornerstone in the ongoing effort to provide continuous access to the vibratory environment on the ISS. This system has a proven track record of sustained, reliable performance. It first flew in June 1991 and has flown on nearly every major microgravity science mission on the space shuttle. In addition, SAMS was used for four years aboard the Russian space station, Mir, where it measured accelerations in support of scientific investigations. SAMS has been onboard the ISS since 2001. It has streamed acceleration measurement data nearly continuously since then in support of principal investigators, technology developers, and the microgravity community at-large. Last, but certainly not least, SAMS also plays an integral role in daily loads and dynamics monitoring and feeds into the detailed analysis aimed at preserving structural integrity and possibly extending the longevity of the ISS as a microgravity research platform.

SAMS has the ability to instrument and measure the local vibratory regime (0.01 < f < 300 hertz) in all three of the ISS laboratories, including throughout the USL. The accelerations it measures arise from vehicle activities and subsystems, experiment operations, crew movements, and structural dynamics. SAMS Remote Triaxial Sensor (RTS) systems are used primarily to monitor the local vibratory environment for individual experiments requiring acceleration measurement support, and for daily vehicle structural monitoring. Each RTS is capable of measuring acceleration disturbances between 0.01 hertz and 400 hertz. Each RTS consists of two components: the RTS sensor enclosure (SE), and the RTS electronics enclosure (EE). The RTS-SE, is mounted as close to the experiment as possible. There, it measures and translates the data into a digital signal, which gets routed to its RTS-EE. The RTS-EE, in turn, sends the acceleration data to the SAMS Control Unit (CU). The