Microgravity Influence on Physical Systems:

Acceleration Environment and Effects

August 3, 2010

Kevin McPherson

NASA Glenn Research Center, Cleveland, OH USA

Acceleration Measurement Payloads Manager

Phone: 1 216 509 2055

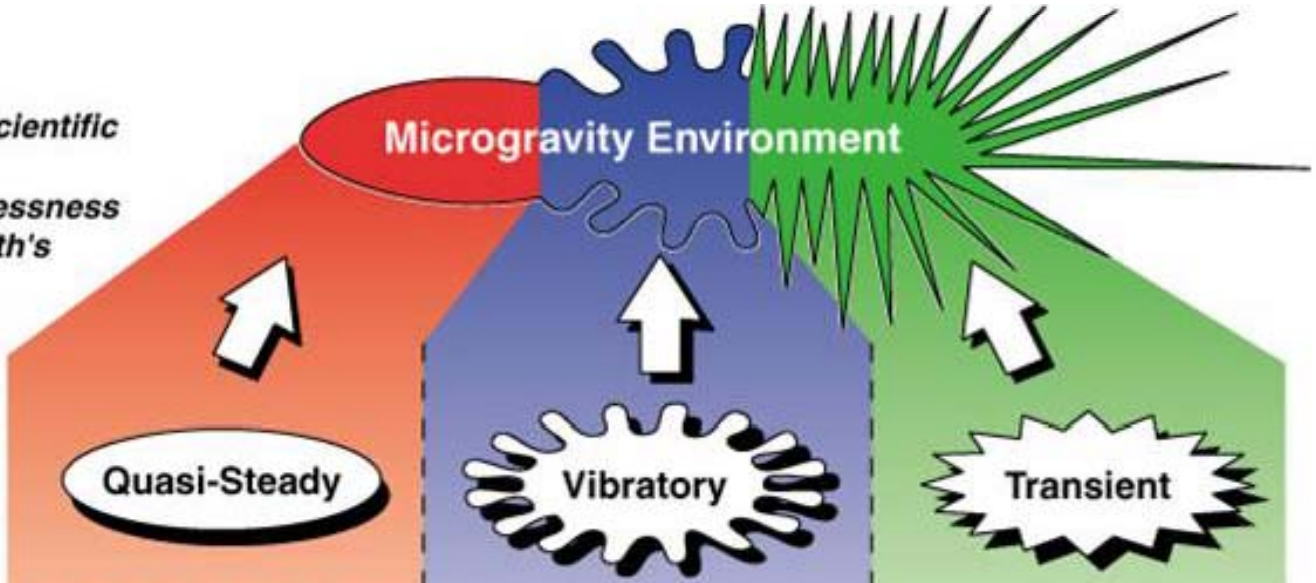
Electronic Mail: Kevin.M.McPherson@nasa.gov

Principal Investigator Microgravity Services

- Supports the International Space Station (ISS) acceleration measurement systems
- Process, analyze and interpret accelerometer data to characterize the microgravity environment of the ISS for the microgravity Principal Investigators (PI) and for the ISS vehicle community
- Long history of microgravity environment support for acceleration data from various microgravity platforms including ISS, Mir, and Space Shuttle microgravity dedicated missions
- Approach
  - Assist the PI team in understanding different aspects of measuring and interpreting the microgravity environment
  - Provide interpretation of the microgravity environment and perform detailed analyses for general and specialized characterization
  - Provide easy access to ISS acceleration data, regardless of the acceleration measurement system

Components of the Microgravity Environment

Microgravity is:
- *a general label for scientific investigations that exploit near-weightlessness*
- *one-millionth of Earth's normal gravity*
- *a reduced gravity environment*



	Quasi-Steady	Vibratory	Transient
Component	Quasi-Steady	Vibratory	Transient
Frequency	$0 \le f < 0.01$ Hz	$0.01 \le f \le 300$ Hz	broadband
Magnitude	μg's (or less) peak	tens to thousands μg_{RMS}	tens of mg's peak
Primary Sources	**gravity gradient & rotational effects:** not at center of mass **drag:** function of altitude, attitude, day/night, etc. **vehicle:** venting water or air	**equipment:** pumps, fans, centrifuges, compressors, etc. **crew:** ergometer or treadmill exercise **vehicle:** structural modes	**vehicle:** thrusters, dockings **crew:** pushoffs & landings, drawer/door closings, experiment setup **equipment:** machinery startup

Acceleration Measurement Systems on the ISS

- **Space Acceleration Measurement System-II (SAMS-II)**
  - **NASA sponsored**
  - **Provide distributed measurement of the vibratory and transient acceleration environment (0.01 ≤ f ≤ 300 Hz) on the ISS**
  - **Operational since ISS Flight 6A (April 2001)**
    - 4 distributed sensors located within the US Lab
      - ER#1, Located at Overhead bay 1, sensors SN 121f03, 121f04
      - Combustion Integrated Rack (CIR), Located at Starboard bay 3, SN es05
      - Fluids Integrated Rack (FIR), Located at Starboard bay 4, SN es06
    - 2 distributed sensors with the Japanese Experiment Module
      - ER #4, Located at Forward bay 4 , sensors SN 121f02, 121f05
    - 2 distributed sensors in Columbus Module
      - ER#3, Located at Aft bay 1, sensors SN 121f08
      - Microgravity Science Glovebox (MSG), Located at Forward 2, SN es08
    - Real-time data downlinked from the ISS

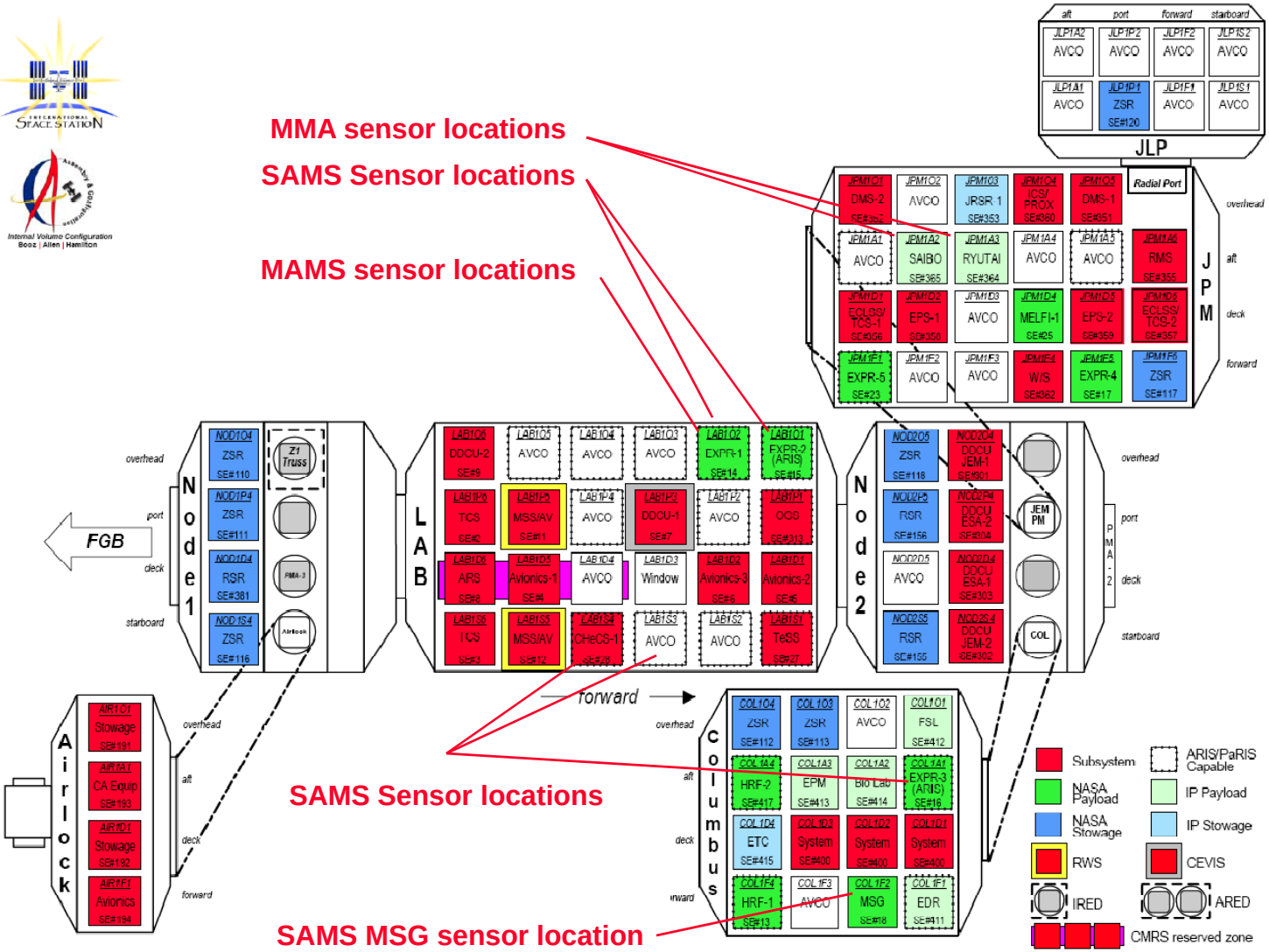
Acceleration Measurement Systems on the ISS

- **Microgravity Acceleration Measurement System (MAMS)**
  - **NASA sponsored**
  - **Measure the ISS quasi-steady acceleration ($f \leq 0.01$ Hz) and the ISS vibratory/transient acceleration environment**
  - **Operational since Flight 6A (April 2001)**
    - Two sensors, MAMS OSS (OARE Sensor Subsystem) and MAMS HiRAP (High Resolution Accelerometer Package) (Overhead location, bay 1)
    - MAMS OSS records quasi-steady accelerations
    - MAMS HiRAP records vibratory environment like SAMS-II
    - Real-time data downlink from the ISS

Acceleration Measurement Systems on the ISS

- **Microgravity Measurement Apparatus (MMA)**
  - **JAXA sponsored**
  - **Measure the ISS quasi-steady acceleration ($f \leq 0.01$ Hz) and the ISS vibratory/transient acceleration environment**
  - **Launched ISS Flight 1J (June 2008) and operational since August 2008**
    - 3 distributed sensors located within the Kibo pressurized module (Aft location, bays 2 and 3)
    - No real-time data downlinked from the ISS
    - Downlink performed post-experiment

Microgravity Influence on Physical Systems Acceleration Environment and Effects



Access to Acceleration Data Archives

- **Access to the PIMS acceleration data archives is available through the PIMS ISS web site**
  - **http://pims.grc.nasa.gov/ftp/pad**
  - **Acceleration data files consist of records typically of the form (t,x,y,z)**
- **Primary objective of the PIMS archive approach**
  - **Adopt a standard data storage format for ISS acceleration data from any ISS acceleration measurement system, i.e. from NASA, JAXA, and ESA**
  - **Simplify access to acceleration data for Principal Investigators**
  - **Consist of pairs of files containing the acceleration data itself and ancillary data associated with the acceleration data**
    - Ancillary data describe the circumstances under which all the acceleration data in the sister file were obtained
    - current ancillary data parameters include: sampling rate, cutoff frequency, station configuration, location, orientation, and coordinate system

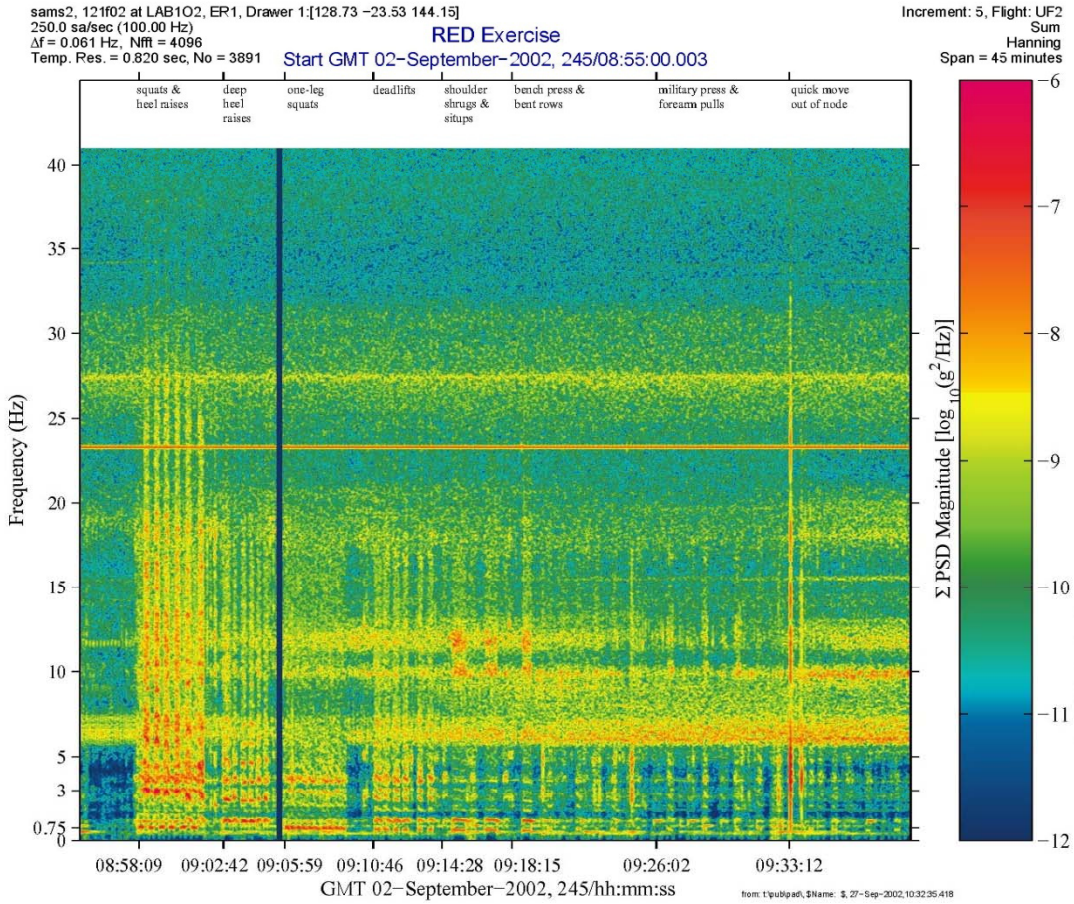
Access to PIMS Handbook Pages

- **PIMS handbook pages summarize documented acceleration environment disturbers in a common format**
  - http://pims.grc.nasa.gov/pimsdb/index.cfm?method=Handbook.pimslist
  - **Each handbook page typically consists of a qualify page and a quantify page**
- **Addition of Columbus and JAXA laboratories provide additional acceleration environment characterization opportunities**
  - **Characterize Columbus and Kibo disturbance signatures**
  - **Characterize known disturbance signatures in Columbus and Kibo laboratories (for example, crew exercise and life support systems)**

Handbook Page Examples

- Figure 1 – Resistive Exercise Device - Qualify
- Figure 2 – Resistive Exercise Device – Quantify
- Figure 3 – Ergometer Exercise - Quantify
- Figure 4 – Ergometer Exercise - Quantify
- Figure 5 – ATV Docking - Quantify
- Figure 6 – ATV Reboost - Quantify
- Figure 7 – Advanced Astrocultures Experiment - Qualify
- Figure 8 – Advanced Astrocultures Experiment - Quantify

Resistive Exercise Device (RED) Qualify



Data Description	
Sensor	121f02 250.0 sa/sec (100.00 Hz)
Location	LAB1O2, ER1, Drawer 1
Inc/Flight	Increment: 5, Flight: UF2
Plot Type	spectrogram

Notes:

- multi-purpose exercise device
- crank canisters to adjust resistance
- in the interim, it is hardmounted
- used routinely and located in the Z1 alcove of Node 1
- base plate parallel with Z1 hatch
- help crew preserve strength and bone mineral
- exercise types: squats, heel raises, deadlifts, bench press, upright rows, bent rows

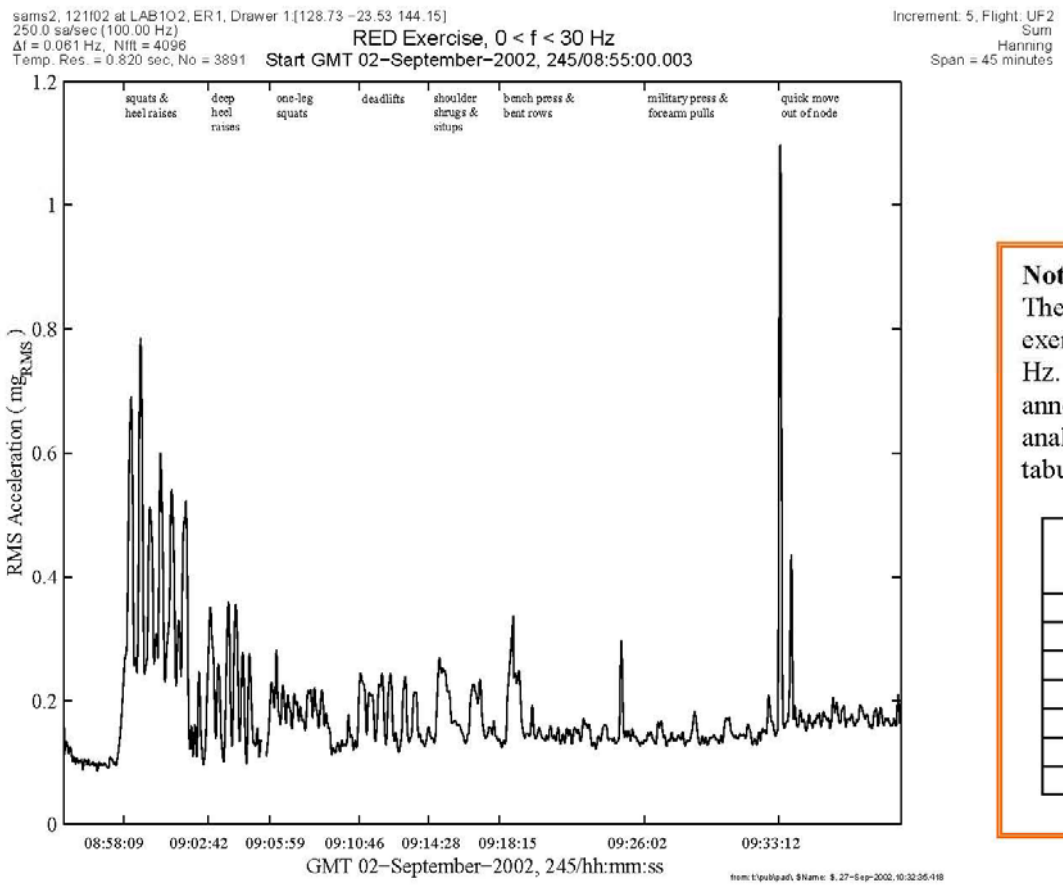
Regime:	Vibratory
Category:	Crew Activity
Source:	Resistive Exercise Device (RED)

Microgravity Science Division

Glenn Research Center

Figure 1

Resistive Exercise Device (RED)
Quantify



Data Description	
Sensor	121f02 250.0 sa/sec (100.00 Hz)
Location	LAB1O2, ER1, Drawer 1
Inc/Flight	Increment: 5, Flight: UF2
Plot Type	interval RMS

Notes:
The interval RMS figure shown spans the entire RED exercise period and covers the frequency range below 30 Hz. This period consisted of several exercise types as annotated in the figure. Several of these types were analyzed for the frequency range below 10 Hz as tabulated below:

Type	Maximum (μg_{RMS})	GMT Start 02-Sep-2002, 245/
baseline (no RED)	60	08:55:00
squats	301	08:58:09
heel raises	691	08:58:26
deep heel raises	336	09:02:42
deadlifts	206	09:10:46
bench/bent rows	222	09:20:21
one-leg squats	255	09:05:59

Regime:	Vibratory
Category:	Crew Activity
Source:	Resistive Exercise Device (RED)

Figure 2

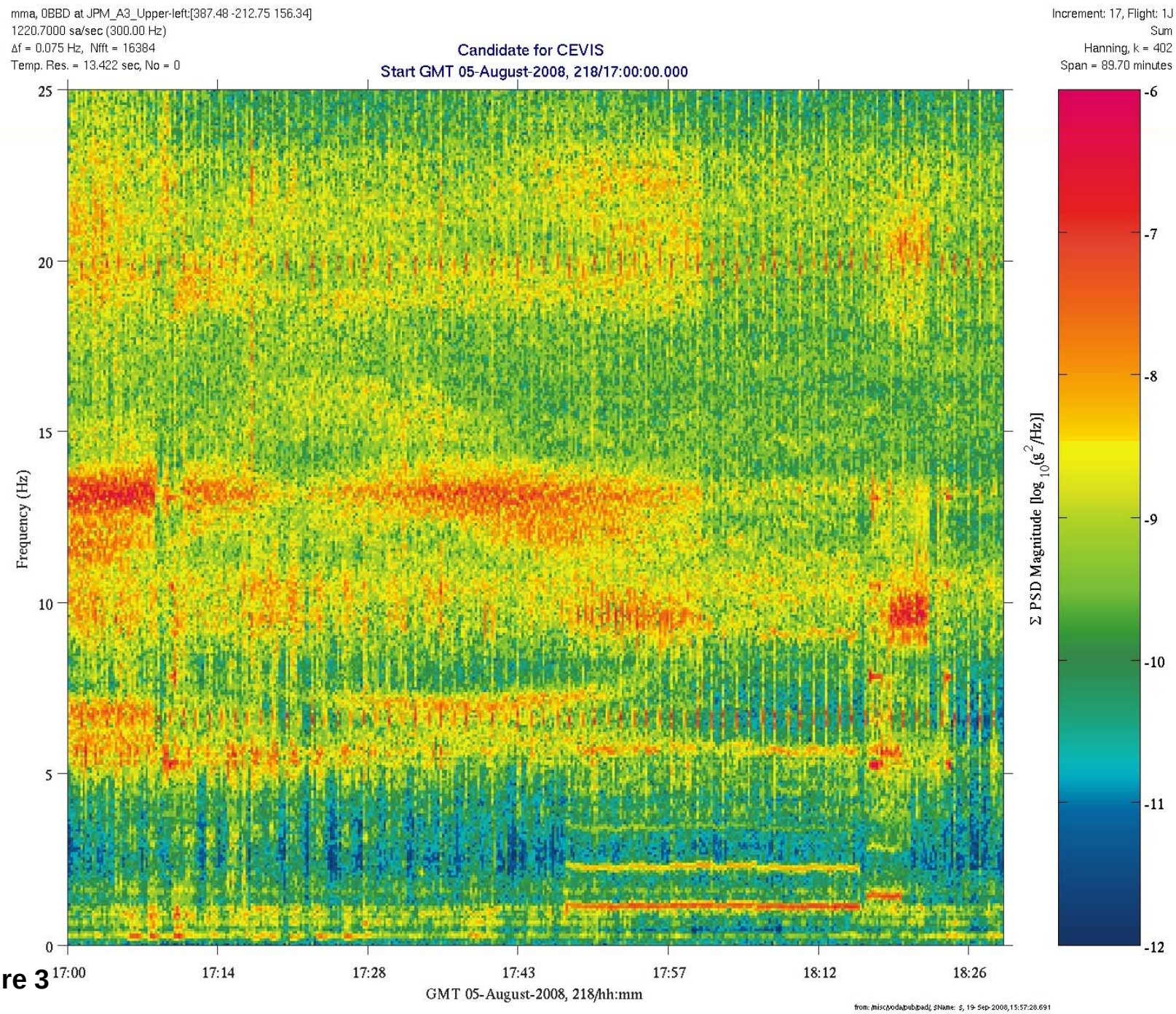

mma, 0BBD at JPM_A3_Upper-left:[387.48 -212.75 156.34]
1220.7000 sa/sec (300.00 Hz)
Δf = 0.075 Hz, Nfft = 16384
Temp. Res. = 13.422 sec, No = 0
Candidate for CEVIS
Start GMT 05-August-2008, 218/17:00:00.000
Increment: 17, Flight: 1J
Sum
Hanning, k = 402
Span = 89.70 minutes
Frequency (Hz)
25
20
15
10
5
0
17:00
17:14
17:28
17:43
17:57
18:12
18:26
GMT 05-August-2008, 218/hh:mm
Σ PSD Magnitude [log10(g2/Hz)]
-6
-7
-8
-9
-10
-11
-12

Figure 3

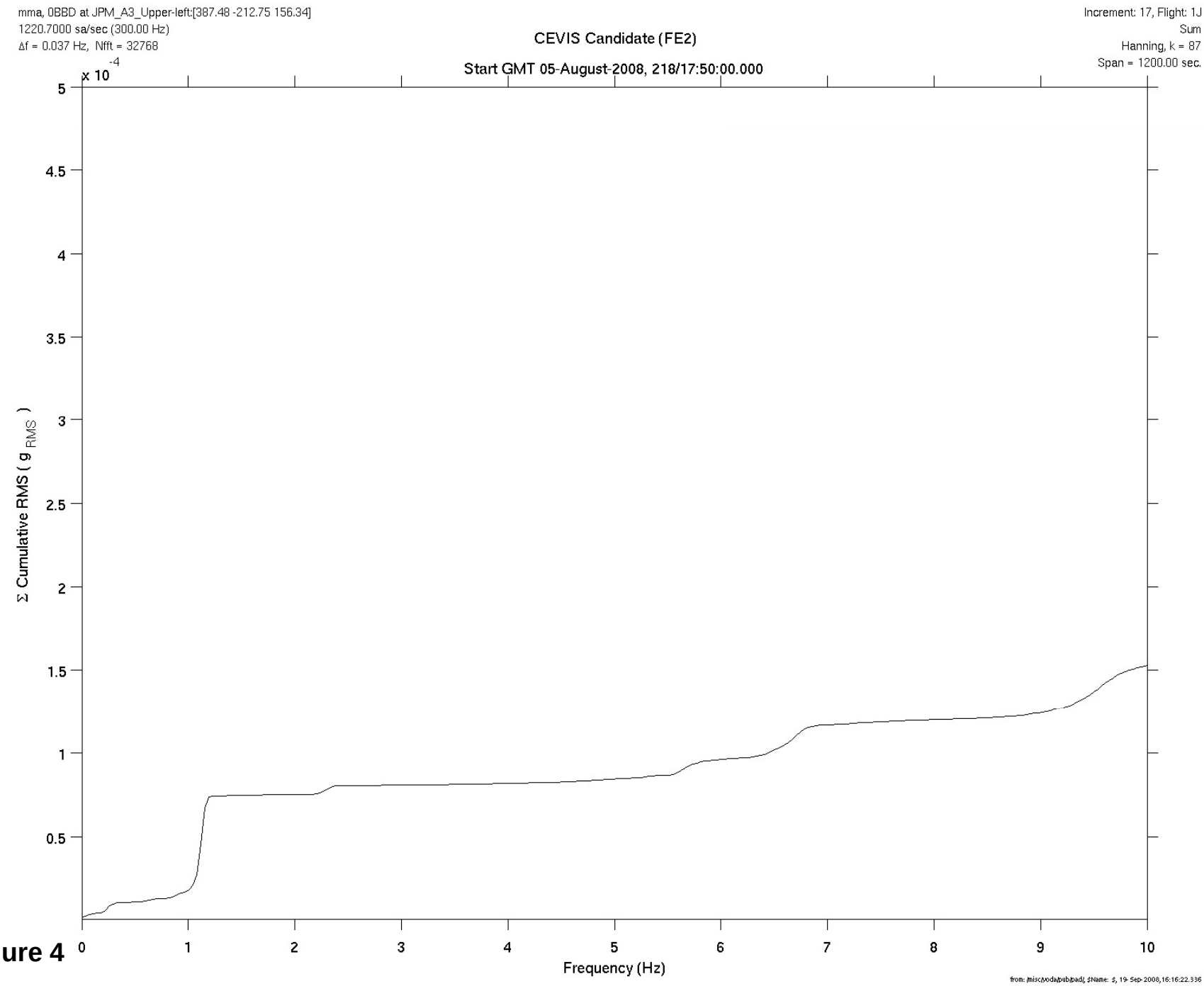
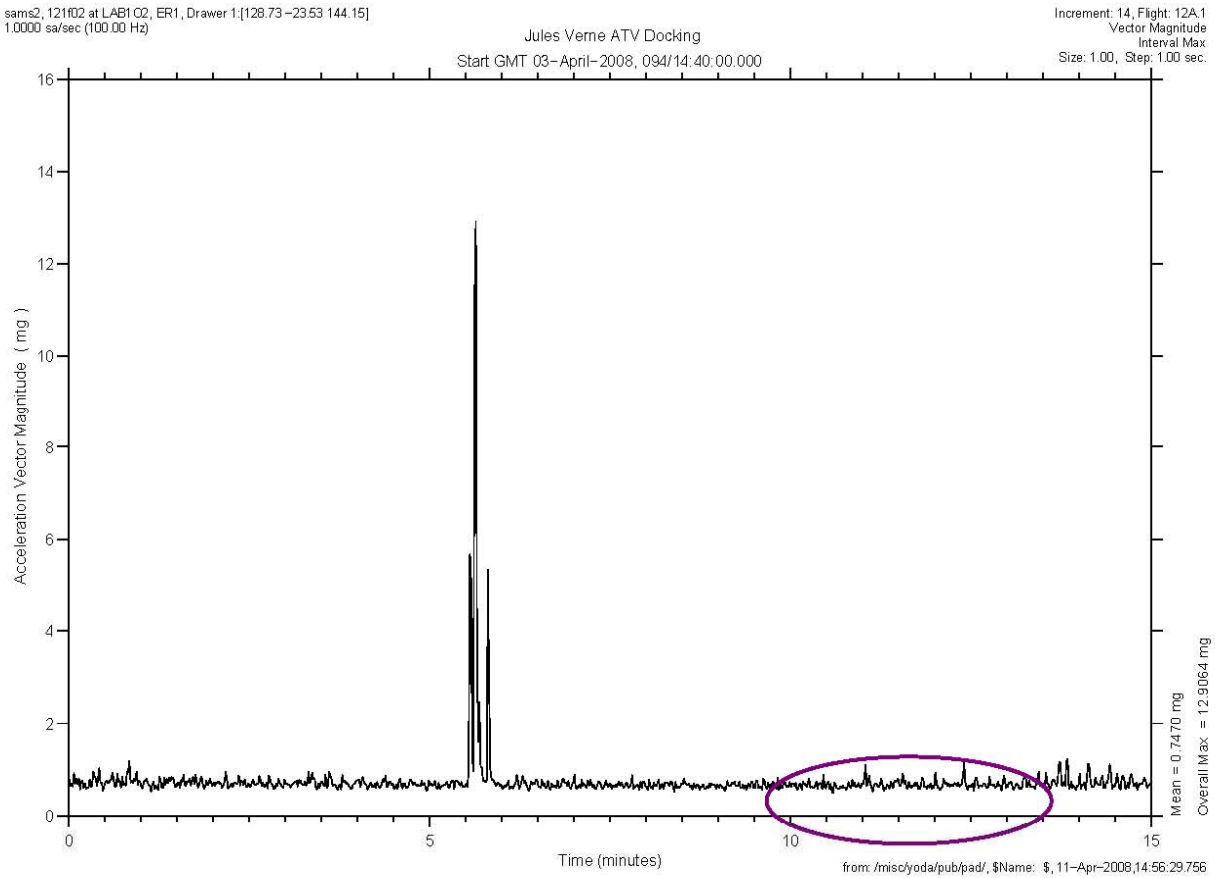

mma, 0BBD at JPM_A3_Upper-left:[387.48 -212.75 156.34]
1220.7000 sa/sec (300.00 Hz)
Δf = 0.037 Hz, Nfft = 32768
CEVIS Candidate (FE2)
Start GMT 05-August-2008, 218/17:50:00.000
Increment: 17, Flight: 1J
Sum
Hanning, k = 87
Span = 1200.00 sec.
x 10^-4
Σ Cumulative RMS (g RMS)
Frequency (Hz)
0
1
2
3
4
5
6
7
8
9
10
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
from: /misc/xoda/pub/pad/, $Name: $, 19-Sep-2008,16:16:22.336

Figure 4

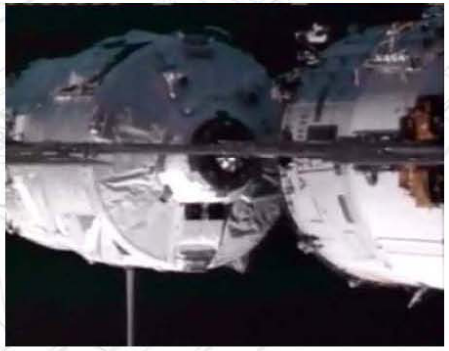
Jules Verne ATV Docking
QUANTIFY



Description	
Sensor	121f02 250.0 sa/sec (100.00 Hz)
Location	LAB1O2, ER1, Drawer 1
Inc/Flight	Increment: 16, Flight: S15
Plot Type	spectrogram

NOTES:

- The ATV's initial contact with ISS occurs at approximately 6 minutes into the interval max plot.
- Peak magnitude of initial contact as measured by 121f02 was12.9 mg.
- Unlike shuttle dockings, the driving of the latches is not readily apparent in these plots. The oval calls out the time period where the driving of the latches occurred.



ATV Docking (Image from ESA Website)

Regime:	Vibratory
Category:	Vehicle
Source:	ATV Docking

Microgravity Science Division

Glenn Research Center

Figure 5

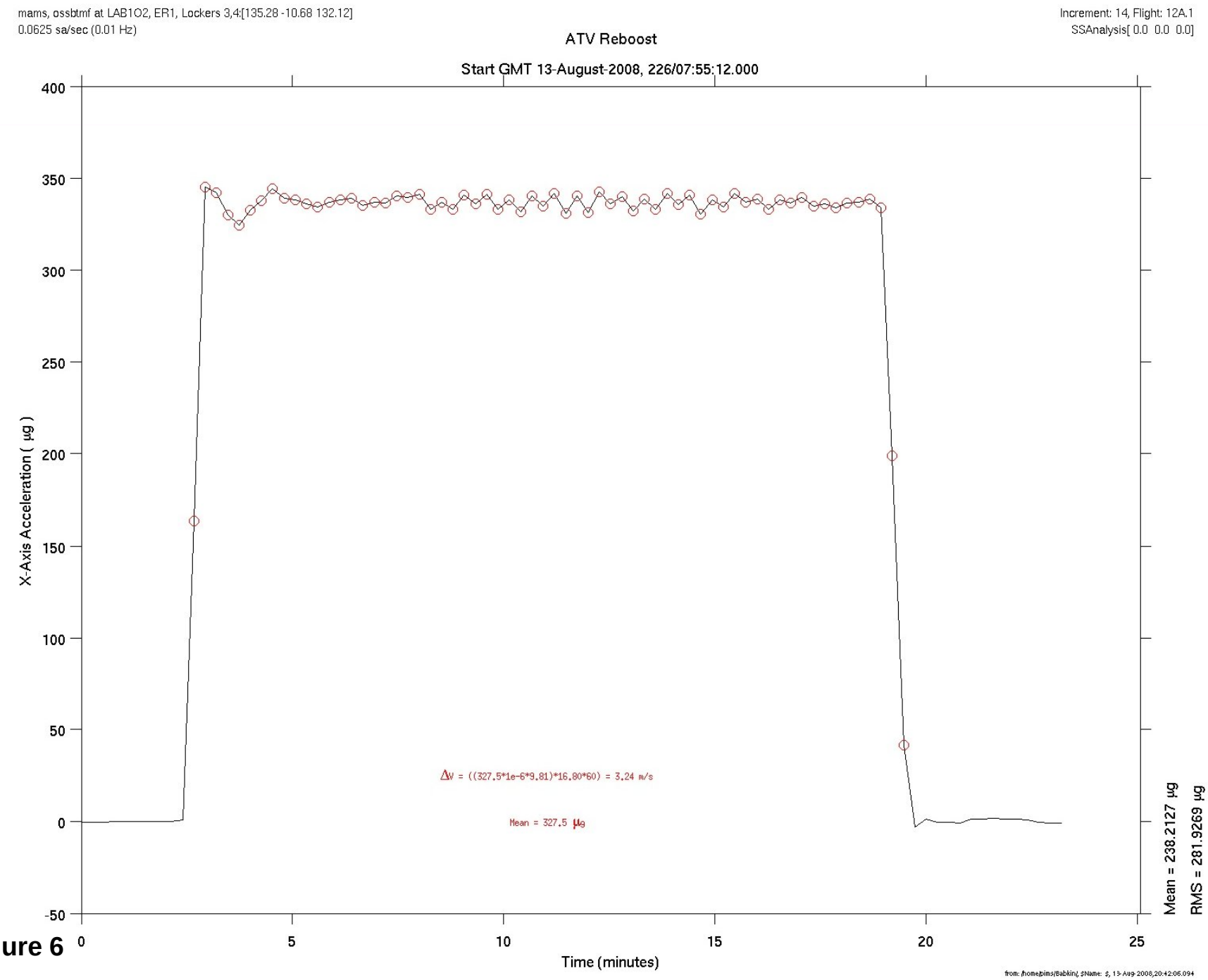
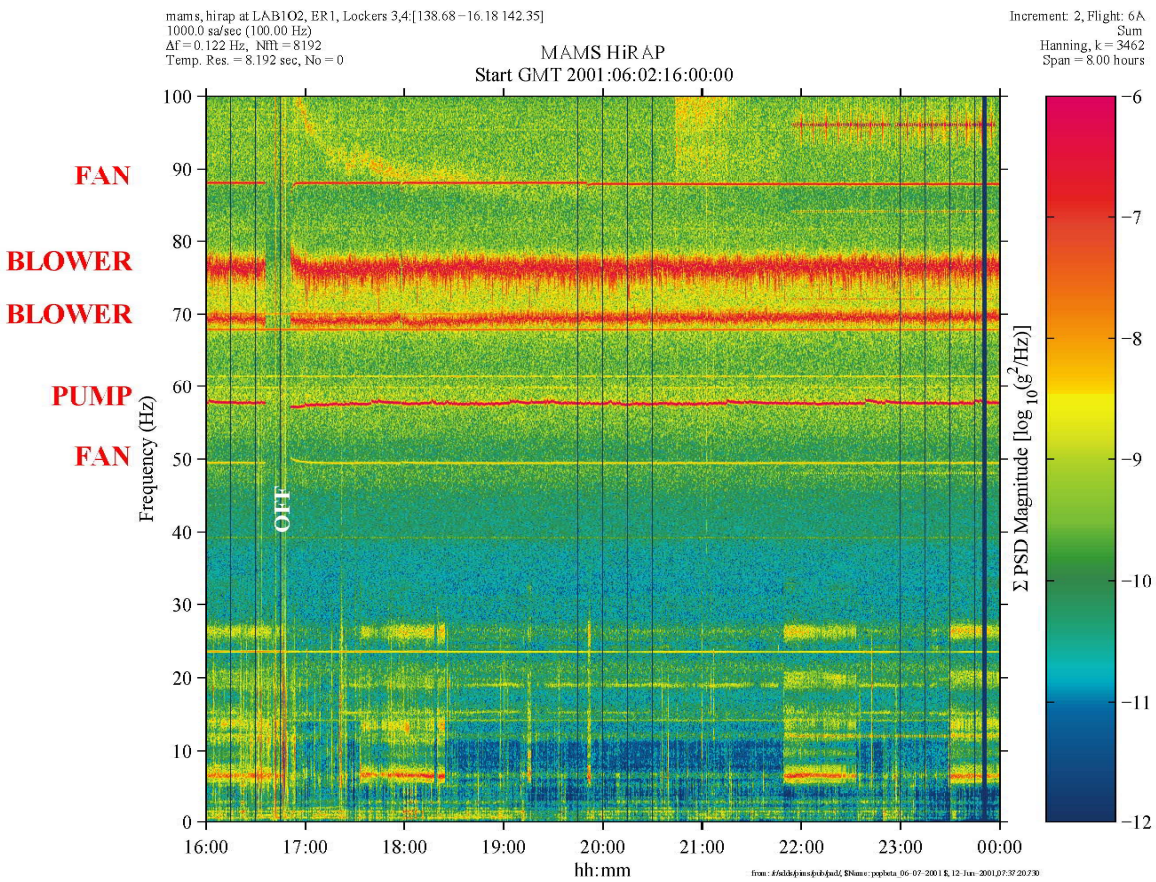

mams, ossbtmf at LAB1O2, ER1, Lockers 3,4:[135.28 -10.68 132.12]
0.0625 sa/sec (0.01 Hz)
Increment: 14, Flight: 12A.1
SSAnalysis[0.0 0.0 0.0]
ATV Reboost
Start GMT 13-August-2008, 226/07:55:12.000
X-Axis Acceleration (µg)
Time (minutes)
ΔV = ((327.5*1e-6*9.81)*16.80*60) = 3.24 m/s
Mean = 327.5 µg
Mean = 238.2127 µg
RMS = 281.9269 µg
from: /home/pims/Babkin/, $Name: $, 13-Aug-2008,20:42:06.094

Figure 6

ADVanced AStroCulture (ADVASC) Experiment Equipment Qualify



Data Description	
Sensor	HiRAP 1000.0 sa/sec (100.00 Hz)
Location	LAB1O2, ER1, Lockers 3,4
Inc/Flight	Increment: 2, Flight: 6A
Plot Type	spectrogram

Notes:

- ADVASC experiment equipment*:
  - **pump** – narrowband signal centered at about 53.5 Hz
  - **2 fans** – narrowband signals centered at about 48 and 88 Hz.
  - **2 blowers** – broadband signals centered at about 72 and 78 Hz

* as confirmed by ADVASC team at University of Wisconsin

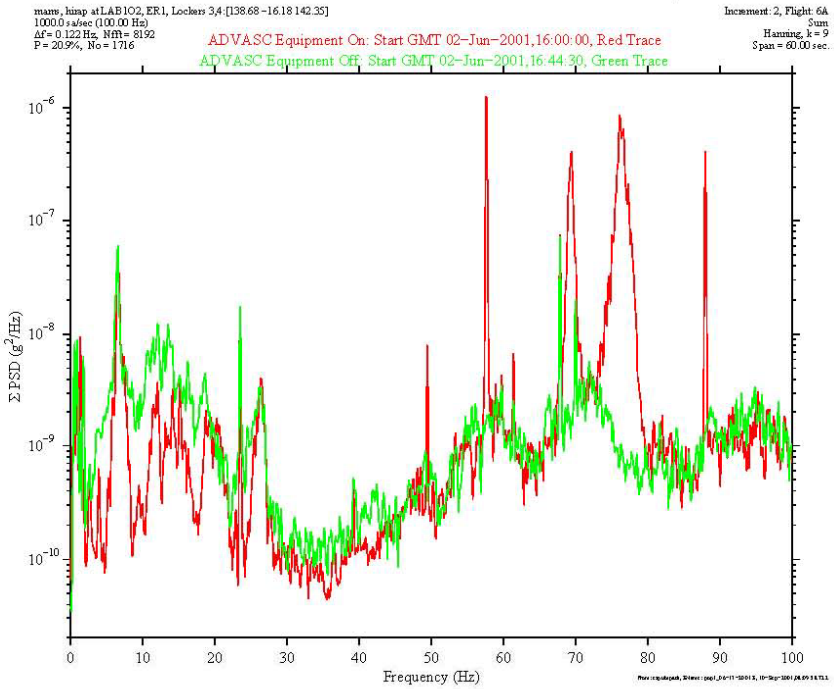
Regime:	Vibratory
Category:	Experiment Equipment
Source:	ADVanced AStroCulture (ADVASC)

Microgravity Science Division

Glenn Research Center

Figure 7

ADVanced AStroCulture (ADVASC) Experiment Equipment Quantify



Data Description	
Sensor	HiRAP 1000.0 sa/sec (100.00 Hz)
Location	LAB1O2, ER1, Lockers 3,4
Inc/Flight	Increment: 2, Flight: 6A
Plot Type	spectrogram

Notes:

Frequency (Hz)			ADVASC Disturbance	RMS Acceleration (μg_{RMS})	
HiRAP Measured		Expected		ADVASC ON	ADVASC OFF
Center	Range				
49.4	49.1 - 49.7	48.3	2,900 RPM fan	41.6	19.0
57.6	57.3 - 57.9	52 - 55	air pump	568.9	31.4
69.5	68.1 - 70.9	71.7	4,300 RPM blower	512.9	97.4
76.5	73.0 - 79.7	78.3	4,700 RPM blower	940.9	86.9
88.0	87.6 - 88.4	88.3	5,300 RPM CPU fan	284.3	32.8

Microgravity Science Division

Glenn Research Center

Regime:	Vibratory
Category:	Experiment Equipment
Source:	ADVanced AStroCulture (ADVASC)

Figure 8

Summary

- PIMS receives, processes, and stores acceleration data for NASA's SAMS-II and MAMS acceleration measurement systems and for JAXA's MMA system
- Acceleration data archives are available for each system in support of microgravity research and the ISS vehicle
  - Simple web-based access to acceleration data
  - standardize formats for data storage to maximize access to all existing acceleration data by international partners
- Handbook pages provide summary information for document acceleration environment disturbers

Backup Charts

- **PIMS Data Analysis Techniques**
- **Useful PIMS web pages**

PIMS Data Analysis Techniques

Display Format	Regime(s)	Notes
Acceleration versus Time	Transient, Quasi-Steady, Vibratory	• precise accounting of measured data with respect to time; best temporal resolution
Interval Min/Max Acceleration versus Time	Vibratory, Quasi-Steady	• displays upper and lower bounds of peak-to-peak excursions of measured data • good display approximation for time histories on output devices with resolution insufficient to display all data in time frame of interest
Interval Average Acceleration versus Time	Vibratory, Quasi-Steady	• provides a measure of net acceleration of duration greater than or equal to interval parameter
Interval RMS Acceleration versus Time	Vibratory	• provides a measure of peak amplitude
Trimmed Mean Filtered Acceleration versus Time	Quasi-Steady	• removes infrequent, large amplitude outlier data
Quasi-Steady Mapped Acceleration versus Time	Quasi-Steady	• use rigid body assumption and vehicle rates and angles to compute acceleration at any point in the vehicle
Quasi-Steady Three-Dimensional Histogram (QTH)	Quasi-Steady	• summarize acceleration magnitude and direction for a long period of time • indication of acceleration "center-of-time" via projections onto three orthogonal planes

PIMS Data Analysis Techniques

Display Format	Regime(s)	Notes
Power Spectral Density (PSD) versus Frequency	Vibratory	• displays distribution of power with respect to frequency
Spectrogram (PSD versus Frequency versus Time)	Vibratory	• displays power spectral density variations with time • identify structure and boundaries in time and frequency
Cumulative RMS Acceleration versus Frequency	Vibratory	• quantifies RMS contribution at and below a given frequency
Frequency Band(s) RMS Acceleration versus Time	Vibratory	• quantify RMS contribution over selected frequency band(s) as a function of time
RMS Acceleration versus One-Third Frequency Bands	Vibratory	• quantify RMS contribution over proportional frequency bands • compare measured data to ISS vibratory requirements
Principal Component Spectral Analysis (PCSA)	Vibratory	• summarize magnitude and frequency excursions for key spectral contributors over a long period of time • results typically have finer frequency resolution and high PSD magnitude resolution relative to a spectrogram at the expense of poor temporal resolution

Principal Investigator Microgravity Services

Acceleration Measurement WWW links

- Principal Investigator Microgravity Services ISS Home Page
  - http://pims.grc.nasa.gov

Microgravity Environment References

- Handbook Pages
  - http://pims.grc.nasa.gov/pimsdb/index.cfm?method=Handbook.pimslist
  - Compilation of major ISS microgravity environment disturbances
- Acceleration Data Analysis and Presentation Techniques TM
  - Detailed description of acceleration data analysis techniques
  - http:// www.grc.nasa.gov/WWW/MMAP/PIMS/HTMLS/adapt.html