Appendix A

Highlights of the Microgravity Environment of the NASA Space Shuttle Orbiters

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MICROGRAVITY ENVIRONMENT

The microgravity environment of all Earth-orbiting laboratories are similar in that they are composed of the same basic contributors.

Gravity gradient effects, atmospheric drag, and rotational motion all contribute to relative motions between free-floating particles (or experiment samples) and a fixed reference frame. Such motion is typically viewed as quasi-steady accelerations.

On-going life support, station-keeping, and experiment operations contribute to transient disturbances and a background vibratory (oscillatory) environment in the frequency range of 0.01 Hz up to at least 300 Hz.

Microgravity Environment Description Handbook

- This handbook is a compilation of our knowledge (through April 1997) of the microgravity environment of various payload carriers on the Orbiters and of Mir.
  - NASA TM-107486, July 1997
  - http://www.grc.nasa.gov/WWW/MMAP/PIMS/HTMLS/Micro-descpt.html

Mission-Specific Descriptions

- Mission-specific environment characterizations contained within mission summary reports; consult reference list

Quasi-Steady Environment

- **Quasi-steady effects measured by OARE on Columbia**
  - **aerodynamic drag, gravity gradient, and vehicle rotation**
  - **effects of crew activity**
  - **effects of thruster firings, venting, cabin depressurization**

  - **Figures A-1, A-2**

Oscillatory Sources

- **Orbiter Structural Modes**
  - **differ slightly among missions and Orbiters**
  - **typically 2.4, 3.5-3.6, 4.7-4.8, 5.2, and 7.4 Hz**
  - **tend to increase in amplitude with increased crew activity**
- **Crew Exercise**
  - **Ergometer: 2-3 Hz legs pedaling, 1-1.5 Hz body rocking**
  - **Treadmill: 1-2 Hz footfall frequency, 0.5-1Hz body rocking**
  - **Both types also have harmonics**
- **Ku-band Antenna Dither**
  - **dithers at ~17.03 Hz**
  - **intensity varies with time (periodic)**
    - 40-120 μg_{RMS} during STS-65 (IML-2)
    - 50-300 μg_{RMS} during STS-87 (USMP-4)
      - for USMP-4, about 10 μg_{RMS} when Ku dither deactivated

Oscillatory Sources, cont.

- **SAMS Optical Disk Drives (last used on Mir and STS-79)**
  - **just under 20 Hz but very weak**
- **Fans**
  - **Glovebox fans on Orbiters: for different models of GBX, have seen vibrations at 20, 38, 43, 48, 53, 63.5, 66.5, 98.6, and 127 Hz**
- **Compressors**
  - **LSLE R/F: 20-22 Hz, cycles on/off throughout missions seen on Orbiters**
- **Pumps**
  - **TEMPUS water pump: nominal 4,800 rpm (80 Hz) on STS-65, 2,000-2,600 rpm (41.7-43.3 Hz) on STS-83, STS-94**
    - isolation mountings used for MSL-1 reduced accelerations by at least 3,500 μg_{RMS}

Oscillatory Sources, cont.

- **Crew experiment operations**
  - **Crew member swung bag of liquid sample in circles to separate air bubbles from liquid**
  - **Eight rotations confirmed by downlink video**
- **Unknown Sources**
  - **Continuous; constant frequency; variable frequency**
  - **Effects seen throughout frequency range available with current accelerometer systems: 0.01 to 250 Hz**
- **<u>Figures A-3, A-4</u>**

Transient Disturbances

- **Thruster Systems**
  - **Orbiter Reaction Control System (RCS) Thrusters**
    - firings produce dc-offset, followed by a damped ringing behavior
    - OMS firings impart 20-50 milli-g, typically up to 40 seconds duration
    - PRCS firings impart tens of milli-g, can last up to tens of seconds
    - VRCS firings impart tenths of milli-g, usually lasting fraction of a second
  - **Orbiter Flight Control System (FCS) Checkout**
    - vents exhaust gas (0-30 lb. thrust) at 1 to 1.5 second intervals
    - increased use of VRCS jets for attitude maintenance
    - impulse train causes an oscillatory signal

- **Figures A-5, A-6**

Transient Disturbances, cont.

- **Experiment Operations**
  - **CM-1 setup on STS-94 (mallet impacts)**
    - hammering at Spacelab Rack 8, SAMS sensor at Rack 12
    - series of 4 hits, reaching 2 milli-g magnitude, directionality evident
    - damped ringing observed after each impact
  - **MEPHISTO latch release (USMP-2)**
    - performed to introduce localized disturbance to experiment
    - characteristic behavior most noticeable on Orbiter Z-axis
  - **Orbiter Cargo Bay Radiator Latch Release**
- **Crew Movement**
- **Figures A-7, A-8**

References

- DeLombard, R., K. McPherson, K. Hrovat, M. Moskowitz, M.J.B. Rogers, T. Reckart: Microgravity Environment Description Handbook, NASA Technical Memorandum TM-107486, July 1997.
- Hakimzadeh, R., K. Hrovat, K.M. McPherson, M.E. Moskowitz, M.J.B. Rogers: Summary Report of Mission Acceleration Measurements for STS-78, NASA Technical Memorandum TM-107401, January 1997.
- Rogers, M.J.B., R. DeLombard: Summary Report of Mission Acceleration Measurements for STS-73, NASA Technical Memorandum TM-107269, July 1996.
- Rogers, M.J.B., K. Hrovat, K.M. McPherson, M.E. Moskowitz, R. DeLombard: Summary Report of Mission Acceleration Measurements for STS-75, NASA Technical Memorandum TM-107359, November 1996.
- Rogers, M.J.B., M.E. Moskowitz, K. Hrovat, T. Reckart: Summary Report of Mission Acceleration Measurements for STS-79, NASA Contractor Report CR-202325, March 1997.
- Moskowitz, M.E., K. Hrovat, P. Tschen, K. McPherson, M. Nati, T.A. Reckart: Summary Report of Mission Acceleration Measurements for MSL-1, NASA Technical Memorandum TM-1998-206979, May 1998.
- DeLombard, R.; K. McPherson; Moskowitz, M.; and Hrovat, K.: Comparison Tools for Assessing the Microgravity Environment of Missions, Carriers and Conditions, NASA TM-107446, 1997.

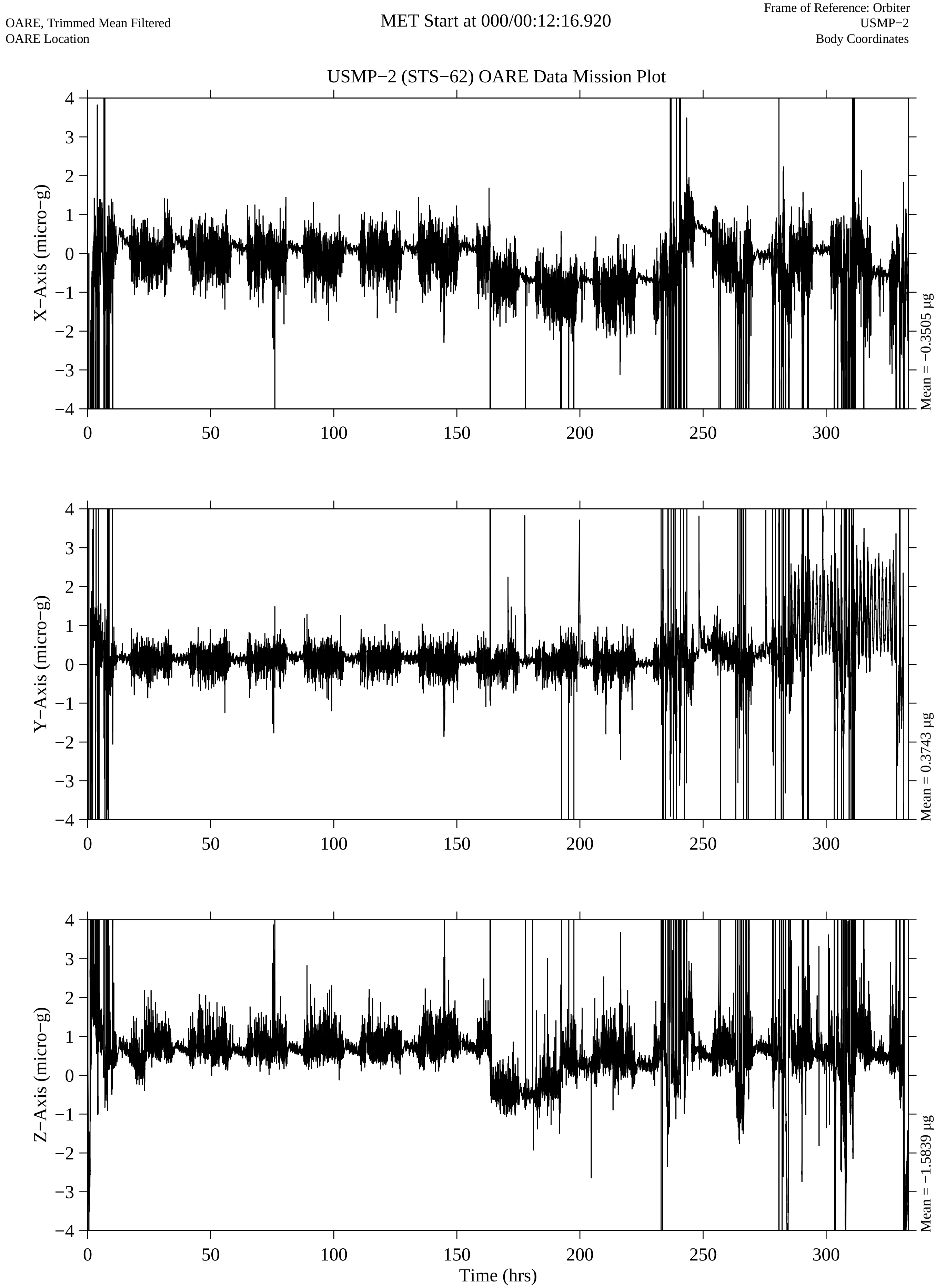

OARE, Trimmed Mean Filtered
OARE Location
MET Start at 000/00:12:16.920
Frame of Reference: Orbiter
USMP−2
Body Coordinates
USMP−2 (STS−62) OARE Data Mission Plot
X−Axis (micro−g)
Mean = −0.3505 μg
Y−Axis (micro−g)
Mean = 0.3743 μg
Z−Axis (micro−g)
Mean = −1.5839 μg
Time (hrs)

Figure A-1

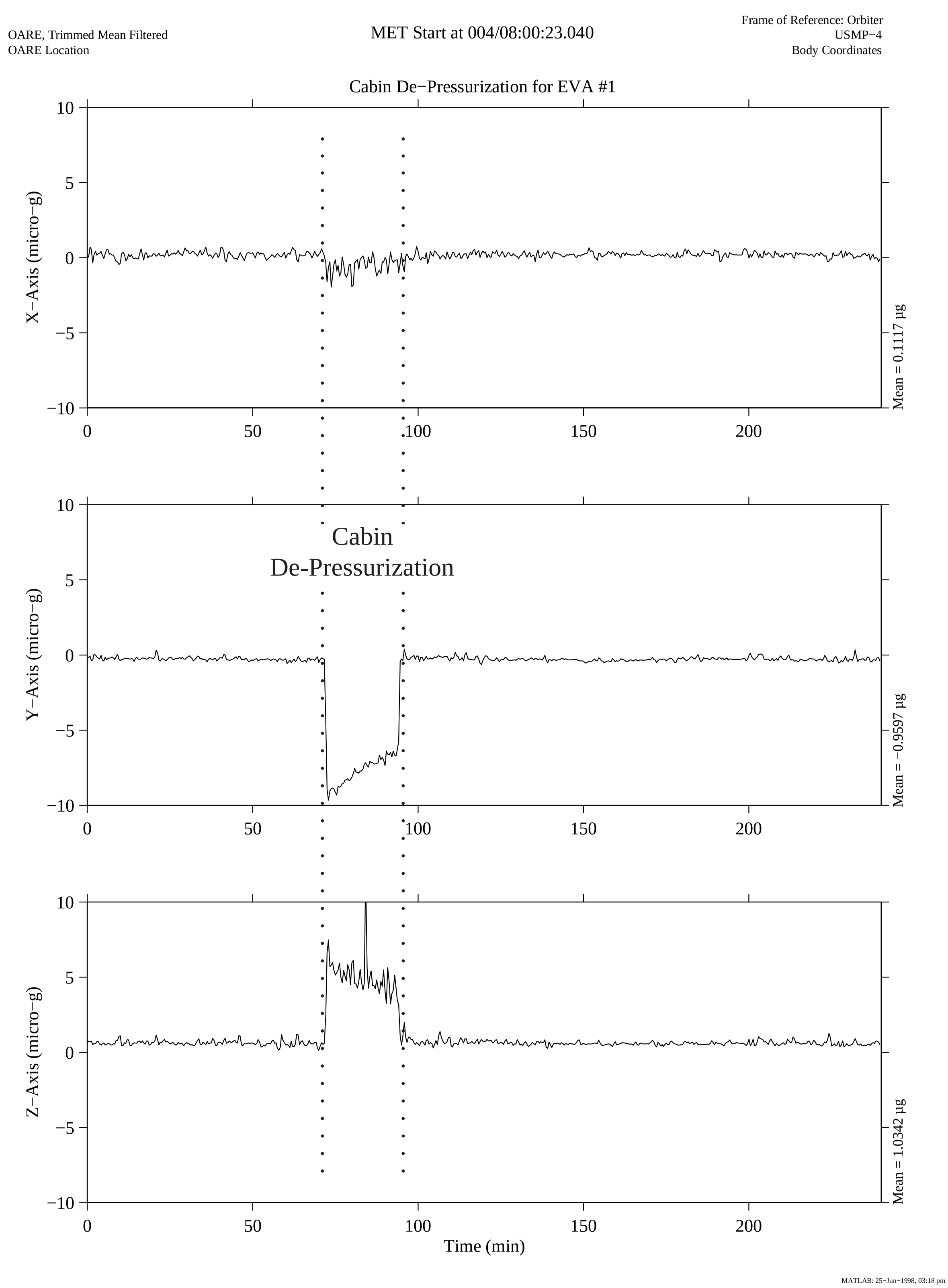
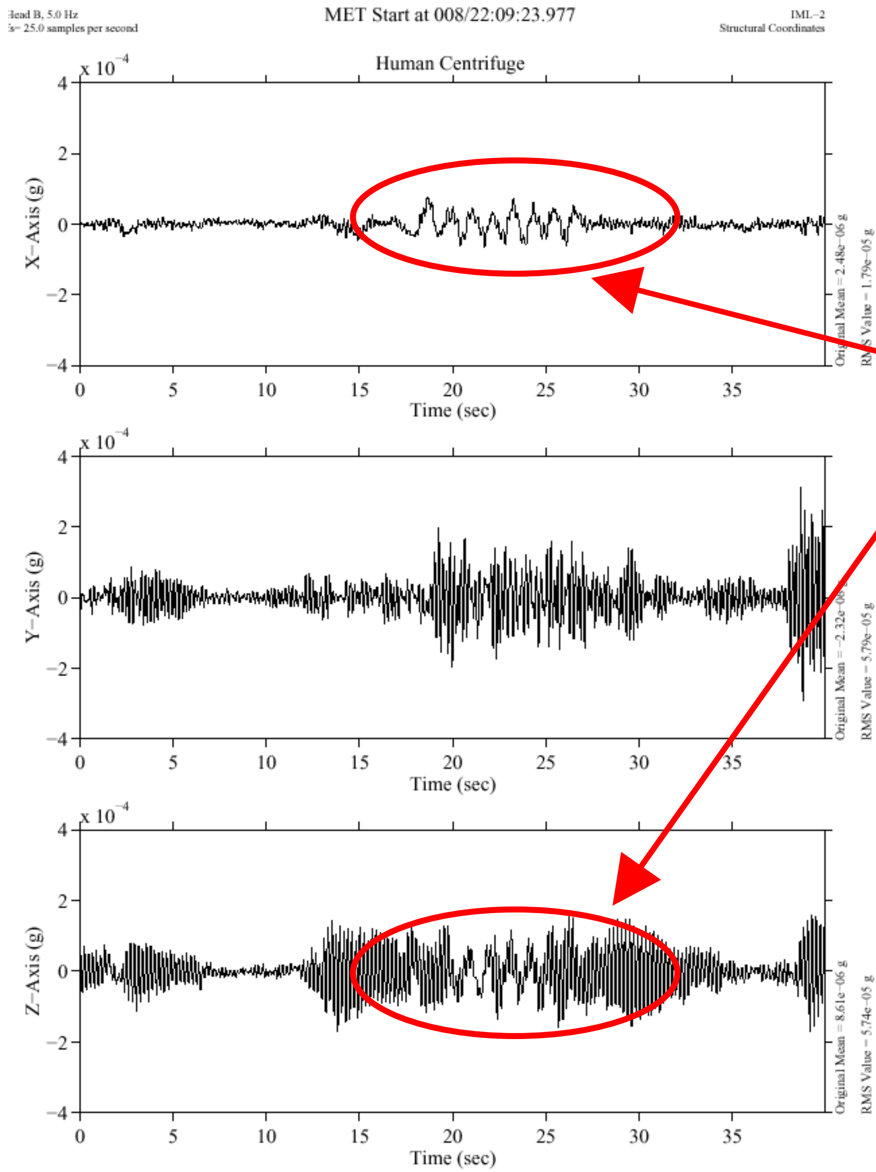

OARE, Trimmed Mean Filtered
OARE Location
MET Start at 004/08:00:23.040
Frame of Reference: Orbiter
USMP−4
Body Coordinates
Cabin De−Pressurization for EVA #1
X−Axis (micro−g)
Mean = 0.1117 μg
Cabin
De-Pressurization
Y−Axis (micro−g)
Mean = −0.9597 μg
Z−Axis (micro−g)
Mean = 1.0342 μg
Time (min)
MATLAB: 25−Jun−1998, 03:18 pm

Figure A-2

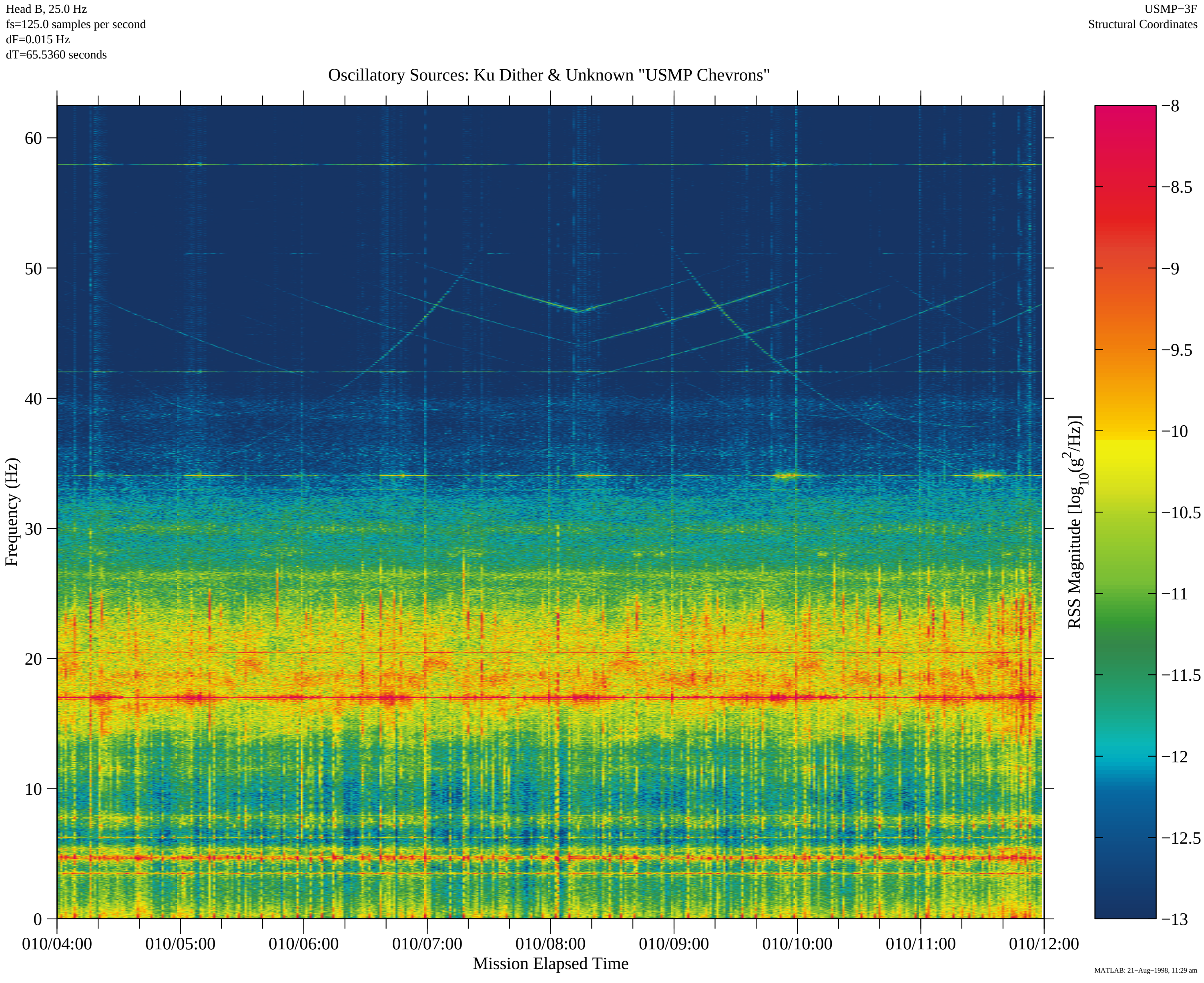
Crew, Experiment Ops, Human Centrifuge



- STS-65, IML-2 Mission
- Part of Bubble, Drop and Particle Unit (BDPU) investigation, video downlink showed crew acting as human centrifuge for one of those liquid-filled, clear intravenous bags.
- He was trying to move all the air to “top” of bag and made ...

... 8 windmill-type cycles with bag in hand.

Figure A-3



Head B, 25.0 Hz
fs=125.0 samples per second
dF=0.015 Hz
dT=65.5360 seconds
USMP−3F
Structural Coordinates
Oscillatory Sources: Ku Dither & Unknown "USMP Chevrons"
Frequency (Hz)
0
10
20
30
40
50
60
010/04:00
010/05:00
010/06:00
010/07:00
010/08:00
010/09:00
010/10:00
010/11:00
010/12:00
Mission Elapsed Time
RSS Magnitude [log10(g2/Hz)]
−8
−8.5
−9
−9.5
−10
−10.5
−11
−11.5
−12
−12.5
−13
MATLAB: 21−Aug−1998, 11:29 am

Figure A-4

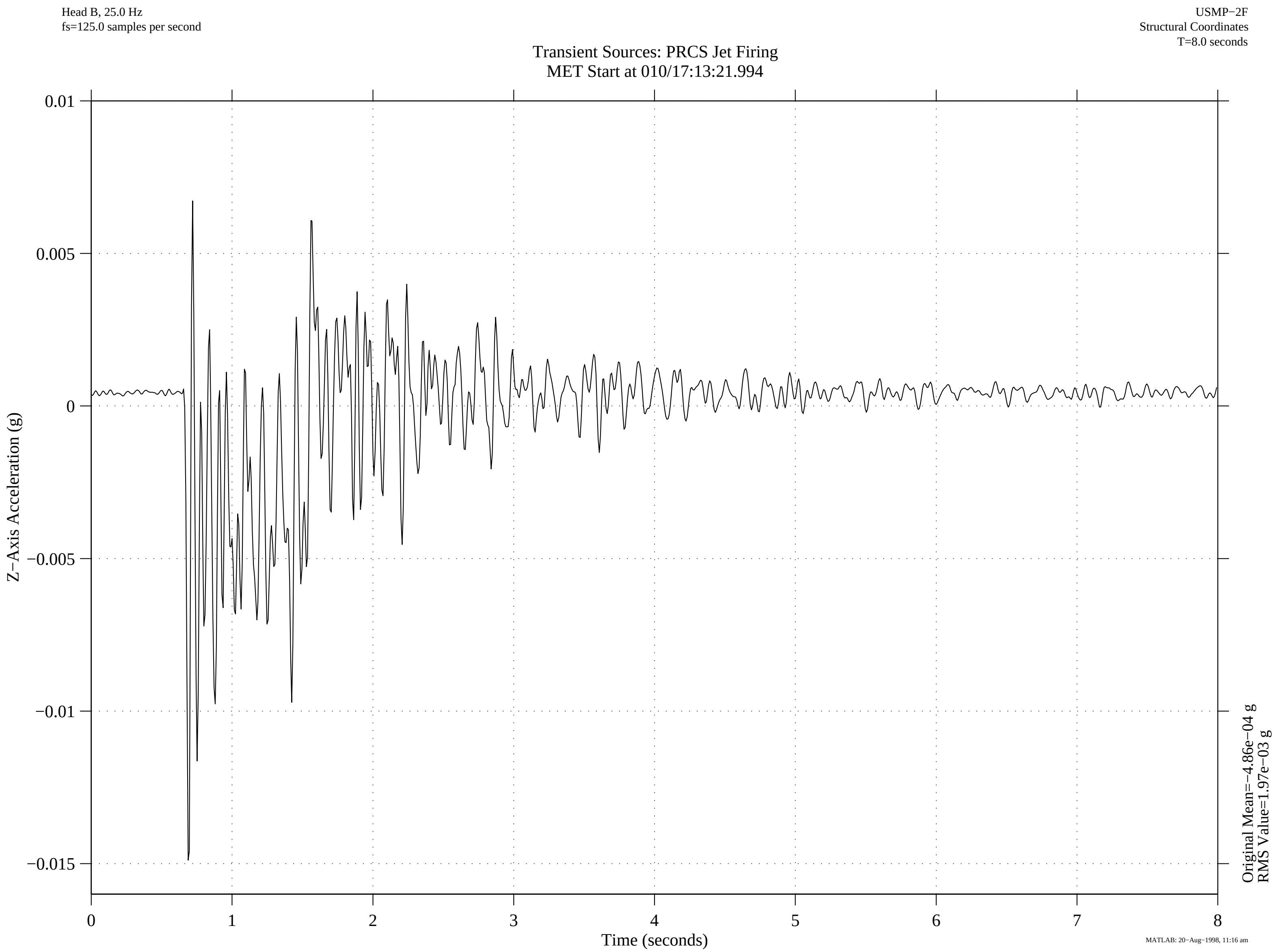

Head B, 25.0 Hz
fs=125.0 samples per second
USMP−2F
Structural Coordinates
T=8.0 seconds
Transient Sources: PRCS Jet Firing
MET Start at 010/17:13:21.994
Z−Axis Acceleration (g)
Time (seconds)
Original Mean=−4.86e−04 g
RMS Value=1.97e−03 g
MATLAB: 20−Aug−1998, 11:16 am

Figure A-5

Vehicle, Thruster Firings

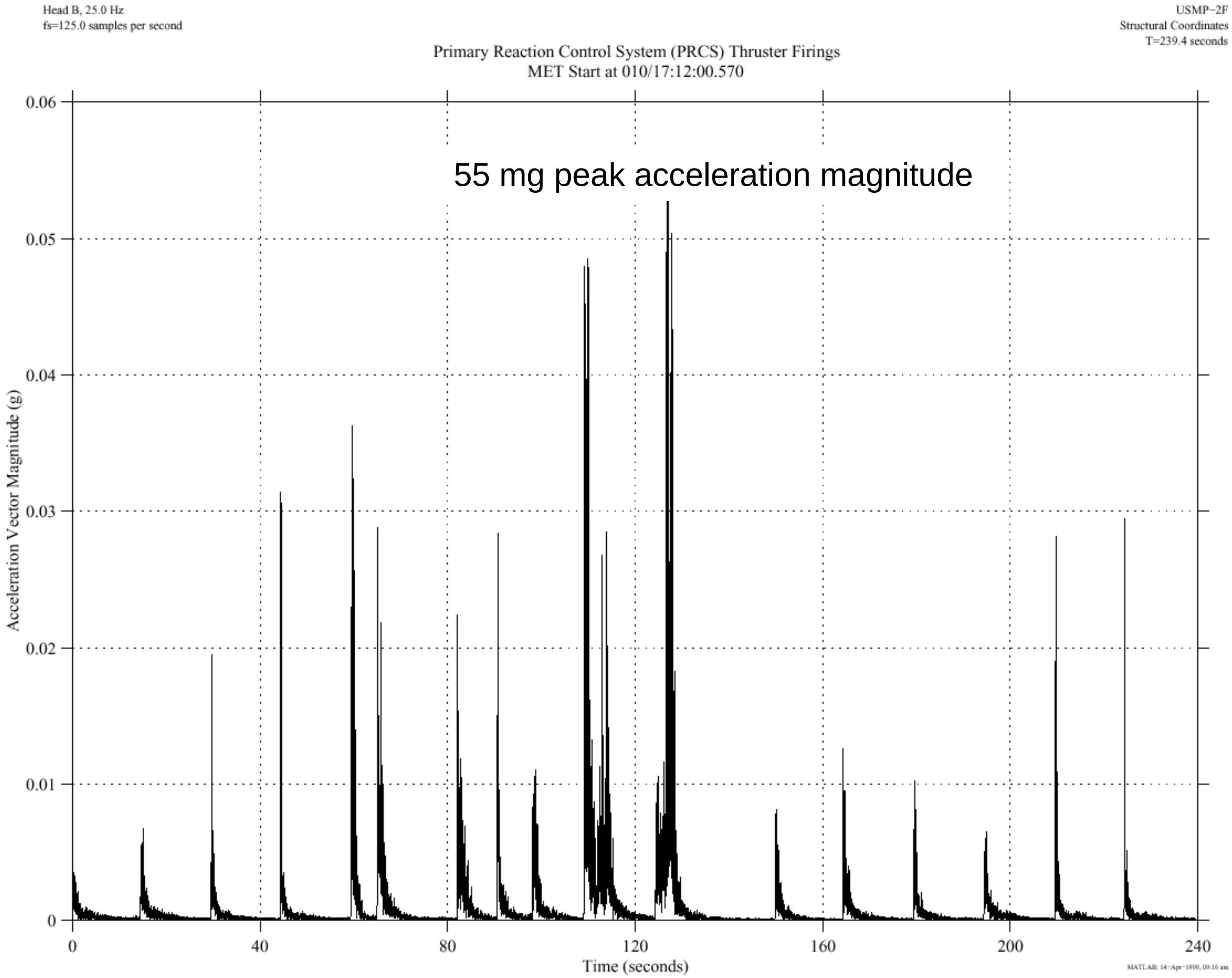
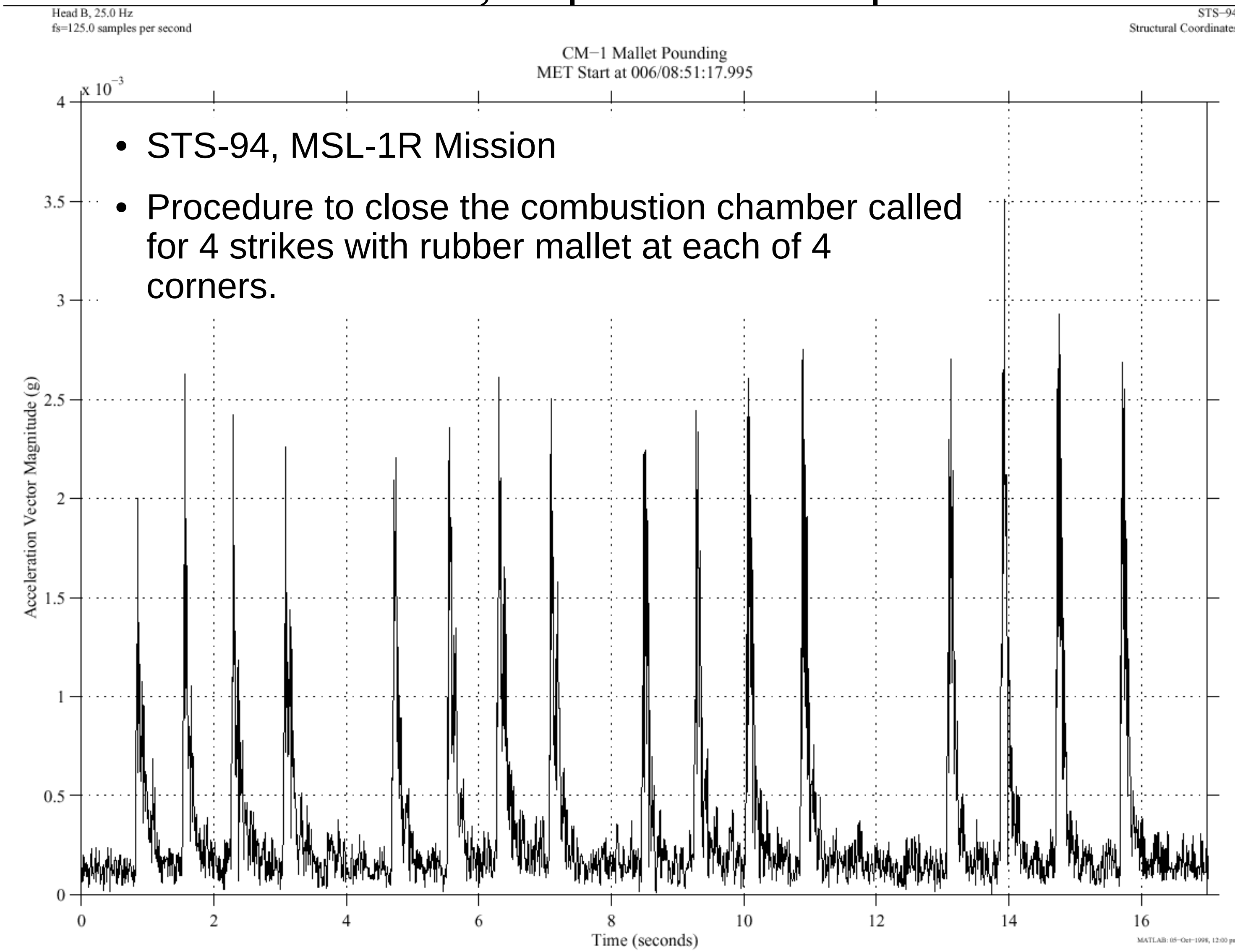


Figure A-6

Crew, Experiment Setup



- STS-94, MSL-1R Mission
- Procedure to close the combustion chamber called for 4 strikes with rubber mallet at each of 4 corners.

Figure A-7

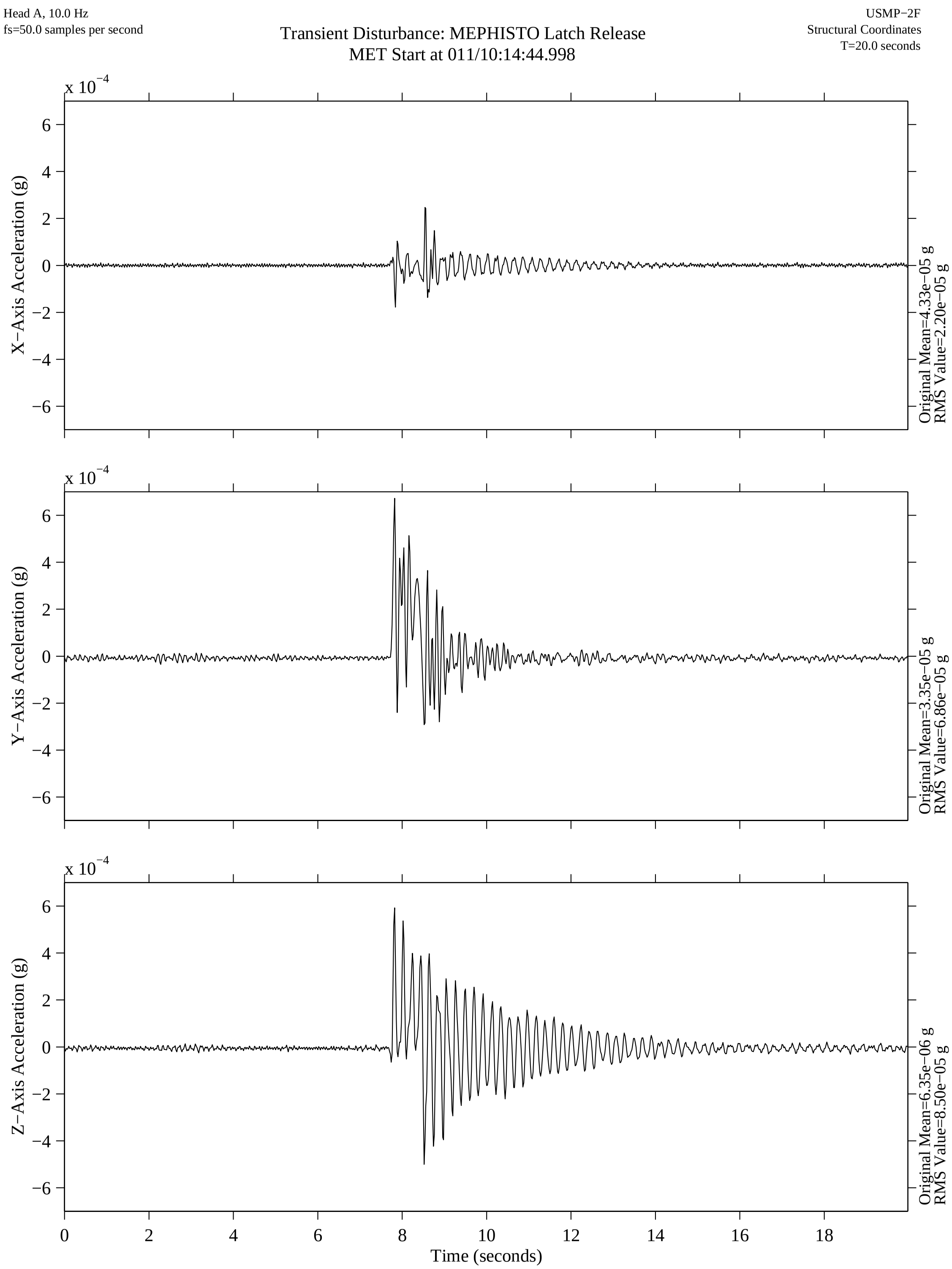

Head A, 10.0 Hz
fs=50.0 samples per second
Transient Disturbance: MEPHISTO Latch Release
MET Start at 011/10:14:44.998
USMP−2F
Structural Coordinates
T=20.0 seconds
x 10^−4
X−Axis Acceleration (g)
Original Mean=4.33e−05 g
RMS Value=2.20e−05 g
Y−Axis Acceleration (g)
Original Mean=3.35e−05 g
RMS Value=6.86e−05 g
Z−Axis Acceleration (g)
Original Mean=6.35e−06 g
RMS Value=8.50e−05 g
Time (seconds)
MATLAB: 20−Aug−1998, 11:25 am

Figure A-8