Section 12

Highlights of the Microgravity Environment of the NASA Space Shuttle Orbiters and Mir Space Station

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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 0.1 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.lerc.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 12-1, 12-2**
- **Modeling of Mir quasi-steady environment takes into account drag, gravity gradient, rotation**
  - **Sazonov, Komarov, Polezhaev, Nikitin, Ermakov, Stazhkov, Zykov, Ryaboukha, Acevedo, Liberman: "Microaccelerations on Board the Mir Orbital Station and Quick Analysis of the Gravitational Sensitivity of Convective Heat/Mass Transfer Processes," MGMG 16, May 1997.**
  - **Belyaev, Zykov, Ryabukha, Sazonov, Sarychev, Stazhkov: "Computer Simulation and Measurement of Microaccelerations On the Mir Orbital Station," Fluid Dynamics, Vol. 29, No. 5, 1994.**
  - **Figure 12-3**

Oscillatory Sources

- **Mir Structural Modes**
  - **differ slightly among Mir configurations**
  - **typical in Priroda: 0.5, 0.6, 0.9, 1.1, 1.4, 2.2, 3.6, 5.8, 6.4, 7.5 Hz**
- **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**
- **Orbiter / Mir Structural Modes**
  - **structural modes depend on the size and configurations of the combined vehicle**
  - **structural modes from combined Orbiter & Mir vehicle are different from those of the Orbiter or of Mir alone**

Oscillatory Sources, cont.

- **Crew Exercise**
  - **Ergometer: 2-3 Hz legs pedalling, 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
  - **transmission to Mir when vehicles docked**
    - related to Orbiter resonating at this frequency
- **SAMS Optical Disk Drives (last used on Mir and STS-79)**
  - **just under 20 Hz but very weak**

Oscillatory Sources, cont.

- **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**
  - **multiple life support system fans on Mir around 40 Hz, harmonics at 80 Hz**
- **Compressors**
  - **LSLE R/F: 20-22 Hz, cycles on/off throughout missions seen on Orbiters and transmitted to Mir when docked**
  - **Vozkukh Compressors (BKV-3 dehumidifier, life support) on Mir; evident at 24 Hz with harmonics at 48, 72, 96 Hz**
- **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}
  - **Mir life support vacuum valve pumps operate at 88-92 Hz**

Oscillatory Sources, cont.

- **Unknown Sources**
  - **Continuous; constant frequency; variable frequency**
  - **Effects seen throughout frequency range available with current accelerometer systems: 0.01 to 250 Hz**
- **Mir Gyrodynes**
  - **Gyrodynes operate at 10,000 rpm (166.7 Hz) for attitude maintenance**
  - **Frequency is above SAMS filter cut-off frequency, so measured g-levels appear lower than actual**
  - **Spin up and spin down activities were also observed**

- **Figures 12-4, 12-5**

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
  - **Progress Engine Burn (altitude)**
    - longer duration, lower intensity than Orbiter OMS firing
    - induces a dc-offset, increased ringing/oscillation during event
  - **Mir Maneuvering Thruster (attitude)**
    - imparts an offset on the order of 1-2 milli-g, shorter duration than Progress Engine Firing

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**
  - **Mir / Orbiter Docking & Undocking Transients**
    - docking shows two transient (broad-band) disturbances
      - soft mate and hard mate
    - undocking shows one transient
- **Crew Movement**
- **Figures 12-6, 12-7, 12-8, 12-9**

References

- Belyaev, Zykov, Ryabukha, Sazonov, Sarychev, Stazhkov: Computer Simulation and Measurement of Microaccelerations On the Mir Orbital Station, Fluid Dynamics 29 (1994).
- DeLombard, R., K. Hrovat, M. Moskowitz, K. McPherson: SAMS Acceleration Measurements on Mir from June to November 1995, NASA Technical Memorandum TM-107312, September 1996.
- 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.
- Moskowitz, M.E., K. Hrovat, D. Truong, T. Reckart: SAMS Acceleration Measurements on Mir from March to September 1996, NASA Technical Memorandum TM-107524, August 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.
- Sazonov, Komarov, Polezhaev, Nikitin, Ermakov, Stazhkov, Zykov, Ryaboukha, Acevedo, Liberman: Microaccelerations on Board the Mir Orbital Station and Quick Analysis of the Gravitational Sensitivity of Convective Heat/Mass Transfer Processes, MGMG 16, May 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.

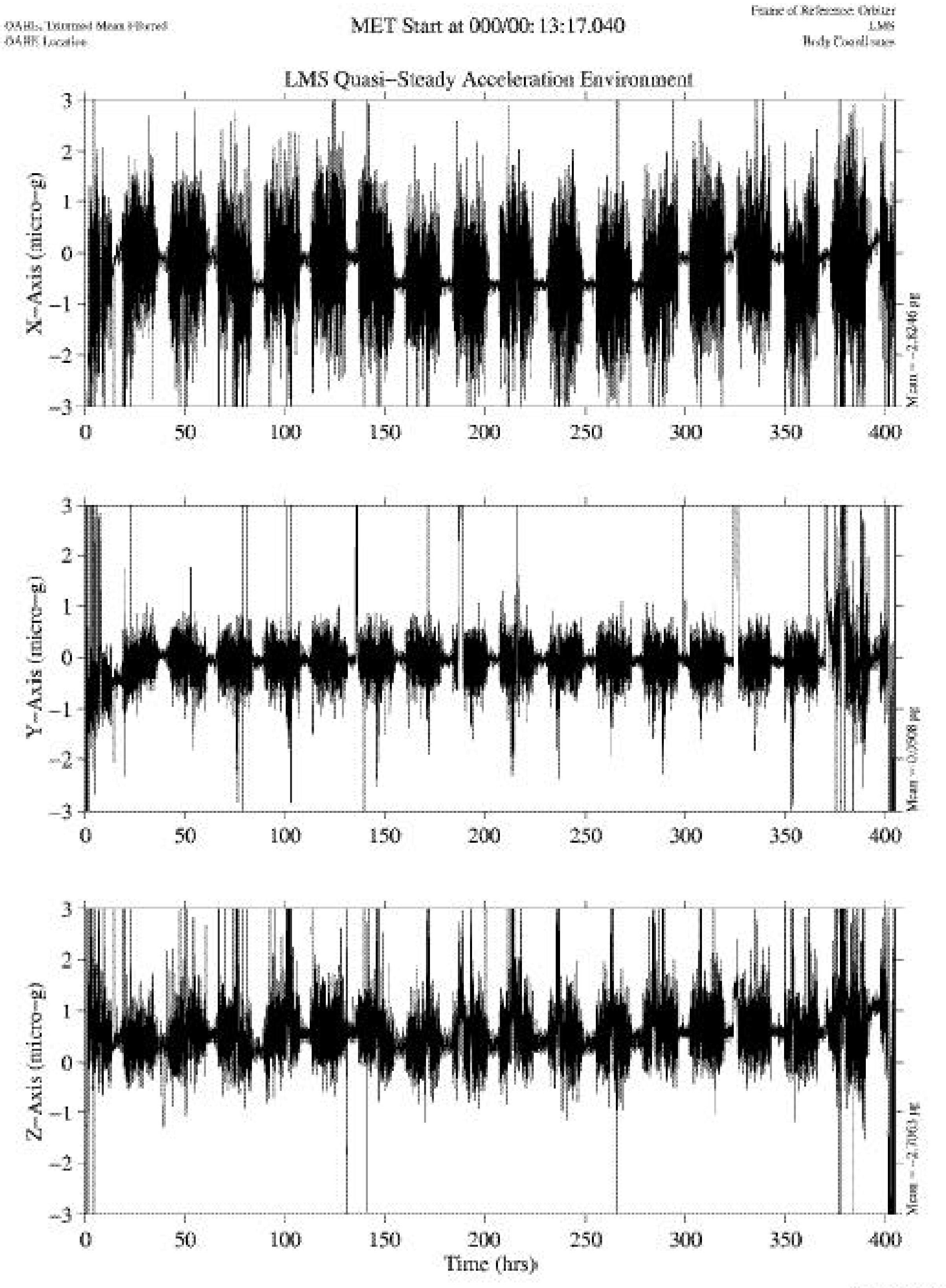

MET Start at 000/00:13:17.040
LMS
LMS Quasi−Steady Acceleration Environment
X−Axis (micro−g)
Y−Axis (micro−g)
Z−Axis (micro−g)
Time (hrs)

Figure 12-1

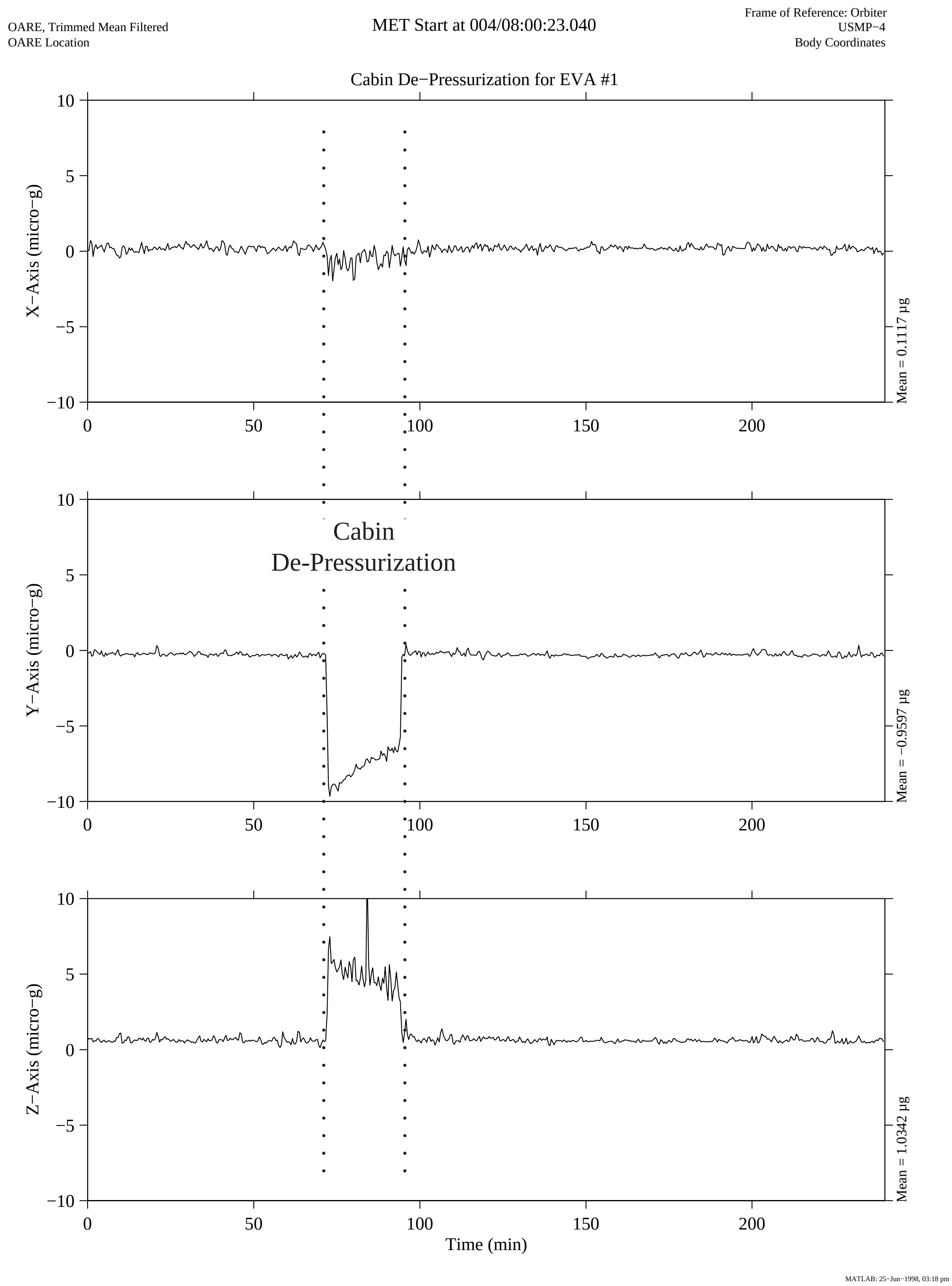
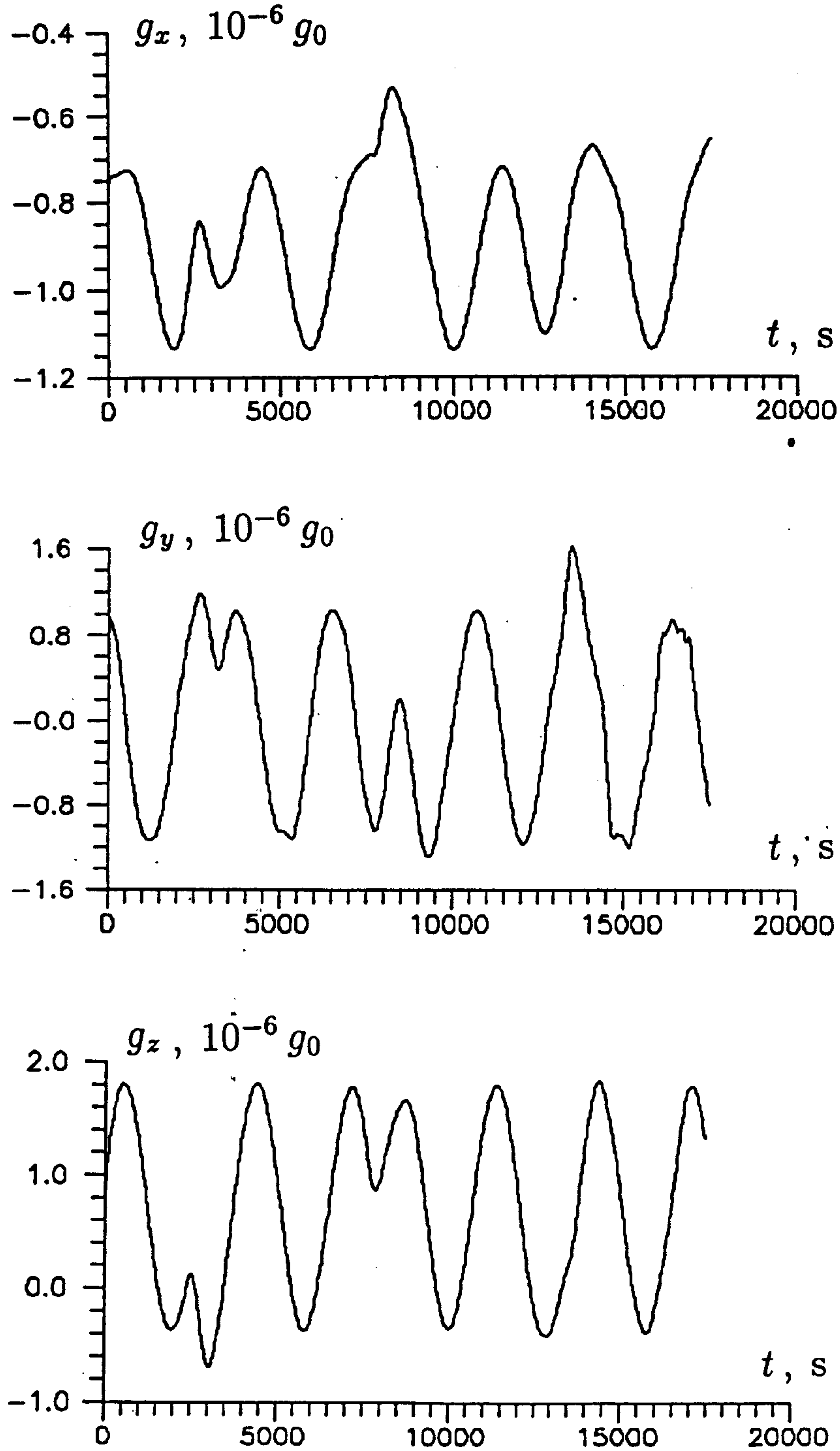
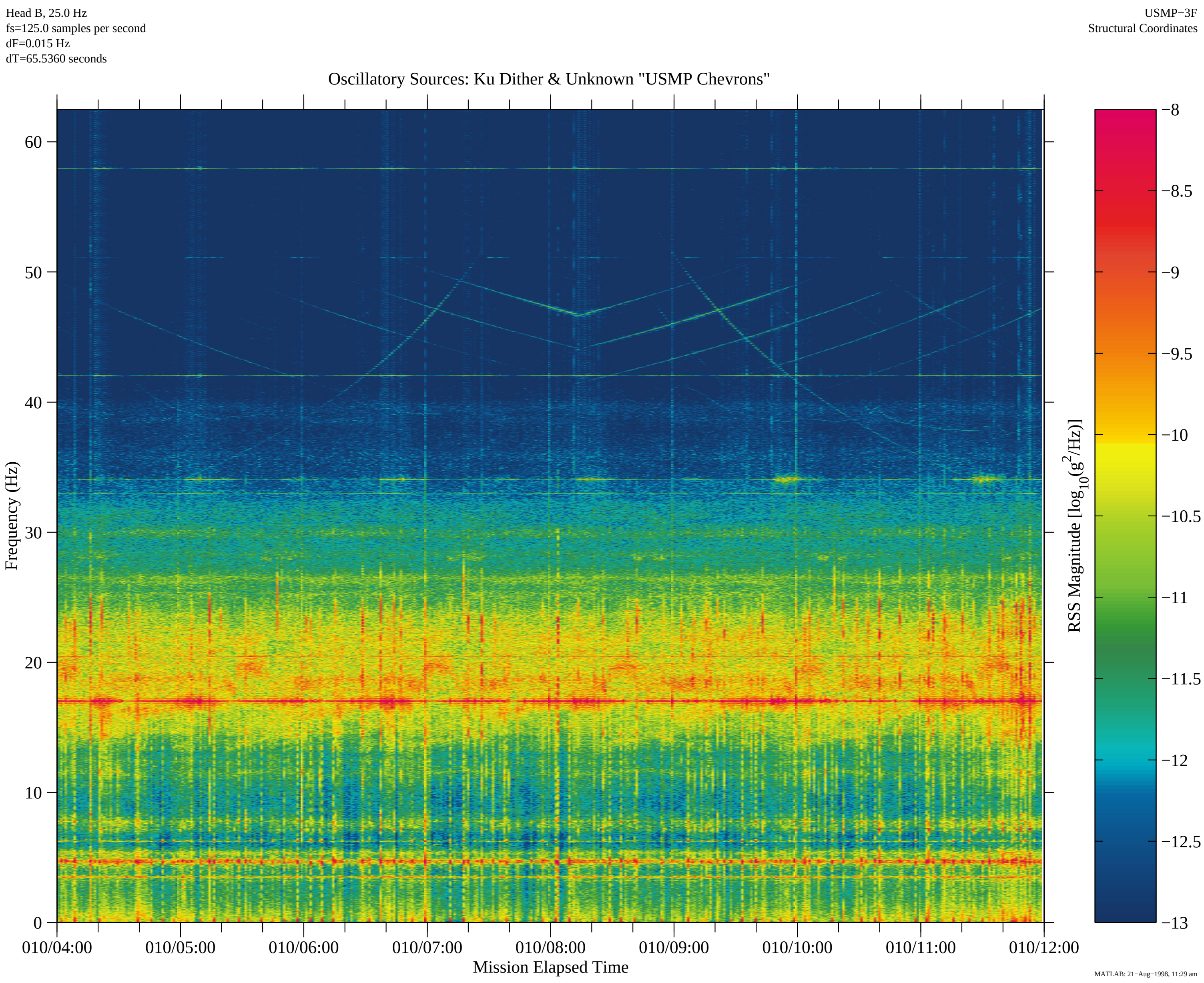

OARE, Trimmed Mean Filtered
OARE Location
MET Start at 004/08:00:23.040
Frame of Reference: Orbiter
USMP−4
Body Coordinates
Cabin De−Pressurization for EVA #1
X−Axis (micro−g)
Mean = 0.1117 µg
Cabin
De-Pressurization
Y−Axis (micro−g)
Mean = −0.9597 µg
Z−Axis (micro−g)
Mean = 1.0342 µg
Time (min)
MATLAB: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

Figure 12-2



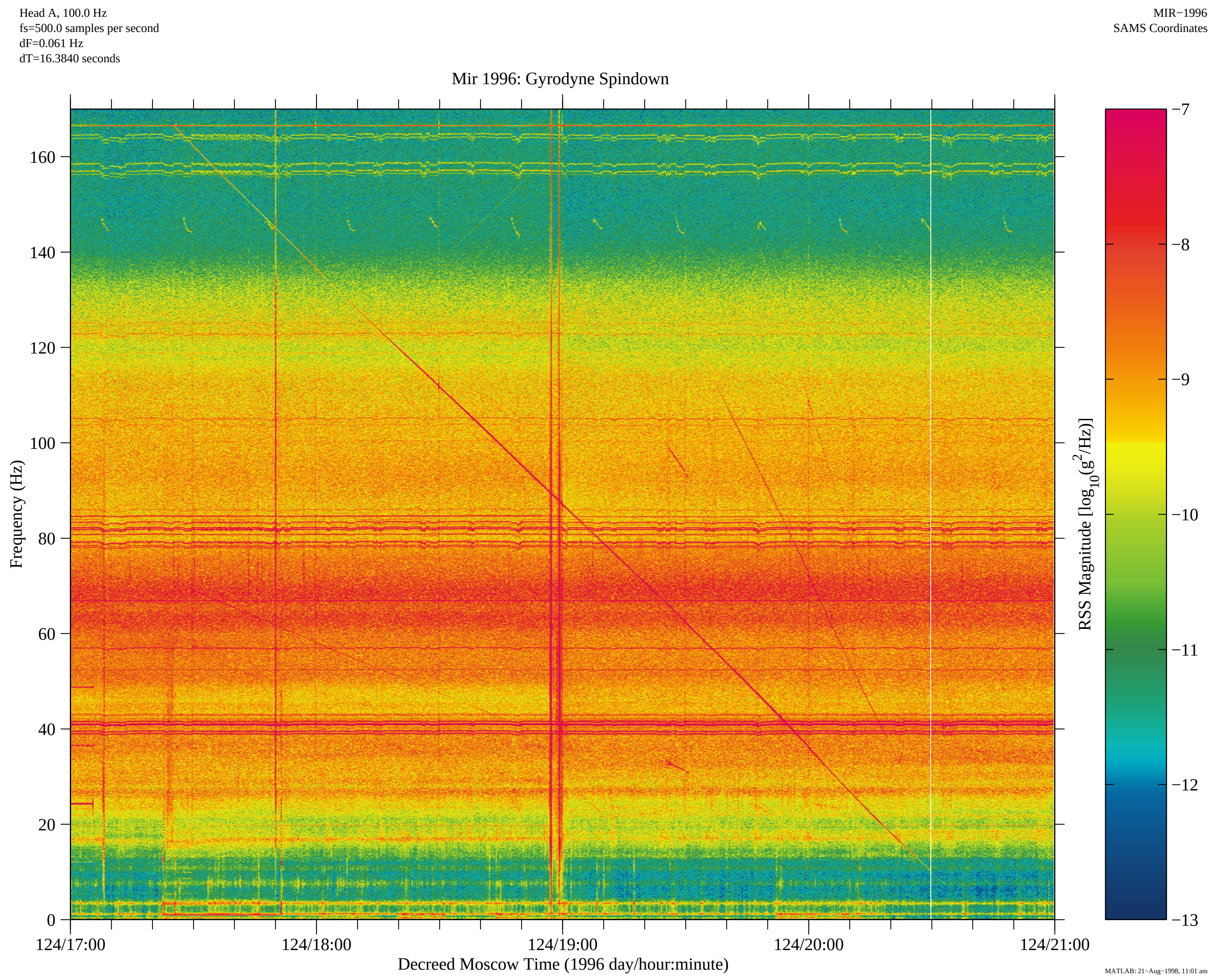
g_x , $10^{-6}\,g_0$
−0.4
−0.6
−0.8
−1.0
−1.2
t , s
0
5000
10000
15000
20000
g_y , $10^{-6}\,g_0$
1.6
0.8
−0.0
−0.8
−1.6
t , s
0
5000
10000
15000
20000
g_z , $10^{-6}\,g_0$
2.0
1.0
0.0
−1.0
t , s
0
5000
10000
15000
20000

Figure 12-3



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 12-4



Head A, 100.0 Hz
fs=500.0 samples per second
dF=0.061 Hz
dT=16.3840 seconds
MIR−1996
SAMS Coordinates
Mir 1996: Gyrodyne Spindown
Frequency (Hz)
0
20
40
60
80
100
120
140
160
124/17:00
124/18:00
124/19:00
124/20:00
124/21:00
Decreed Moscow Time (1996 day/hour:minute)
RSS Magnitude [log10(g2/Hz)]
−7
−8
−9
−10
−11
−12
−13
MATLAB: 21−Aug−1998, 11:01 am

Figure 12-5

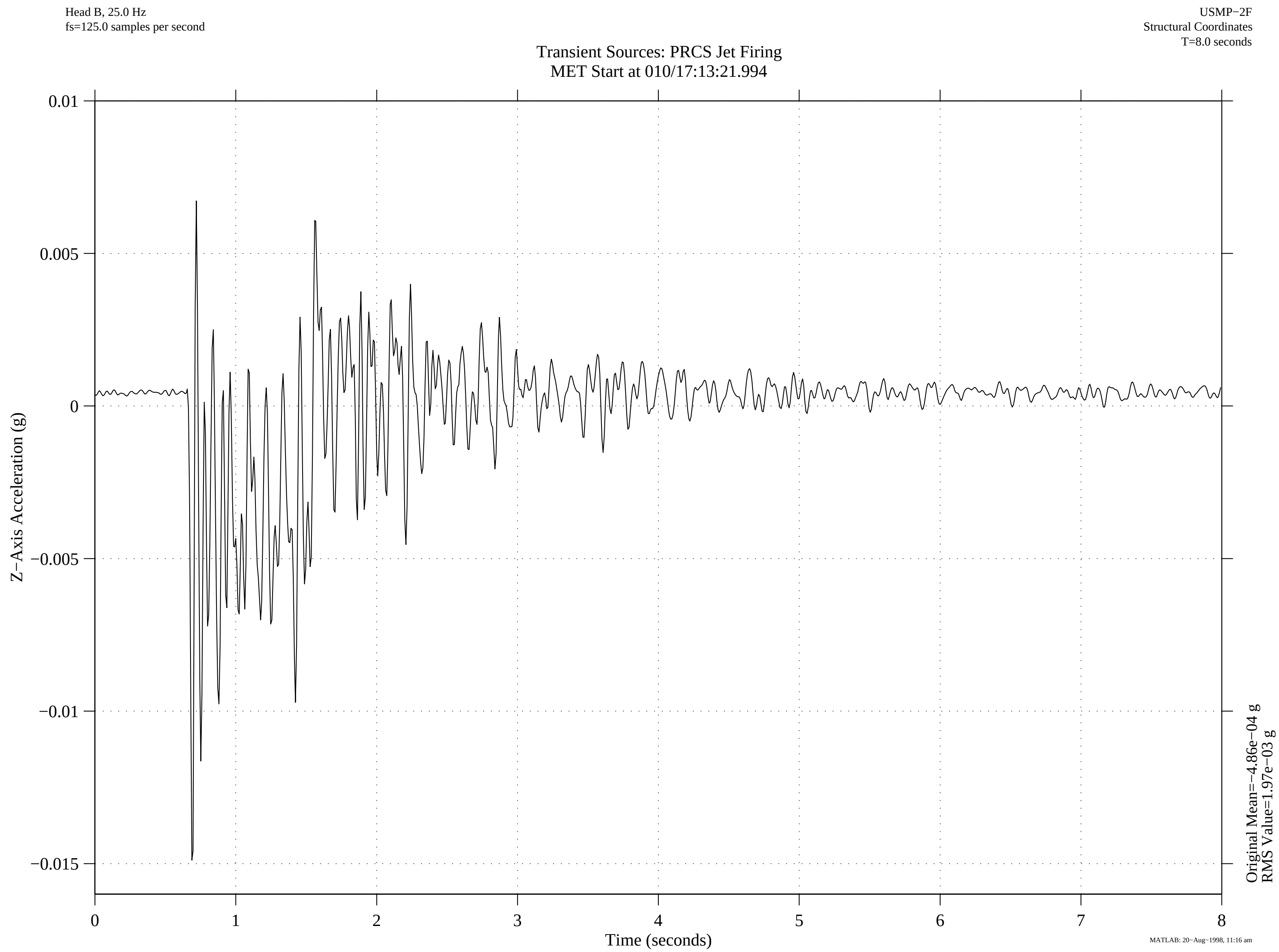

Head B, 25.0 Hz
fs=125.0 samples per second
USMP−2F
Structural Coordinates
T=8.0 seconds
Transient Sources: PRCS Jet Firing
MET Start at 010/17:13:21.994
Z−Axis Acceleration (g)
0.01
0.005
0
−0.005
−0.01
−0.015
0
1
2
3
4
5
6
7
8
Time (seconds)
Original Mean=−4.86e−04 g
RMS Value=1.97e−03 g
MATLAB: 20−Aug−1998, 11:16 am

Figure 12-6

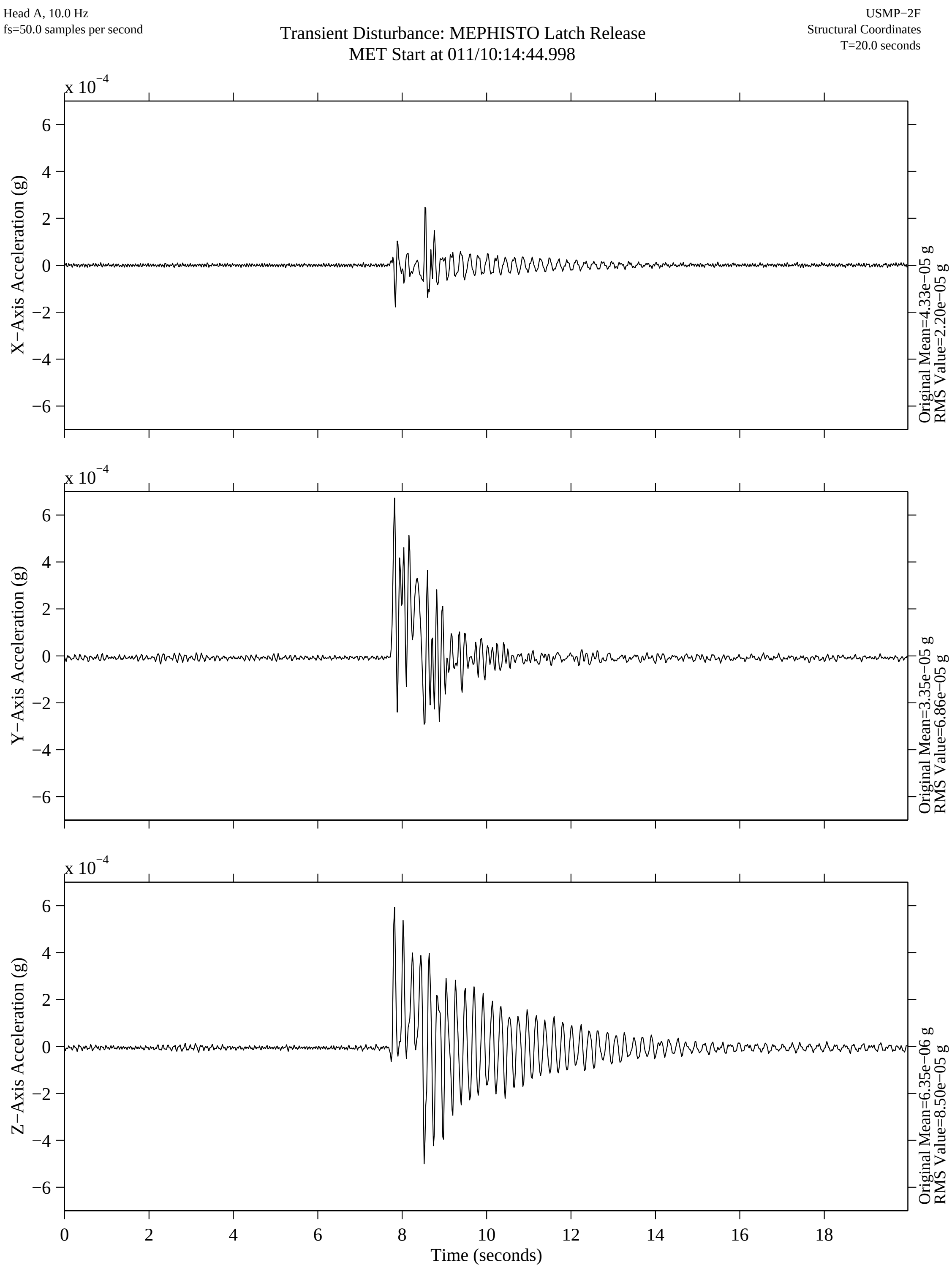

Head A, 10.0 Hz
fs=50.0 samples per second
Transient Disturbance: MEPHISTO Latch Release
MET Start at 011/10:14:44.998
USMP−2F
Structural Coordinates
T=20.0 seconds
x 10−4
X−Axis Acceleration (g)
Original Mean=4.33e−05 g
RMS Value=2.20e−05 g
Y−Axis Acceleration (g)
Original Mean=3.35e−05 g
RMS Value=6.86e−05 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 12-7

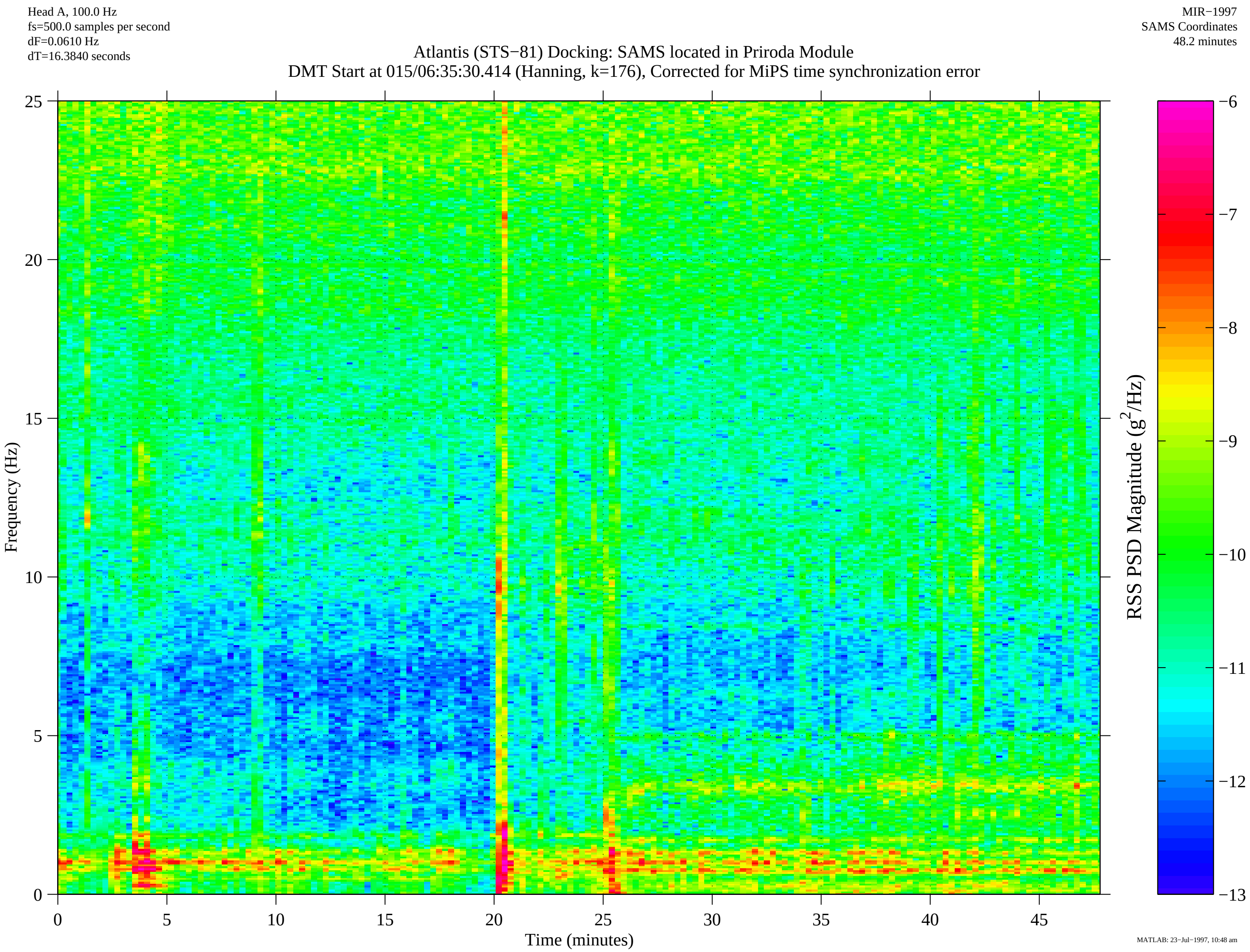

Head A, 100.0 Hz
fs=500.0 samples per second
dF=0.0610 Hz
dT=16.3840 seconds
MIR−1997
SAMS Coordinates
48.2 minutes
Atlantis (STS−81) Docking: SAMS located in Priroda Module
DMT Start at 015/06:35:30.414 (Hanning, k=176), Corrected for MiPS time synchronization error
Frequency (Hz)
Time (minutes)
RSS PSD Magnitude (g²/Hz)
0
5
10
15
20
25
30
35
40
45
−6
−7
−8
−9
−10
−11
−12
−13
MATLAB: 23−Jul−1997, 10:48 am

Figure 12-8

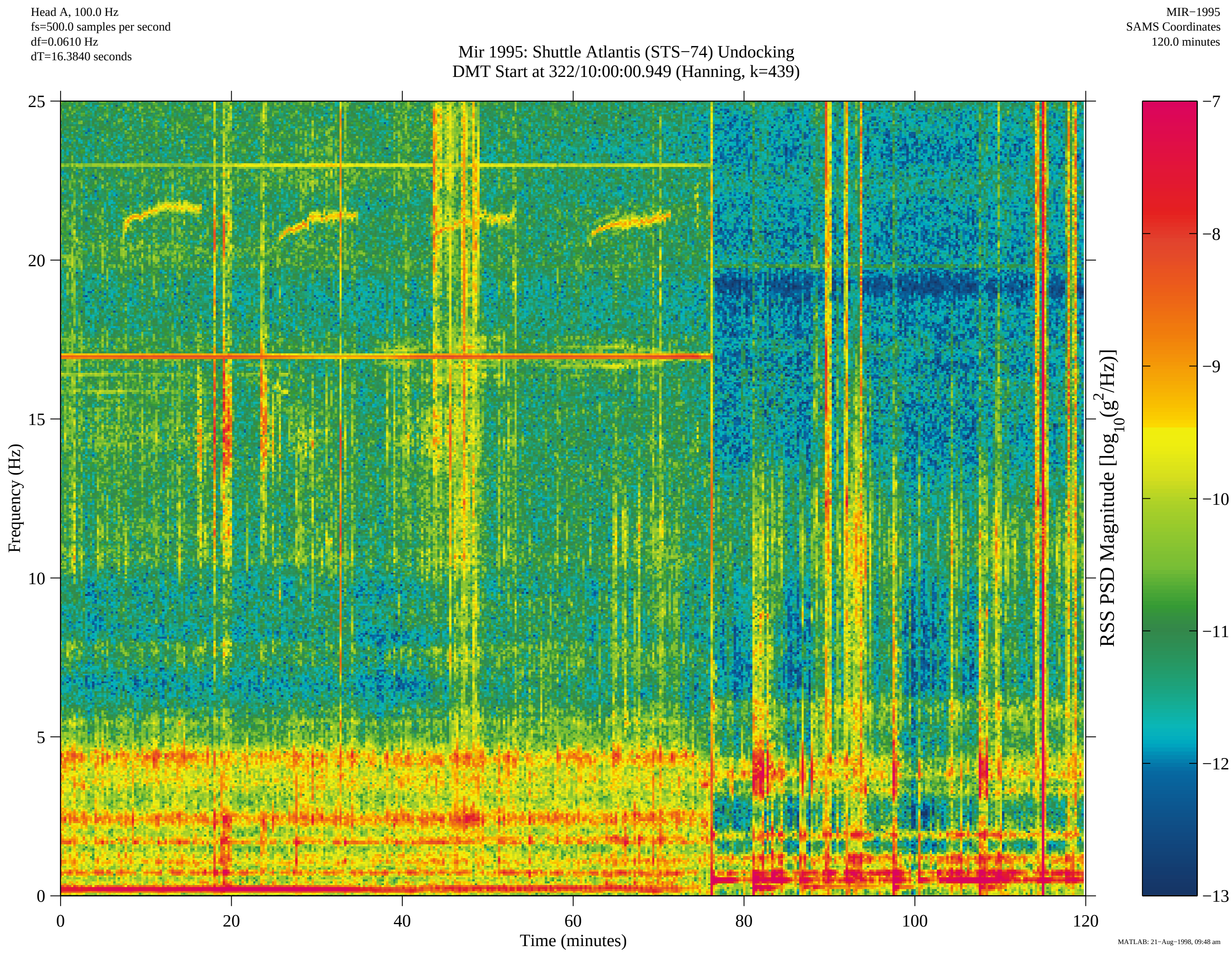

Head A, 100.0 Hz
fs=500.0 samples per second
df=0.0610 Hz
dT=16.3840 seconds
MIR−1995
SAMS Coordinates
120.0 minutes
Mir 1995: Shuttle Atlantis (STS−74) Undocking
DMT Start at 322/10:00:00.949 (Hanning, k=439)
Frequency (Hz)
Time (minutes)
RSS PSD Magnitude [log10(g2/Hz)]
0
5
10
15
20
25
0
20
40
60
80
100
120
−7
−8
−9
−10
−11
−12
−13
MATLAB: 21−Aug−1998, 09:48 am

Figure 12-9