Section 10

Microgravity Environment of Ground-based Facilities and Non-orbital Flight Platforms

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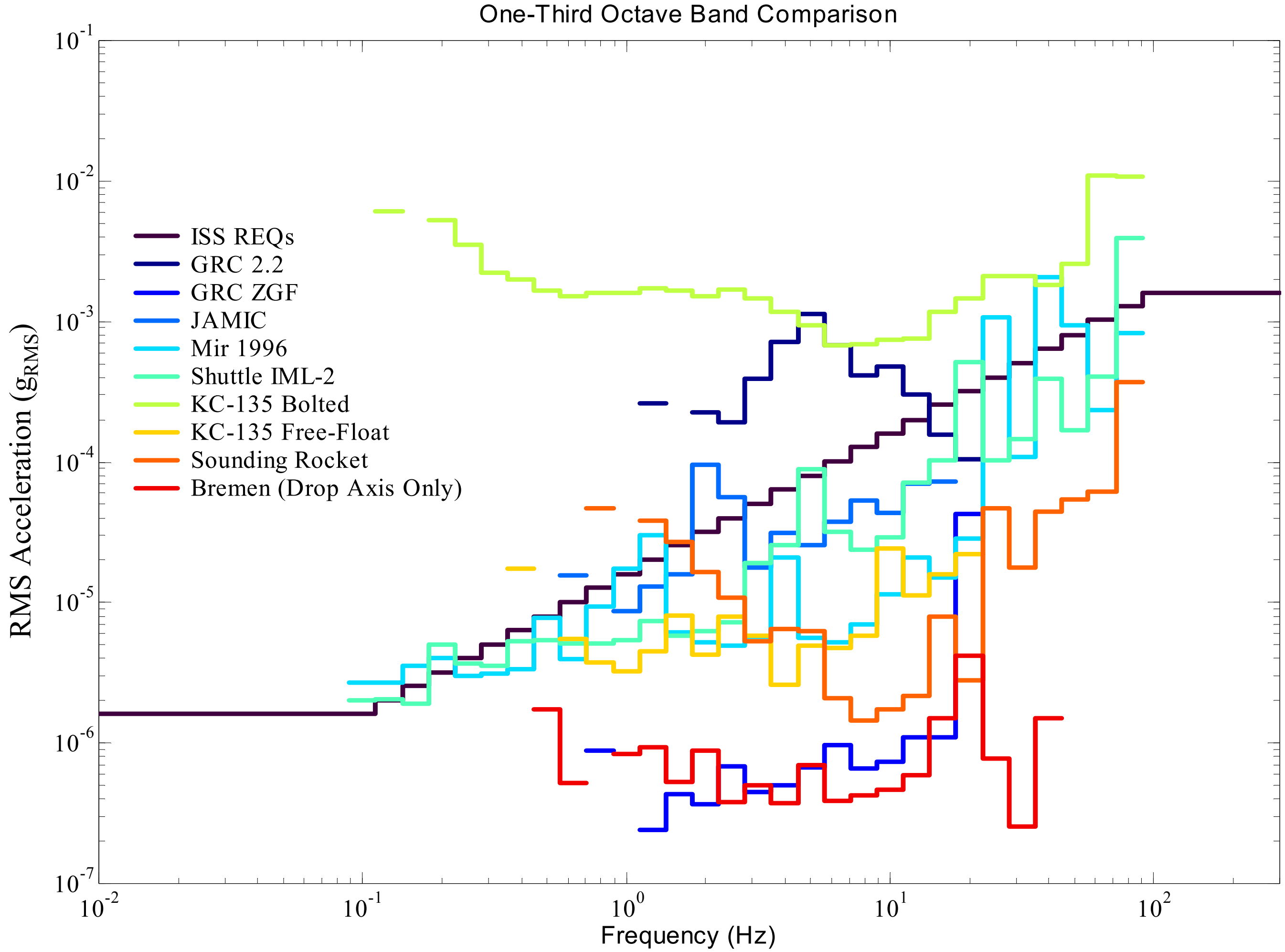
Acceleration measurements for experiments

- **Experiments in microgravity are disturbed by accelerations (e.g. vibrations, shocks, gravity gradient, linear motion)**
- **Experiments in ground laboratories are disturbed by accelerations also**
  - **Gravity (very pervasive!)**
  - **Elevator motions in laboratory building**
  - **Traffic nearby building (e.g. street, loading dock)**
  - **Air conditioning equipment (e.g. compressor, fans, etc.)**
  - **Clumsy lab assistants**
- **Accelerations should be measured during experiment ground operations - not just during orbital operations**

Residual acceleration for various microgravity facilities



(from Ross, 2001)

Methods of creating 'zero-g' or microgravity

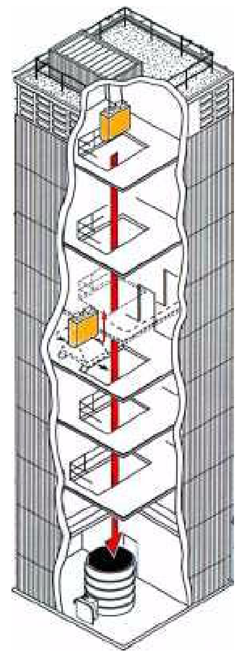
- **Center of Earth's mass ($g_e \sim 0$ m/s²)**
  - **Impractical location for experiment operations**
- **Very distant from Earth or other celestial body ($g_e = 10^{-6}$ m/s²)**
  - **Impractical location for experiment operations**
- **Free fall**
  - **Zero horizontal velocity ------> drop tower ($g_e = 9.8$ m/s²)**
  - **400 kph horizontal velocity ------> aircraft ($g_e = 9.8$ m/s²)**
  - **30,000 kph horizontal velocity ------> orbital ($g_e \sim 9$ m/s²)**
  - **Where g_e is the acceleration due to Earth's gravitational pull**
- **The reduced gravity features comes from free fall, not the absolute reduction or elimination of Earth's gravitational acceleration!**

Ground-based facilities with zero horizontal velocity

- **Seismic mass / vibration isolation**
  - **Not free-fall but vibrationally quiet**
    - Still 1-g environment
  - **Isolated floor mass**
  - **Vibration isolation platform**
- **Drop tower**
  - **Carrier containing experiment is dropped**
  - **Experiments may be complex**
- **Drop tube**
  - **Sample material only is dropped**
  - **Most often sample is molten metal drops**

Ground Facilities with zero horizontal velocity

Seismic Mass
Plum Brook Station
Base of huge vacuum chamber (illustrative of method to utilize vibration-quiet laboratory conditions)

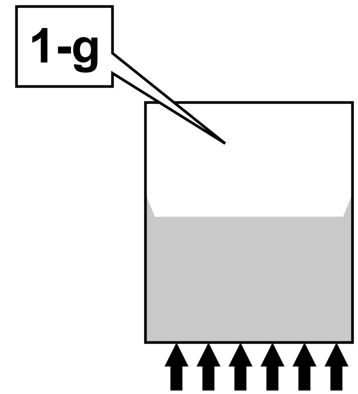


2.2 Second Drop Tower
NASA Glenn
Drag shield being assembled for an experiment drop

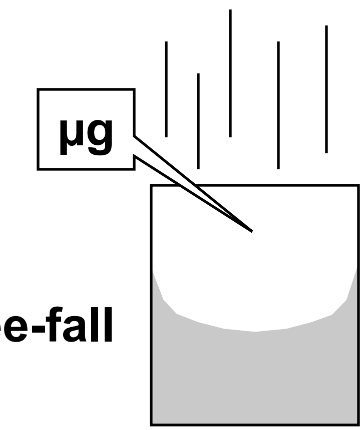
SPF Seismic Mass Characterization

- **Figure 10-1 illustrates the conditions existing on a large mass of concrete**
  - **Concrete foundation of world's largest vacuum chamber**
  - **The X-axis was vertical**
  - **a = F/m implies low levels of acceleration with large value of mass with nominal forces from ground and wind**

Free-fall vs. 1-g



- **1-g condition**
  - **Gravity effects are apparent when a retarding force disturbs free fall**
  - **Beaker exerts a force to stop water from falling**
  - **Floor exerts a force on people (felt as their weight)**
- **Microgravity condition in a free fall**
  - **Gravity effects are not apparent in free fall**
  - **Beaker falls with the fluid**
    - beaker is no longer exerting a retarding force on water
    - sedimentation and buoyancy are reduced
    - surface tension & capillary forces are 'revealed'
  - **Acapulco cliff divers feel weightless during their free-fall to the ocean**

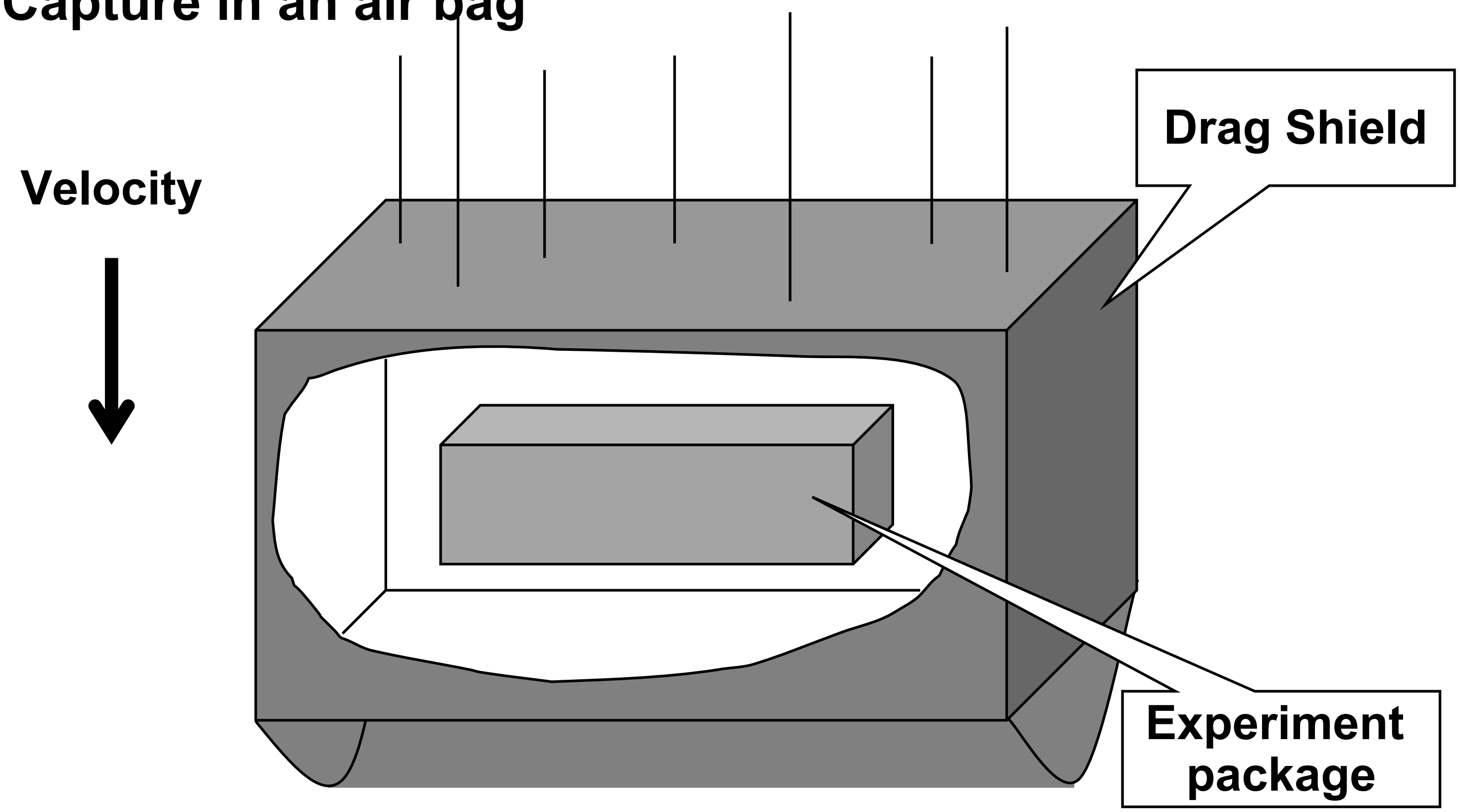


Drop Towers & Tubes

- **Drop towers attempt to minimize external forces**
  - **Air drag is a large external force**
    - Steady force which gradually increases with increasing velocity
  - **Several mechanisms are used to counteract air drag**
    - Drag shield
      - Experiment package surrounded by free falling container
    - Vacuum operation
      - Evacuate air from the chamber in which the experiment is dropped
    - Drag force compensation
      - Apply compensating force (thrust) to experiment carrier
  - **Keys for a 'quiet' drop**
    - Smooth release mechanism to minimize initial transient vibration
    - Structural relaxation depends on design of carrier and experiment
    - Dynamically balance moving experiment and carrier components

Drag Shield

- **NASA GRC 2.2 Second Drop Tower uses a drag shield**
- **Capture in an air bag**



NASA GRC 2.2 Second Drop Tower

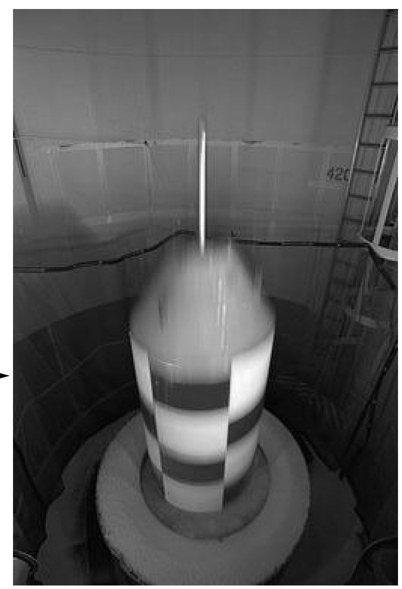
Experiment rig assembly

Drag shield preparation

Vacuum Operation

- **Vacuum drop towers include:**
  - **Zero Gravity Research Facility at NASA GRC**
    - Capture in foam pellet container
  - **ZARM facility at University of Bremen, Germany**
    - Capture in foam pellet container

Experiment capture in Zero Gravity Research Facility

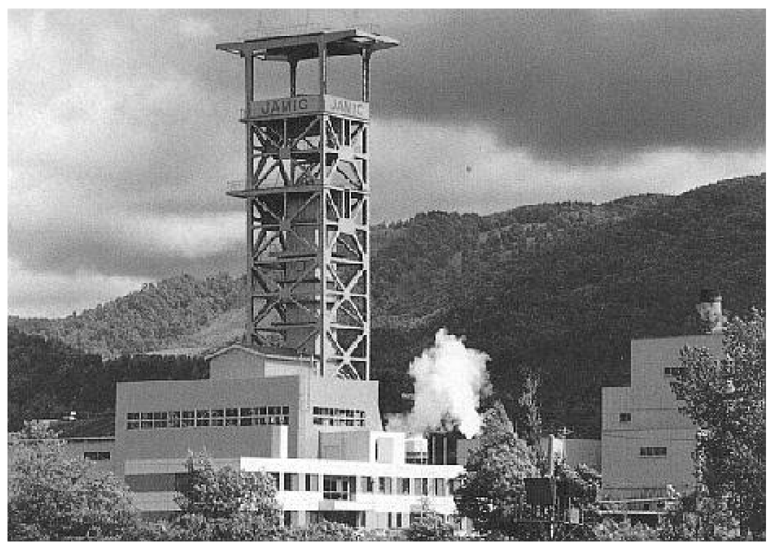


ZARM tower exterior

Drag Force Compensation

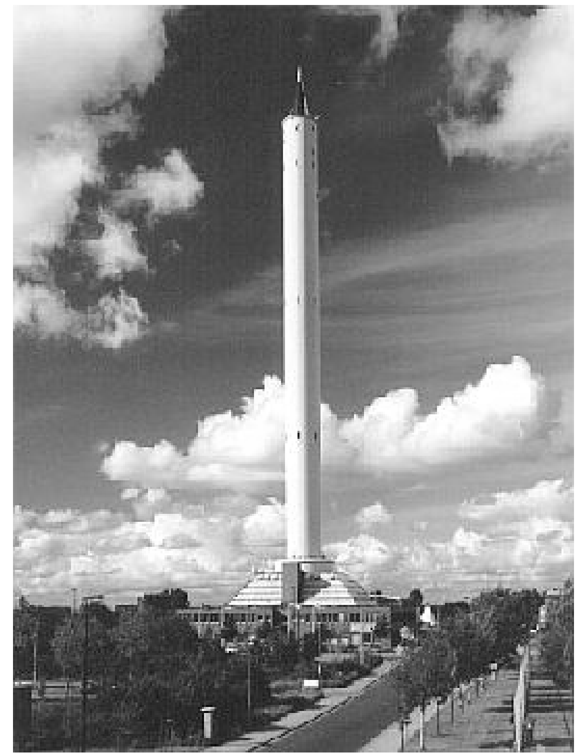
- **Japan Microgravity Center**
  - **Inner & outer capsule (i.e. drag shield)**
    - Vacuum drawn between inner & outer capsules
  - **Acceleration added to outer capsule for drag compensation**
    - Cold-gas jet
  - **Capture accomplished with air pressure then mechanical brake**

JAMIC



Drop Tower Comparison

- **NASA GRC 2.2 Second Drop Tower**
  - **2.2 seconds 24.1 m 10^{-4} g**
- **ZARM Drop Tower**
  - **4.74 seconds 123 m 10^{-5} g**
- **NASA GRC Zero Gravity Research Facility**
  - **5.18 seconds 145 m 10^{-5} g**
- **Japan Microgravity Center**
  - **10 seconds 490 m 10^{-5} g**



ZARM

Acceleration Environment Features of Drop Towers

- **Release**
  - **Step change transition from 1-g to sub-milli-g level**
  - **Transition occurs over very short time that the mechanism actually releases carrier**
- **Vibrations from release mechanism**
  - **The release transition is similar to ringing a bell**
    - Step change causes (unwanted) vibration in experiment carrier
    - The ‘bell ringing’ is damped by carrier and experiment mechanical design
  - **May persist for major portion of microgravity time**

  - **Figure 10-2**

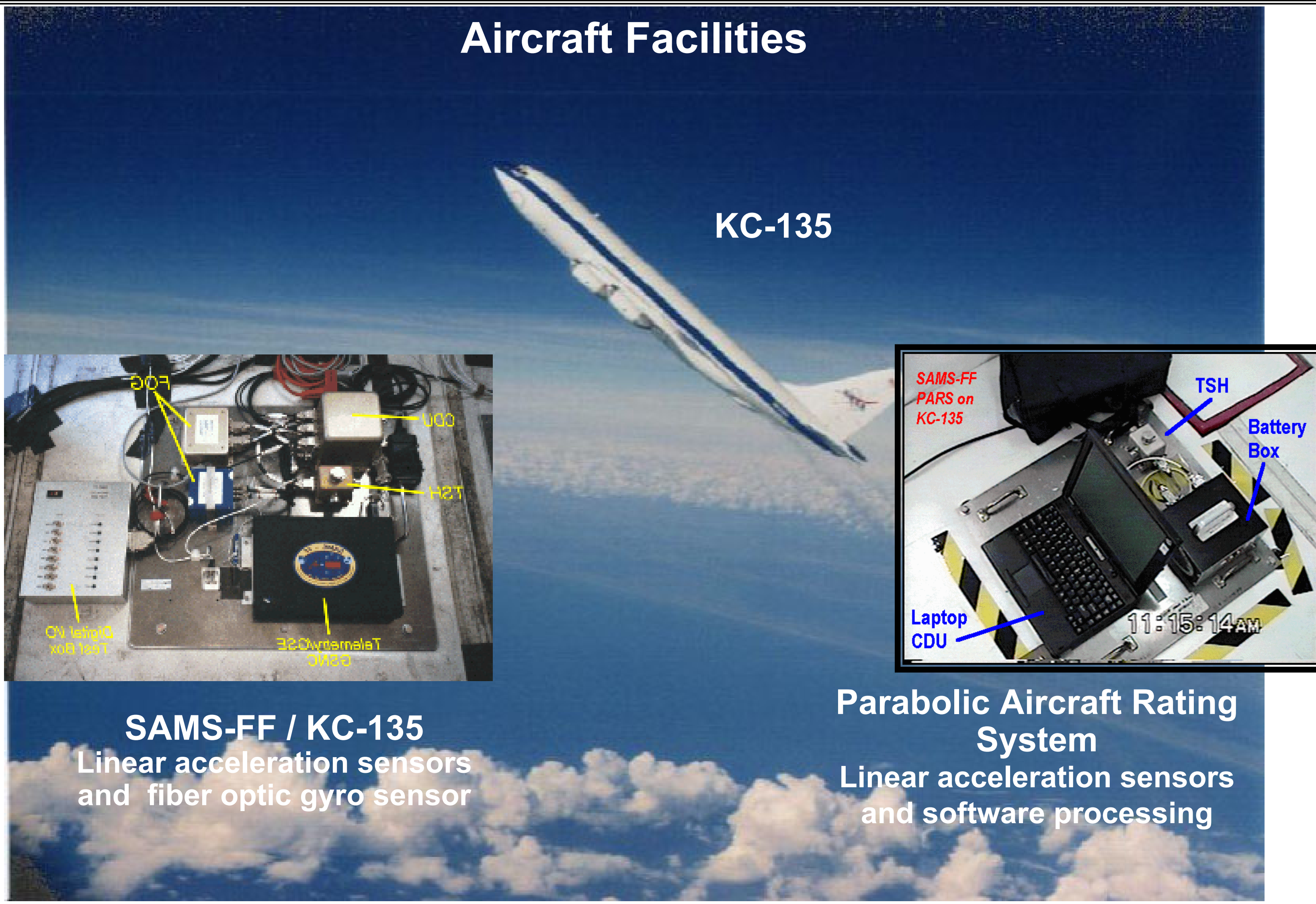
Acceleration Environment Features of Drop Towers

- Vibrations from experiment equipment operation, such as:
  - Camera shutters
  - Film transport
  - Solenoid and relay actions
  - Pumps
  - Motor-driven fluid mixers
  - Figure 10-3
- High level of deceleration at capture
  - Levels depend on capture mechanism and final velocity
  - Figures 10-2 and 10-4

Non-orbital flight platforms
(~ 200 mph horizontal velocity)

- **KC-135 aircraft (NASA)**
  - **Operated by NASA Johnson Space Center**
  - **Each parabola provides 15-20 seconds of reduced gravity environment**
  - **Periodic free-fall interspersed with high-g pull-out**
  - **Approximately 40-50 parabolas per flight (campaign)**
- **Terrier-Black Brant sounding rocket**
  - **Achieves free-fall conditions on the order of 500 seconds after motor burn-out**
  - **One of several types of sounding rockets**

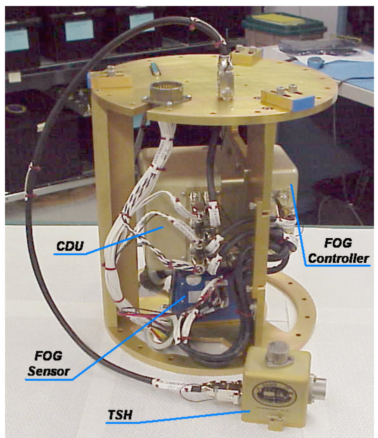
Aircraft Facilities



SAMS-FF / KC-135
Linear acceleration sensors
and fiber optic gyro sensor

Parabolic Aircraft Rating System
Linear acceleration sensors
and software processing

Sounding Rockets



SAMS-FF / Sounding Rocket
Linear acceleration sensors and fiber optic gyro sensor

KC-135 Environment Characterization

- **Figure 10-5 illustrates the KC-135 overall environment over multiple parabolas during a typical campaign**
- **Figure 10-6 is a detailed plot of the KC-135 environment during the reduced gravity portion of the parabola**
- **Figure 10-7 is a plot of KC-135 parabola recorded in support of SAL experiment. Shows free-float of SAL test equipment and timelines the activity within the parabola**
- **Figure 10-8 is a detailed plot of the free-float period of the parabola**

Sounding Rocket Environment Characterization

- **Terrier-Black sounding rocket DARTFire flight timeline is shown in the graphic in Figure 10-9**
- **Figure 10-10 illustrates the acceleration vector magnitude for the time period when the sampling rate was 25 samples per second**
  - **environment measured to be less than 30 micro-g root sum square (RSS) for the time interval analyzed**
- **Figure 10-11 is the RSS power spectral density for the time period when the sampling rate was 25 samples per second**
  - **frequency domain characteristics track known disturbance sources from the DARTFire equipment**
    - Intensified Multispectral Imager filter wheel operates at 5 Hz
    - Infrared Imager filter wheel operates at 1 Hz

References

- **Zero Gravity Research Facility**
  - http://microgravity.grc.nasa.gov/zero-g/index.html
- **2.2 Second Drop Tower**
  - http://microgravity.grc.nasa.gov/drop2/
- **ZARM Drop Tower**
  - http://www.zarm.uni-bremen.de/main.htm
  - ZARM Drop Tower Bremen - Users Manual, Version 28, April 2000
- **JAMIC Drop Tower**
  - http://www.jamic.co.jp/ENG/JAMIC/3.html
- **Microgravity Carrier Summary**
  - http://microgravity.msfc.nasa.gov/NASA_Carrier_User_Guide.pdf
  - Ross, H. D. (2001) *Microgravity Combustion*, Academic Press

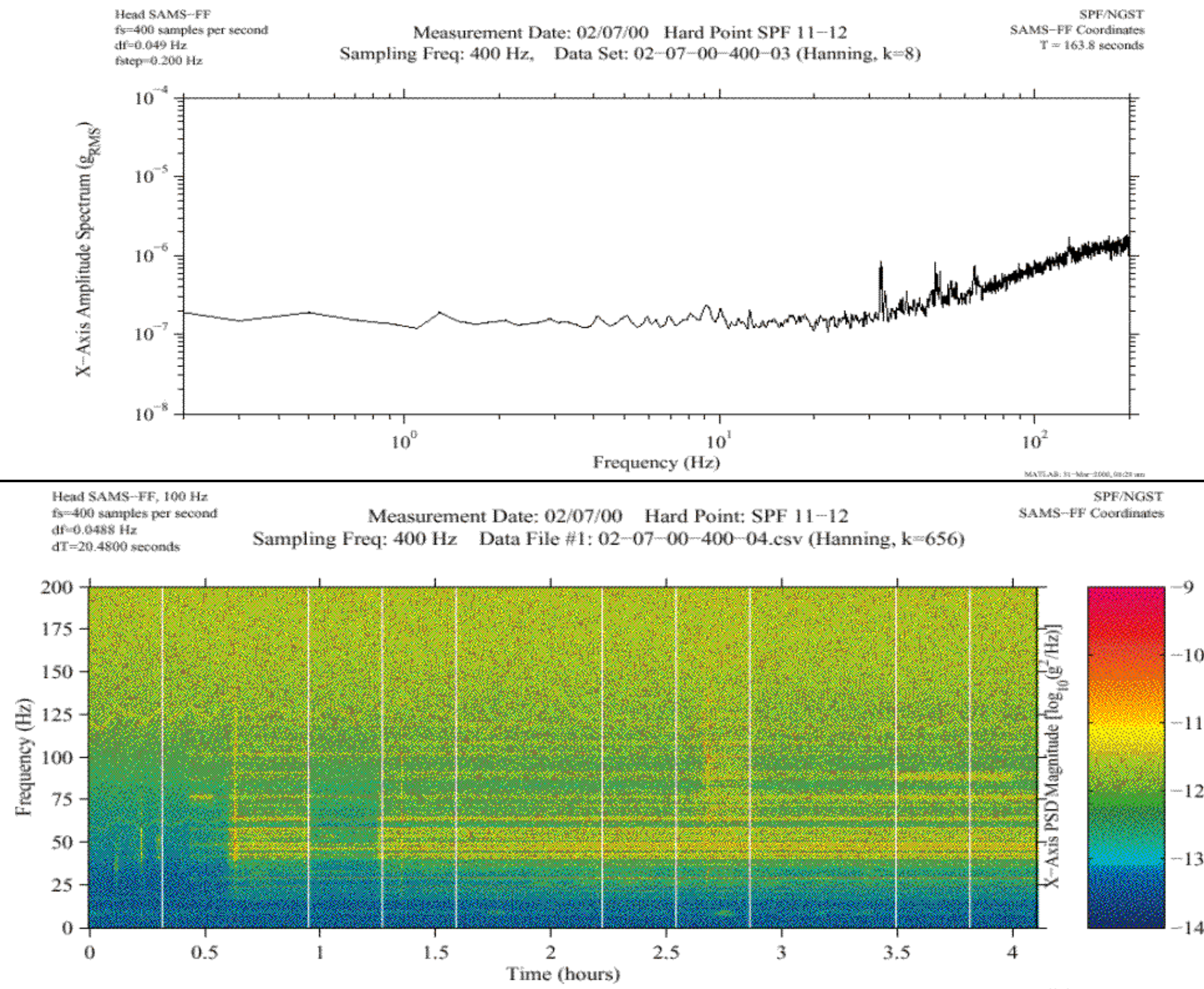


Figure 10-1: Ground Testing – SPF data

Data from the vertical axis in NASA GRC 2.2 Second Drop Tower facility.

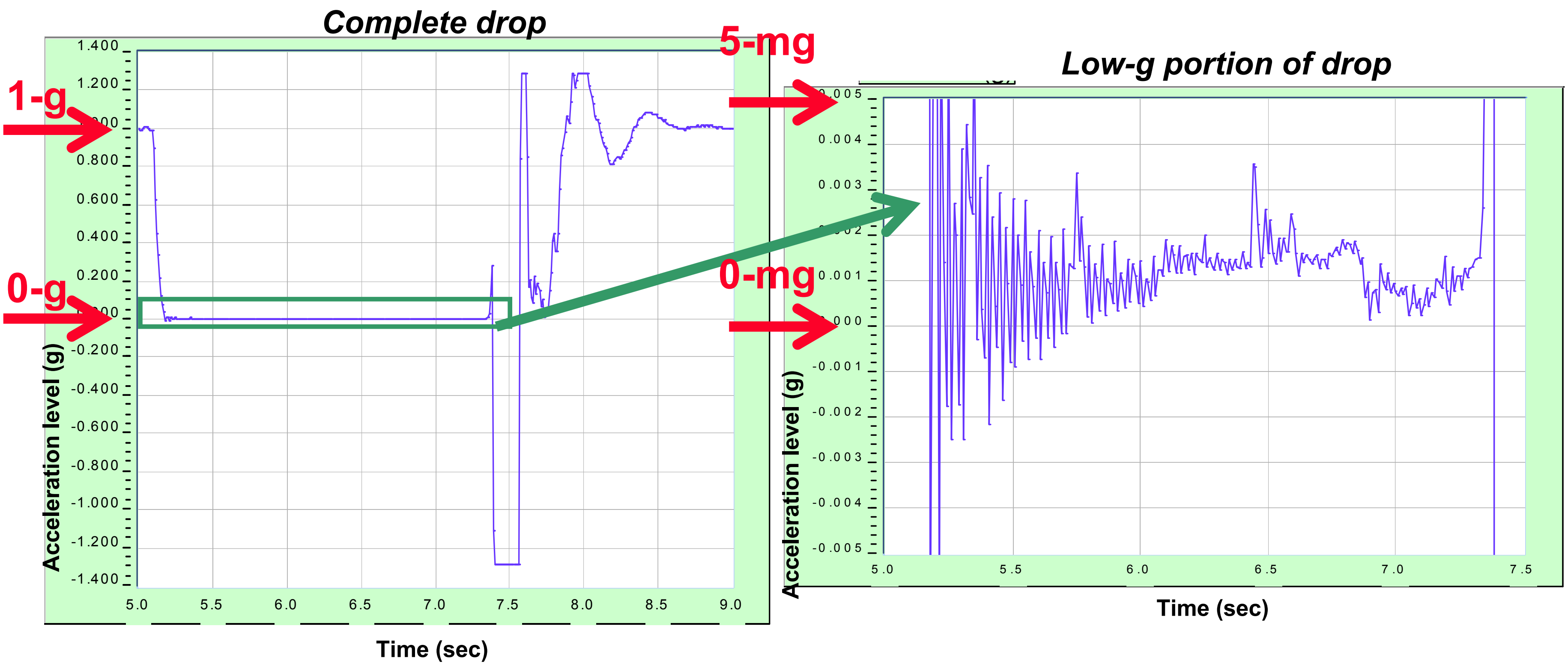


Figure 10-2: Acceleration level for drop tower test

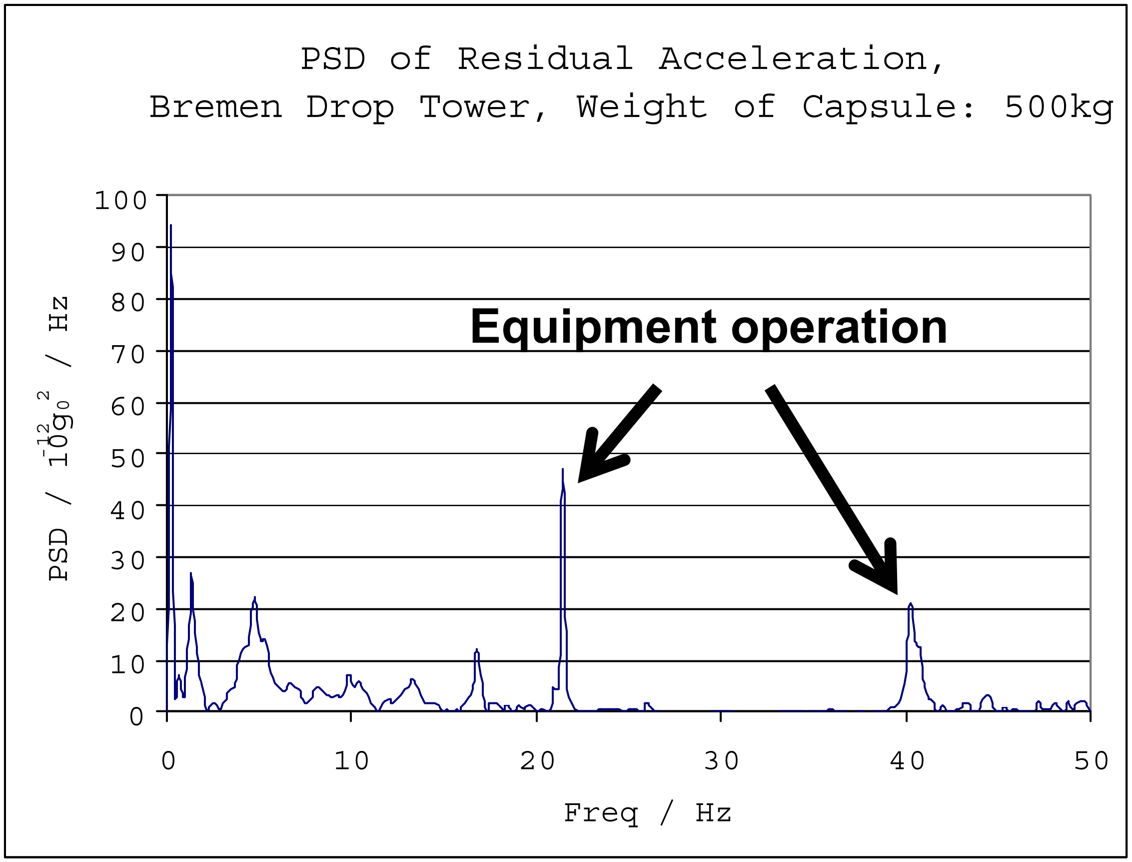


Figure 10-3: Power Spectral Density plot during drop (ZARM)
(note: release disturbances not included)

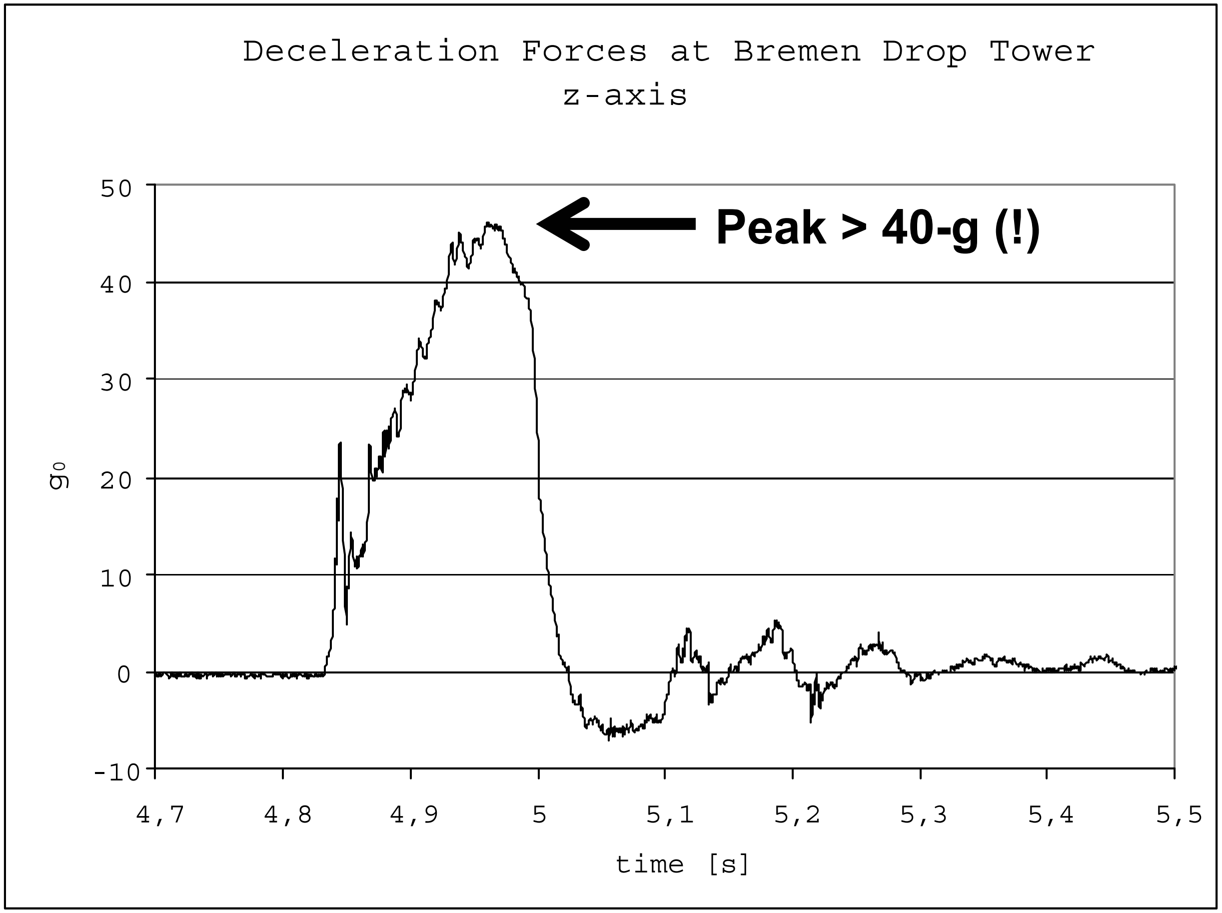


Figure 10-4: Deceleration at capture (ZARM)

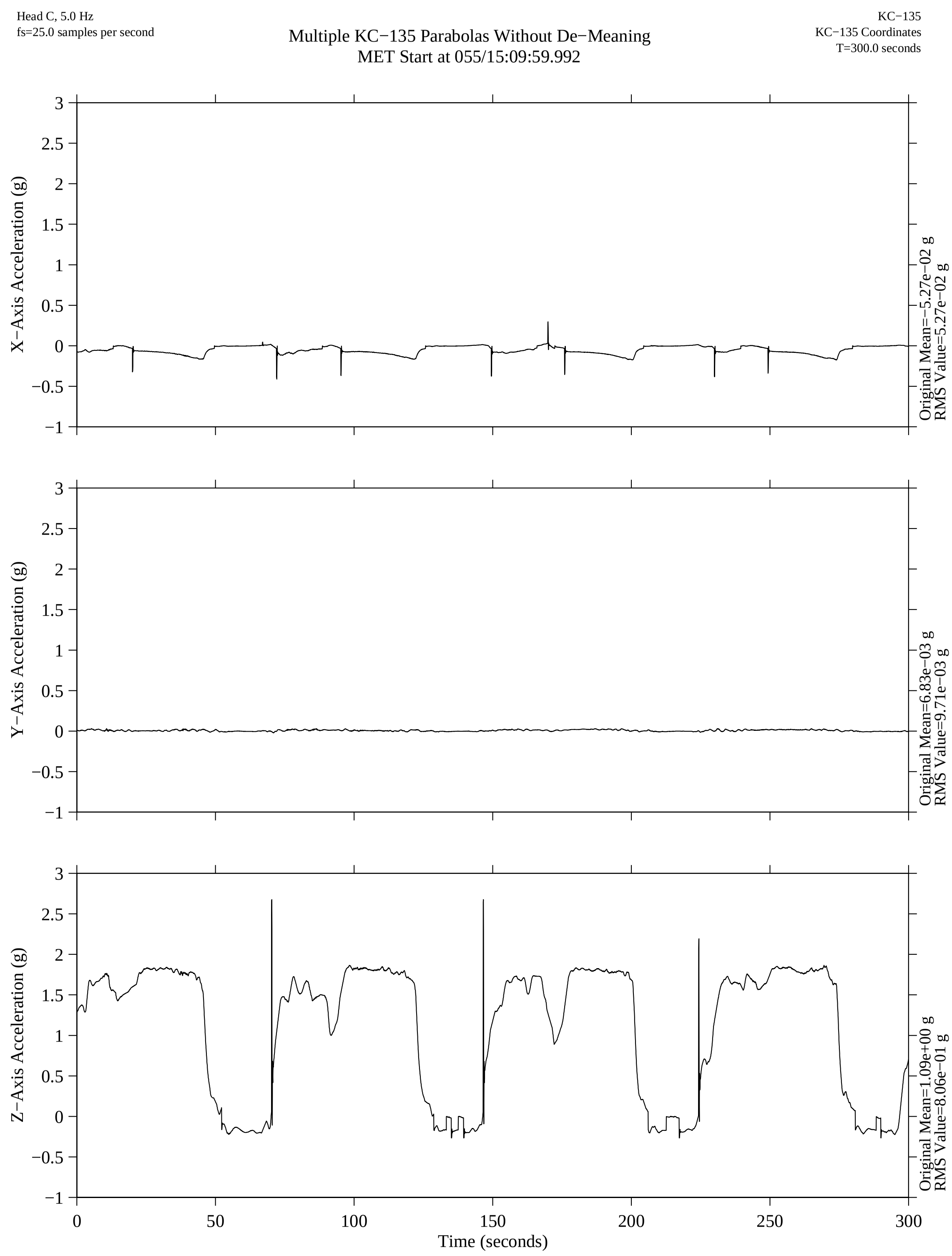

Head C, 5.0 Hz
fs=25.0 samples per second
Multiple KC−135 Parabolas Without De−Meaning
MET Start at 055/15:09:59.992
KC−135
KC−135 Coordinates
T=300.0 seconds
X−Axis Acceleration (g)
Original Mean=−5.27e−02 g
RMS Value=5.27e−02 g
Y−Axis Acceleration (g)
Original Mean=6.83e−03 g
RMS Value=9.71e−03 g
Z−Axis Acceleration (g)
Original Mean=1.09e+00 g
RMS Value=8.06e−01 g
Time (seconds)
MATLAB: 13−Aug−1998, 10:35 am

Figure 10-5

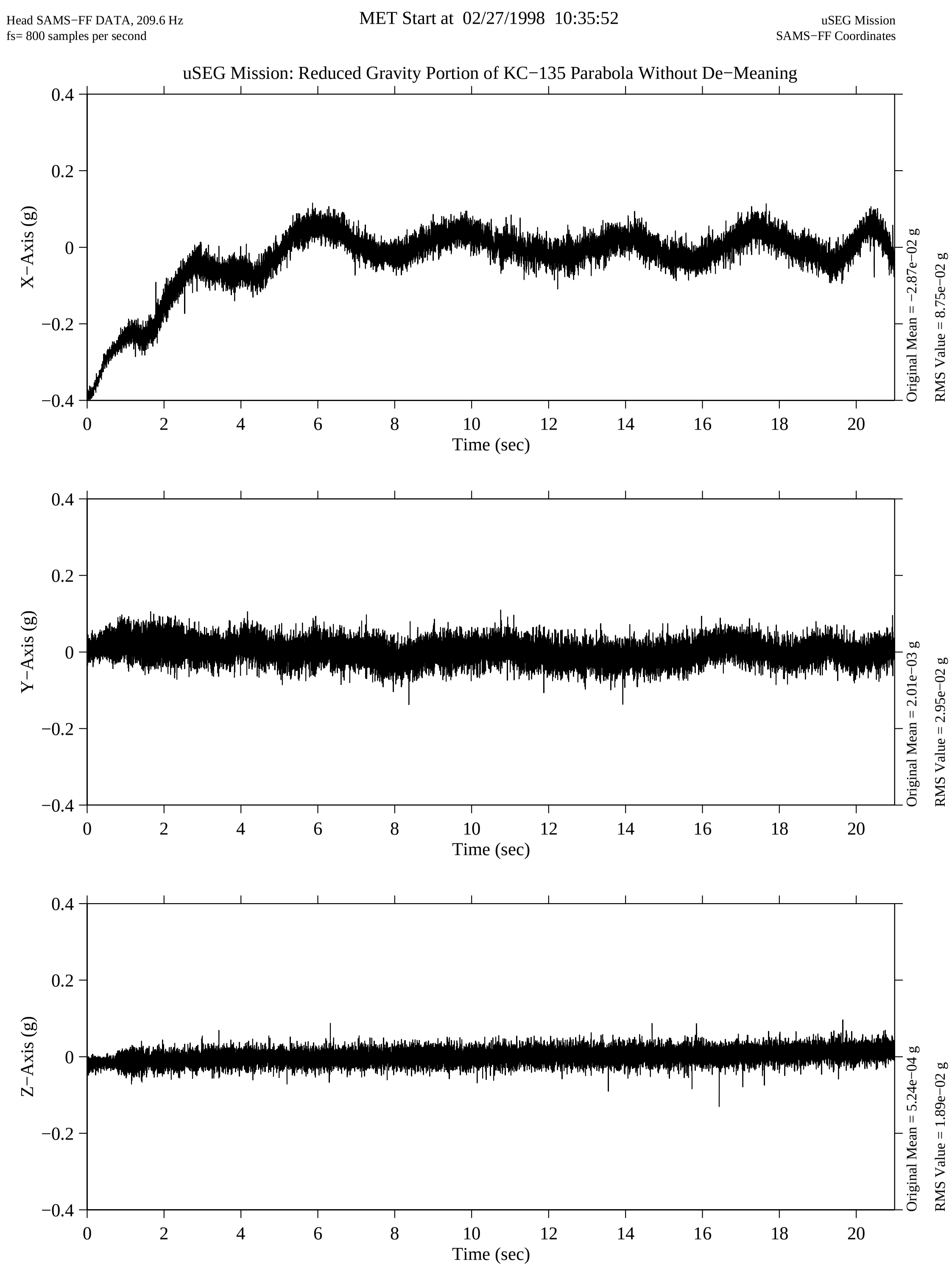
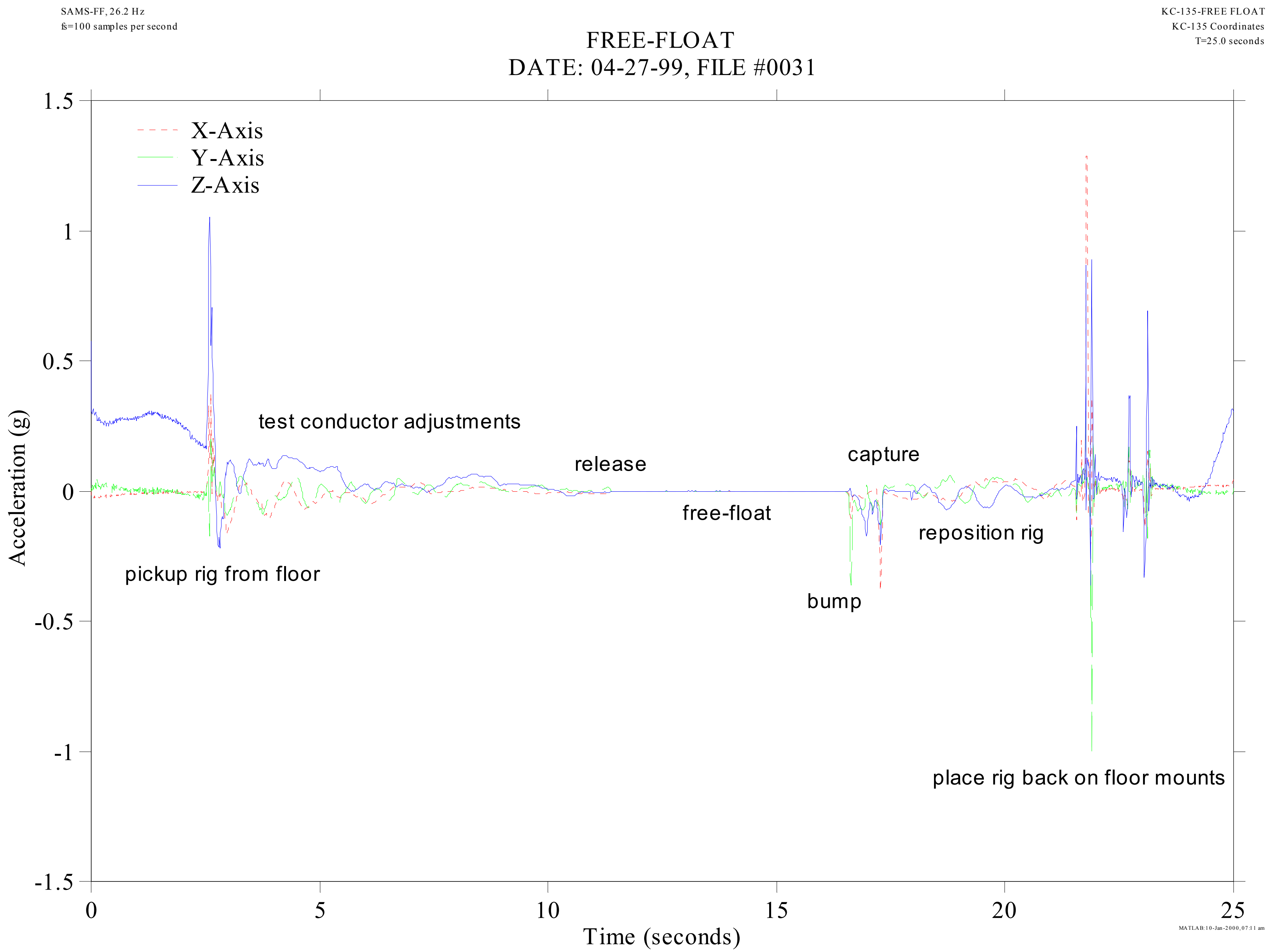

Head SAMS−FF DATA, 209.6 Hz
fs= 800 samples per second
MET Start at 02/27/1998 10:35:52
uSEG Mission
SAMS−FF Coordinates
uSEG Mission: Reduced Gravity Portion of KC−135 Parabola Without De−Meaning
X−Axis (g)
Original Mean = −2.87e−02 g
RMS Value = 8.75e−02 g
Y−Axis (g)
Original Mean = 2.01e−03 g
RMS Value = 2.95e−02 g
Z−Axis (g)
Original Mean = 5.24e−04 g
RMS Value = 1.89e−02 g
Time (sec)
MATLAB: 15−Jun−1998, 04:41 pm

Figure 10-6

Figure 10-7



SAMS-FF Data Recorded in Support of SAL Experiment Showing Free-Float Interval

Figure 10-8

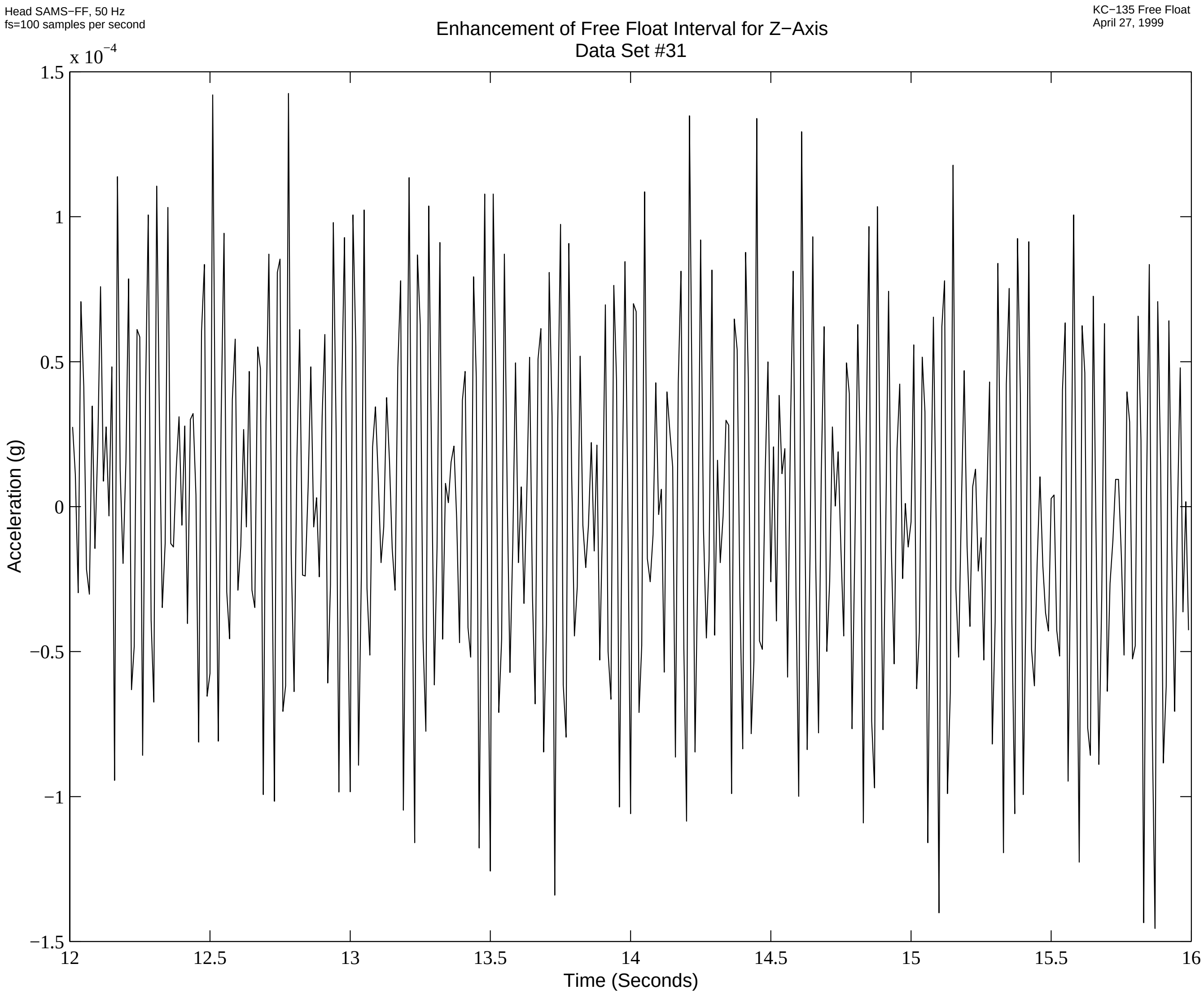


Figure 8−7: Enhancement of the Free Float Period for the Z−Axis

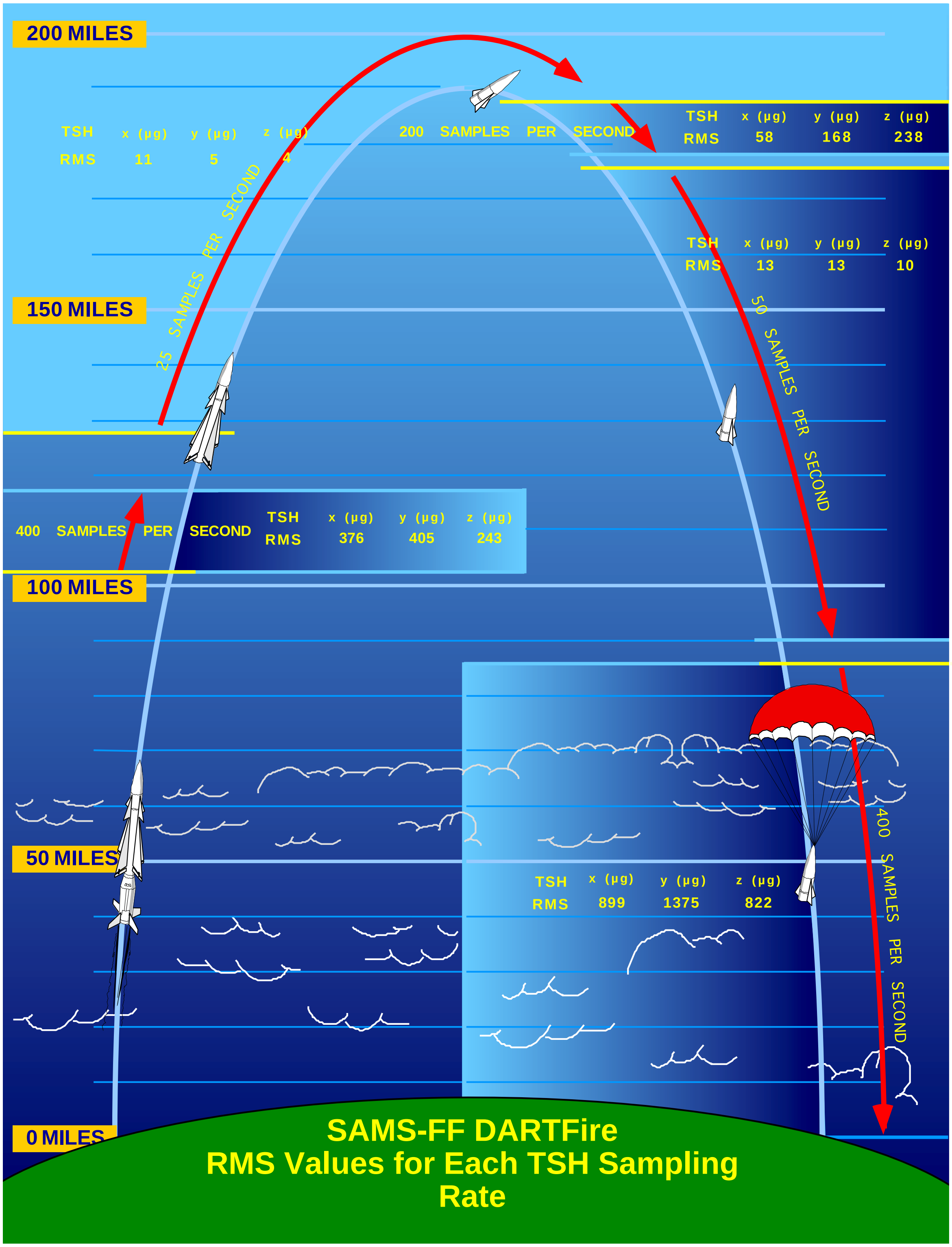
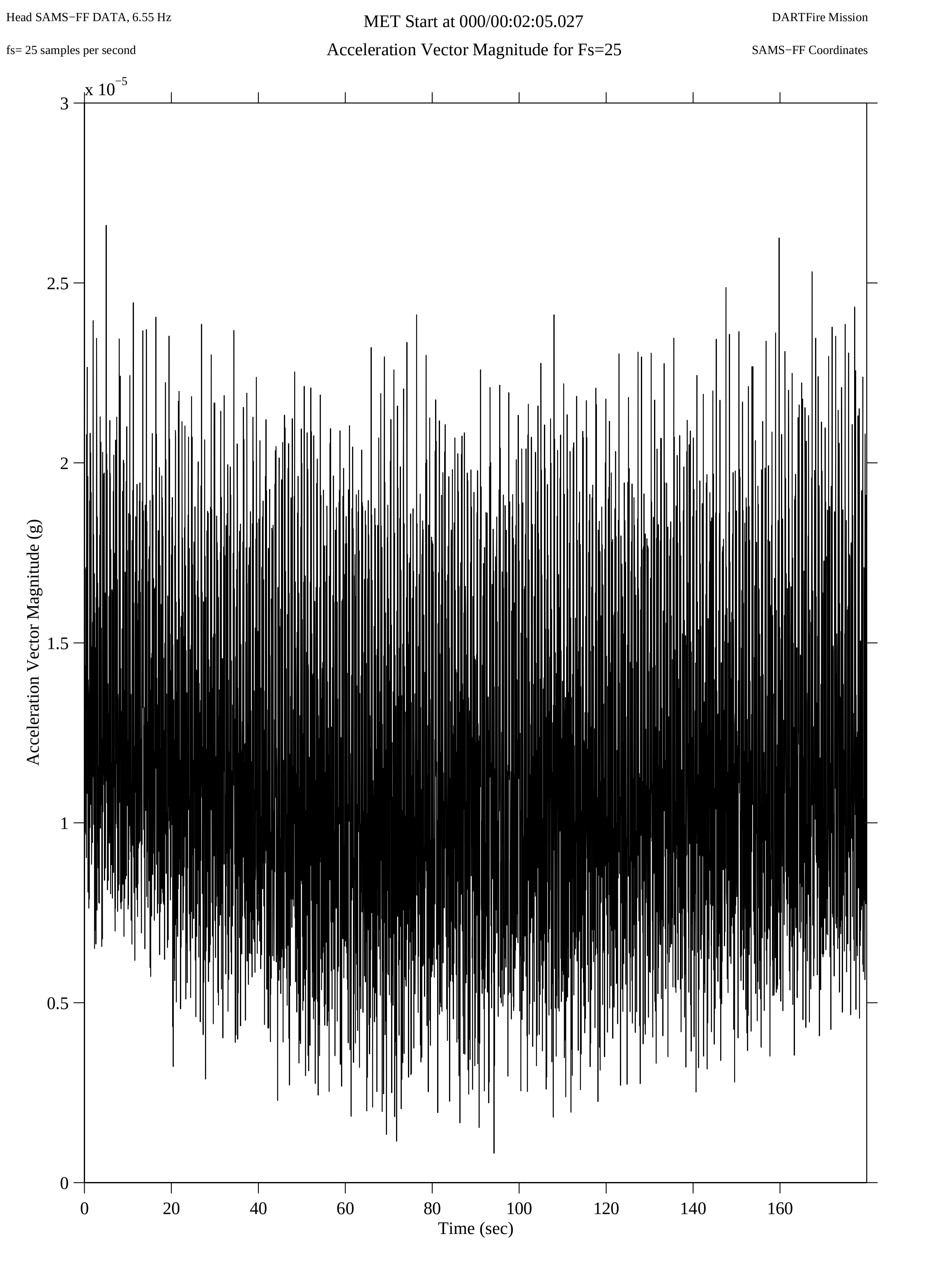
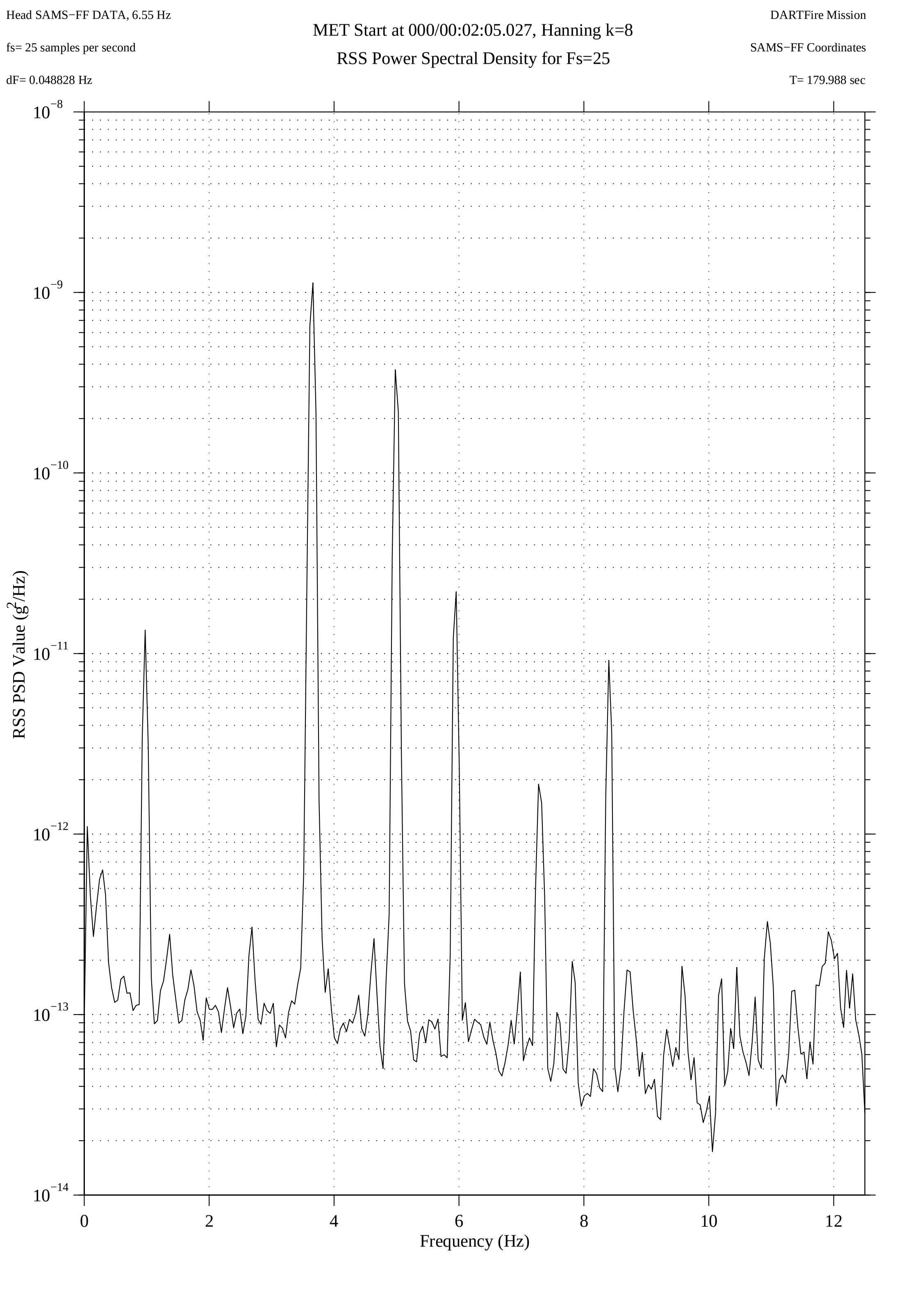

200 MILES
150 MILES
100 MILES
50 MILES
0 MILES
TSH x (μg) y (μg) z (μg)
RMS 11 5 4
25 SAMPLES PER SECOND
200 SAMPLES PER SECOND
TSH x (μg) y (μg) z (μg)
RMS 58 168 238
TSH x (μg) y (μg) z (μg)
RMS 13 13 10
50 SAMPLES PER SECOND
400 SAMPLES PER SECOND
TSH x (μg) y (μg) z (μg)
RMS 376 405 243
400 SAMPLES PER SECOND
TSH x (μg) y (μg) z (μg)
RMS 899 1375 822
SAMS-FF DARTFire
RMS Values for Each TSH Sampling Rate

Figure 10-9



Head SAMS−FF DATA, 6.55 Hz
fs= 25 samples per second
MET Start at 000/00:02:05.027
Acceleration Vector Magnitude for Fs=25
DARTFire Mission
SAMS−FF Coordinates
x 10^−5
Acceleration Vector Magnitude (g)
0
0.5
1
1.5
2
2.5
3
0
20
40
60
80
100
120
140
160
Time (sec)
MATLAB: 11−Aug−1998, 06:02 pm

Figure 10-10



Head SAMS−FF DATA, 6.55 Hz
fs= 25 samples per second
dF= 0.048828 Hz
MET Start at 000/00:02:05.027, Hanning k=8
RSS Power Spectral Density for Fs=25
DARTFire Mission
SAMS−FF Coordinates
T= 179.988 sec
RSS PSD Value (g^2/Hz)
10^−8
10^−9
10^−10
10^−11
10^−12
10^−13
10^−14
0
2
4
6
8
10
12
Frequency (Hz)
MATLAB: 11−Aug−1998, 06:05 pm

Figure 10-11