Section 14

Reduced-gravity Environment of Ground-based Facilities and Non-orbital Flight Platforms

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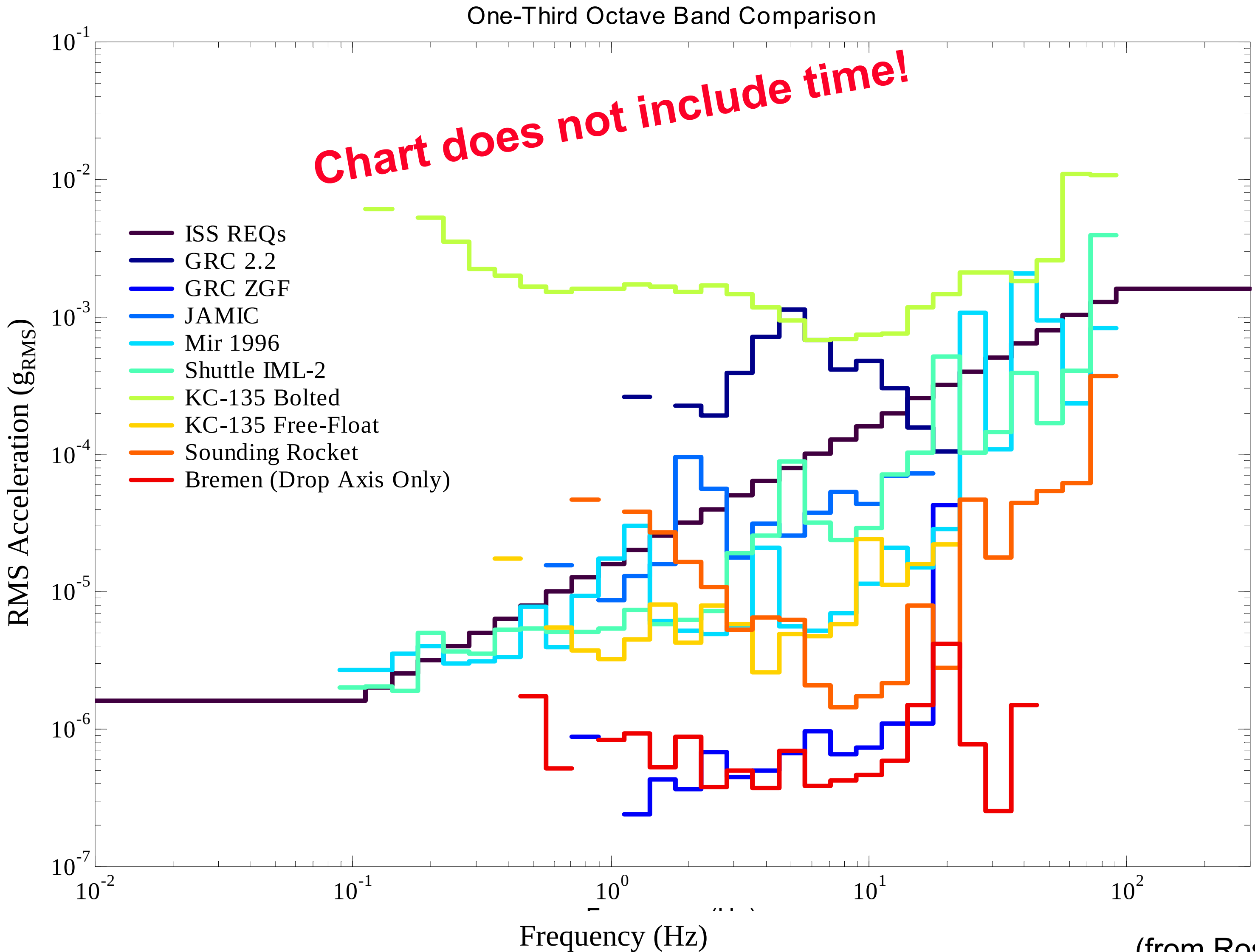
Acronym & Nomenclature List

a	acceleration
DARTFire	Diffusion And Radiative Transport-Controlled Fire (experiment)
F	force
g_e	Earth's gravitational acceleration (location dependent)
GRC	NASA Glenn Research Center
IML	International Microgravity Laboratory (STS mission)
ISS	International Space Station
JAMIC	Japan Microgravity Center
KC	military aircraft designation
kph	kilometers per hour
m	mass
MEIT	Microgravity Environment Interpretation Tutorial
NASA	National Aeronautics and Space Administration
RSS	root sum of squares
SAL	Spread Across Liquids (experiment)
SAMS	Space Acceleration Measurement System
SPF	Space Power Facility
STS	Space Transportation System ("Shuttle")
ug, µg	micro-g; 10^{-6} g
ZARM	Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation, Bremen, Germany
ZGF	Zeolite Growth Furnace

Acceleration measurements for experiments

- Experiments in microgravity are disturbed by accelerations (e.g. vibrations, shocks, gravity gradient, linear motion)
- Experiments in ground laboratories are also disturbed by accelerations
  - 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
- Generally trying to get low-acceleration environment for experiments
- 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

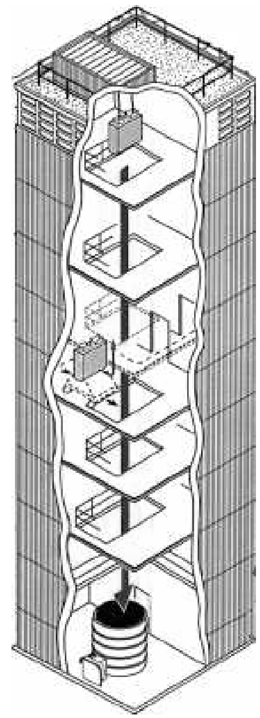
- **Center of Earth’s mass ($g_e \sim 0\ ^m/_{s^2}$)**
  - **Impractical location for experiment operations**
- **Very distant from Earth or other celestial body ($g_e = 10^{-6}\ ^m/_{s^2}$)**
  - **Impractical location for experiment operations**
- **Free fall**
  - **Zero horizontal velocity ------> drop tower ($g_e = 9.8\ ^m/_{s^2}$)**
  - **400 kph horizontal velocity ------> aircraft ($g_e = 9.8\ ^m/_{s^2}$)**
  - **30,000 kph horizontal velocity ------> orbital ($g_e \sim 9\ ^m/_{s^2}$)**
  - **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 with active control**
- **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

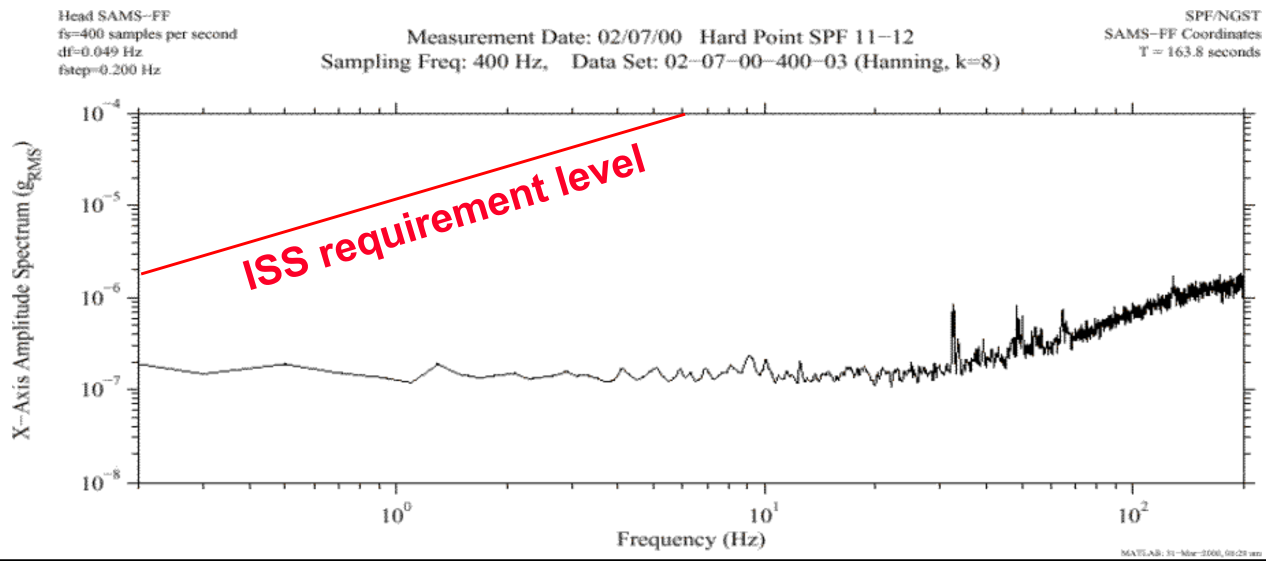
Seismic Mass
Space Power Facility (SPF)
Plum Brook Station, NASA GRC
Base of huge vacuum chamber (illustrative of method to utilize vibration-quiet laboratory conditions)



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

SPF Seismic Mass Characterization

- Figure 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



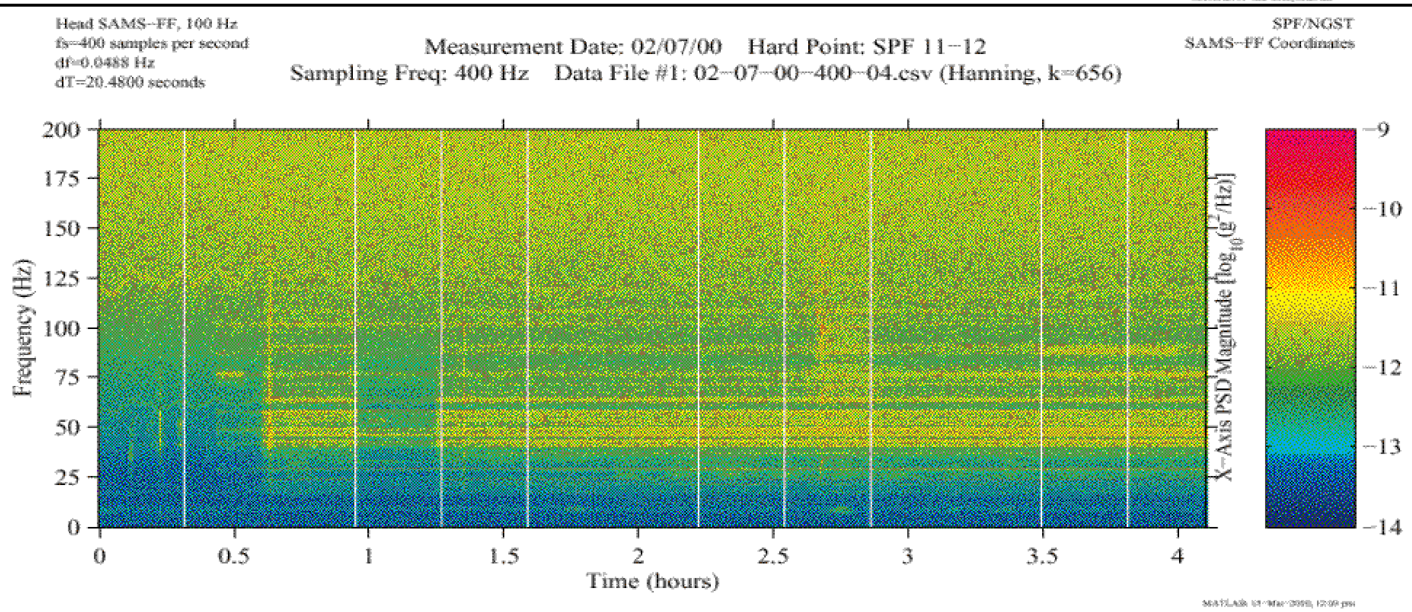
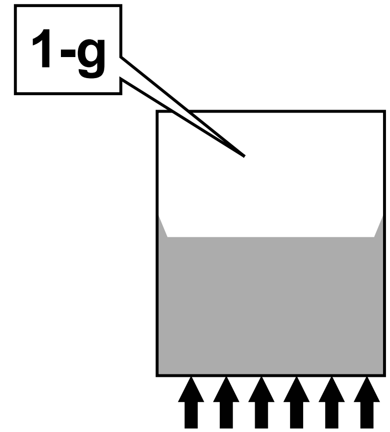
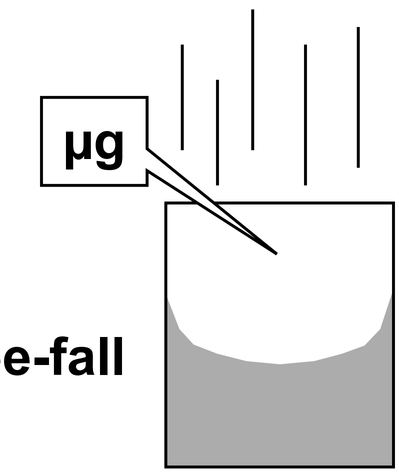


Figure 1: Ground Testing – SPF data

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)**



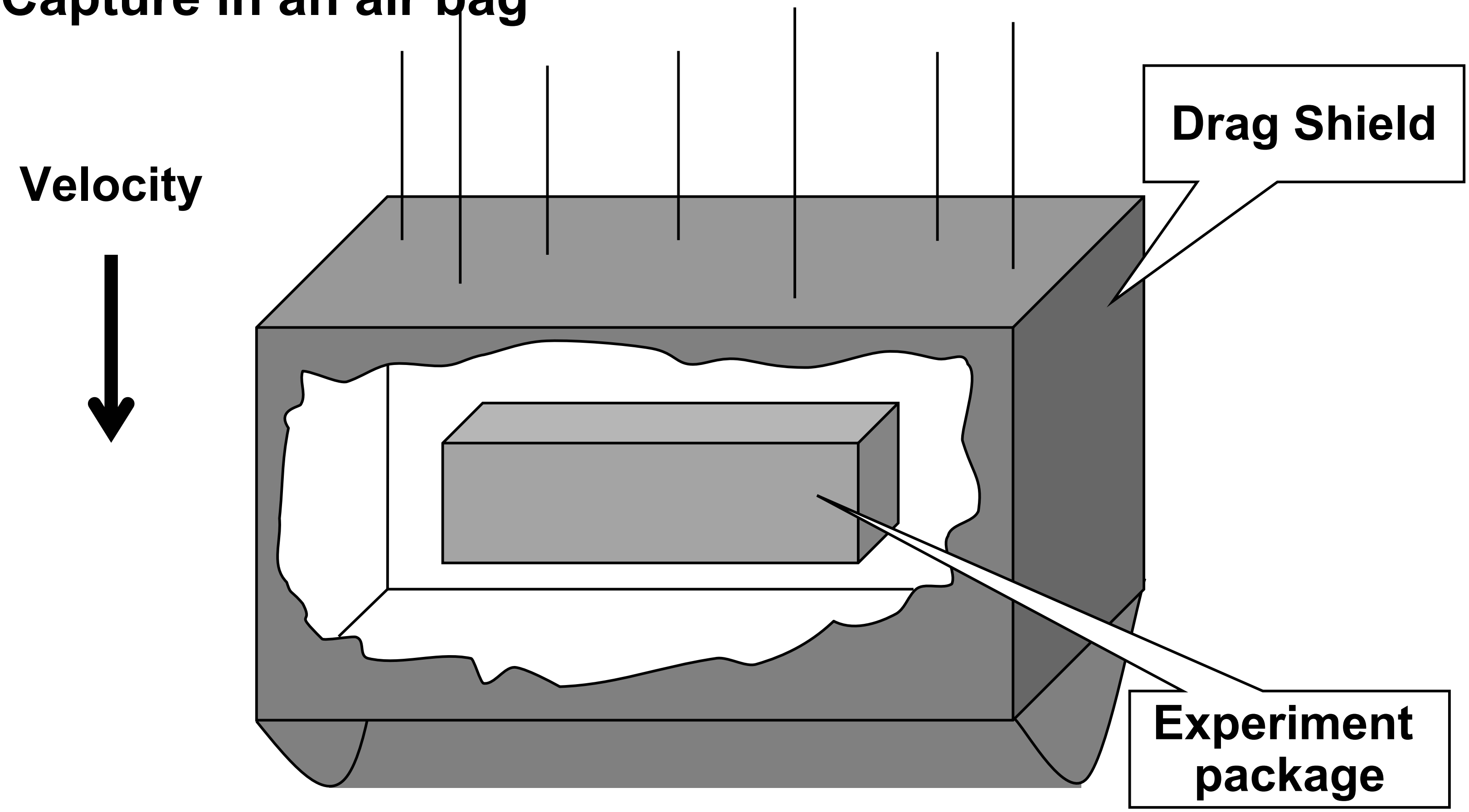
- **Microgravity condition in a free fall**
  - **Gravity effects are not apparent in free fall**
  - **Beaker falls with the fluid**
    - beaker is no longer exerting a retarding force on water
    - sedimentation and buoyancy are reduced
    - surface tension & capillary forces are 'revealed'
  - **Acapulco cliff divers feel weightless during their free-fall to the ocean**
  - **Experiments feel 'weightless' in drop towers**

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

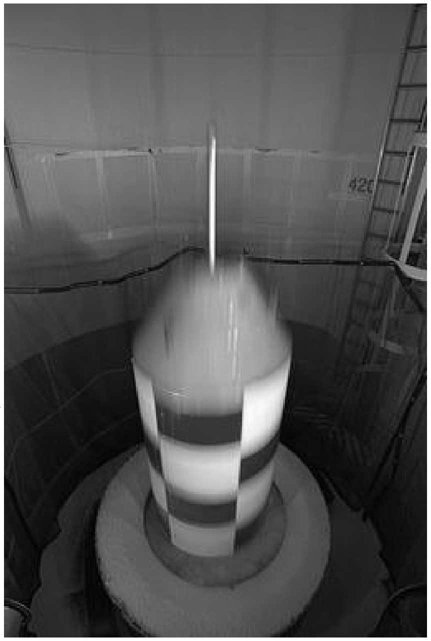
Experiment rig assembly ▲

Drag shield preparation ►

Vacuum Operation

- **Vacuum drop towers include:**
  - **Zero Gravity Research Facility at NASA GRC**
    - Capture in foam pellet container
  - **Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation (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 (JAMIC)**
  - **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**

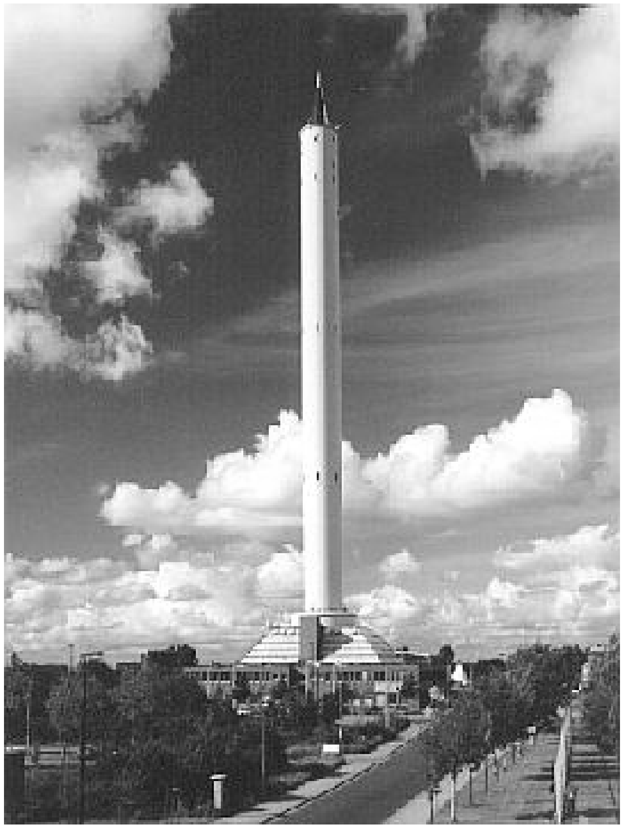
This facility is now closed.

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**

This facility is now closed.



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
    - Transients may persist for major portion of microgravity time
- **Figure 2 illustrates acceleration levels in one axis**
  - **Transition from 1-g to microgravity**
  - **Oscillations during microgravity period (2.2 seconds)**
  - **Transients during "stop" at bottom**

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

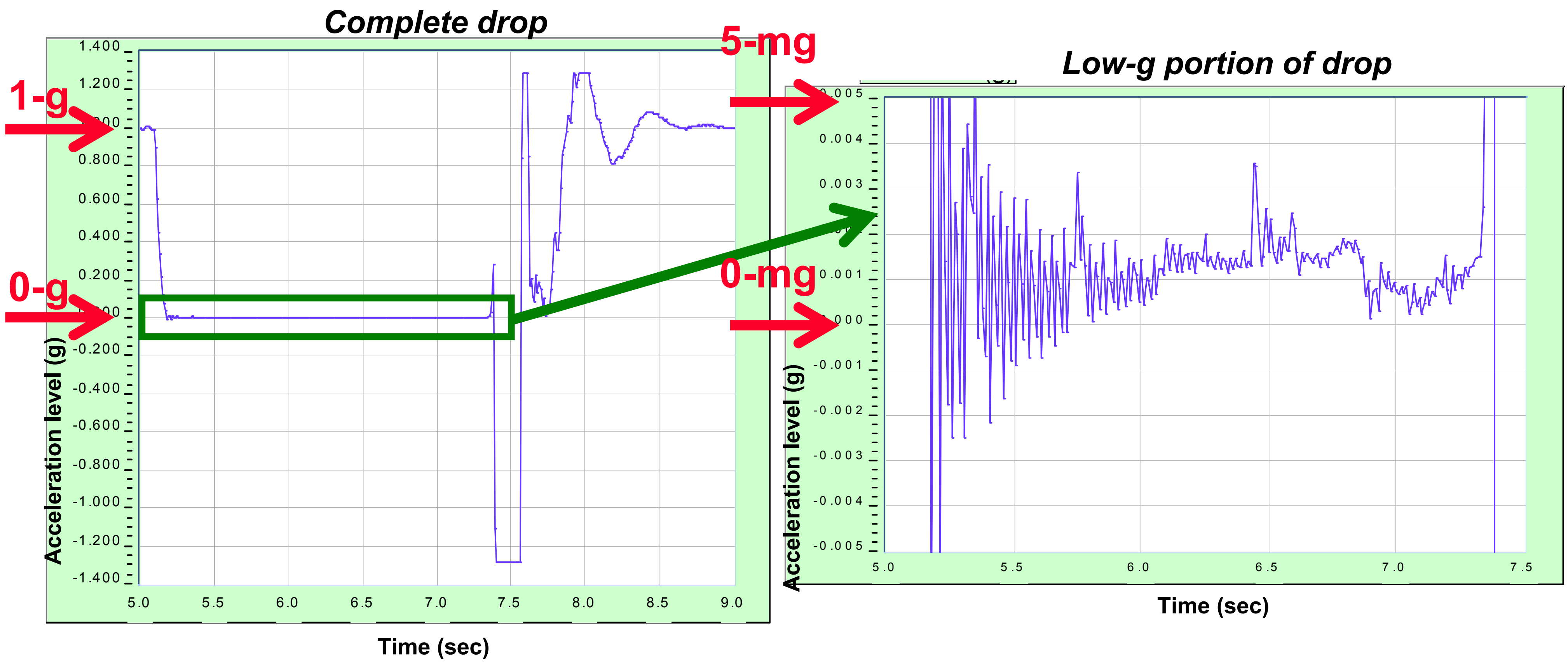


Figure 2: Acceleration level for drop tower test

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 3 illustrates effects of equipment operation during drop**
- **High level of deceleration at capture**
  - **Levels depend on capture mechanism and final velocity**
  - **Figures 2 and 4 illustrate transients during "stop" at the bottom of two different drop towers**

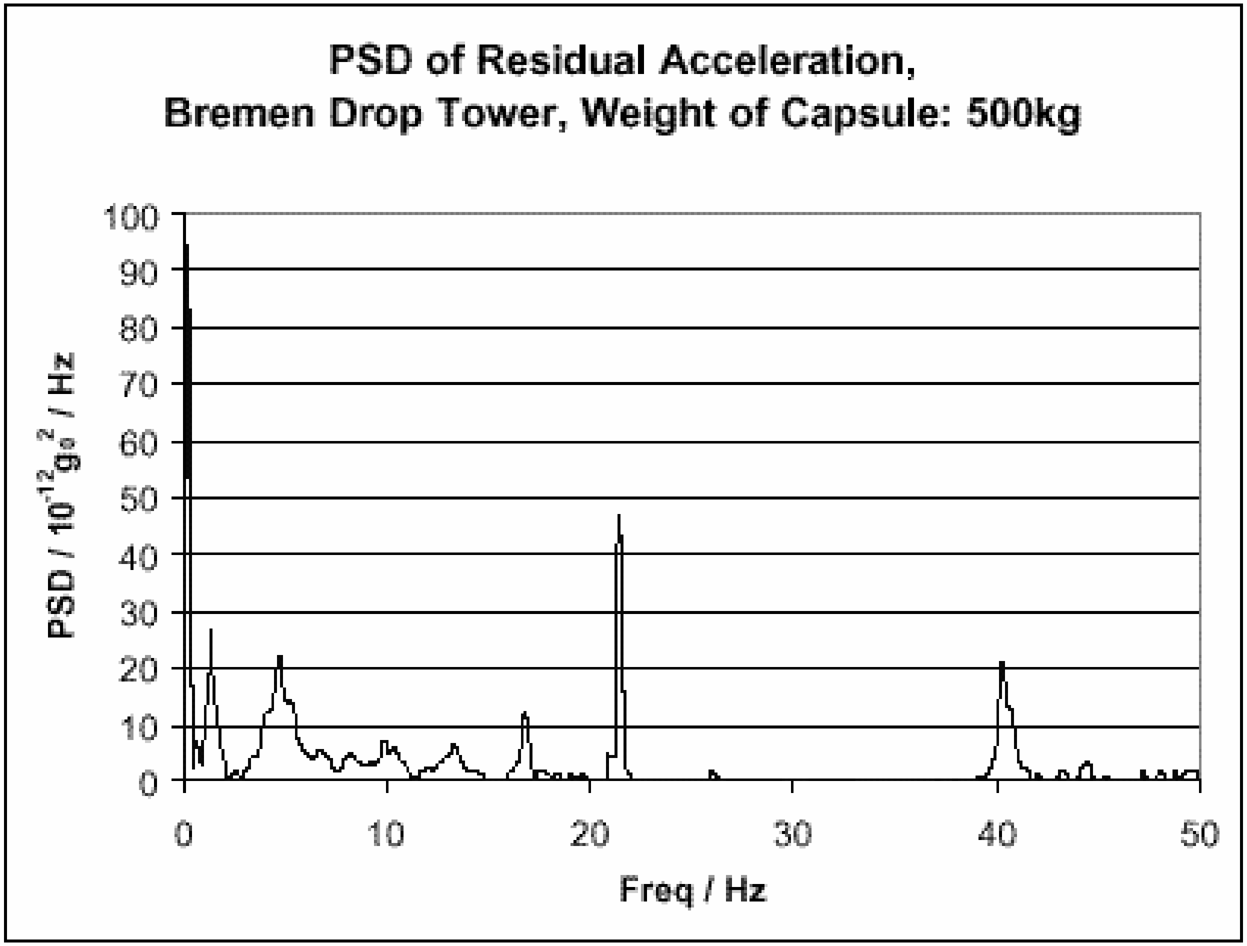


**Figure 3: Power Spectral Density plot during drop (ZARM)
(note: release disturbances not included)**

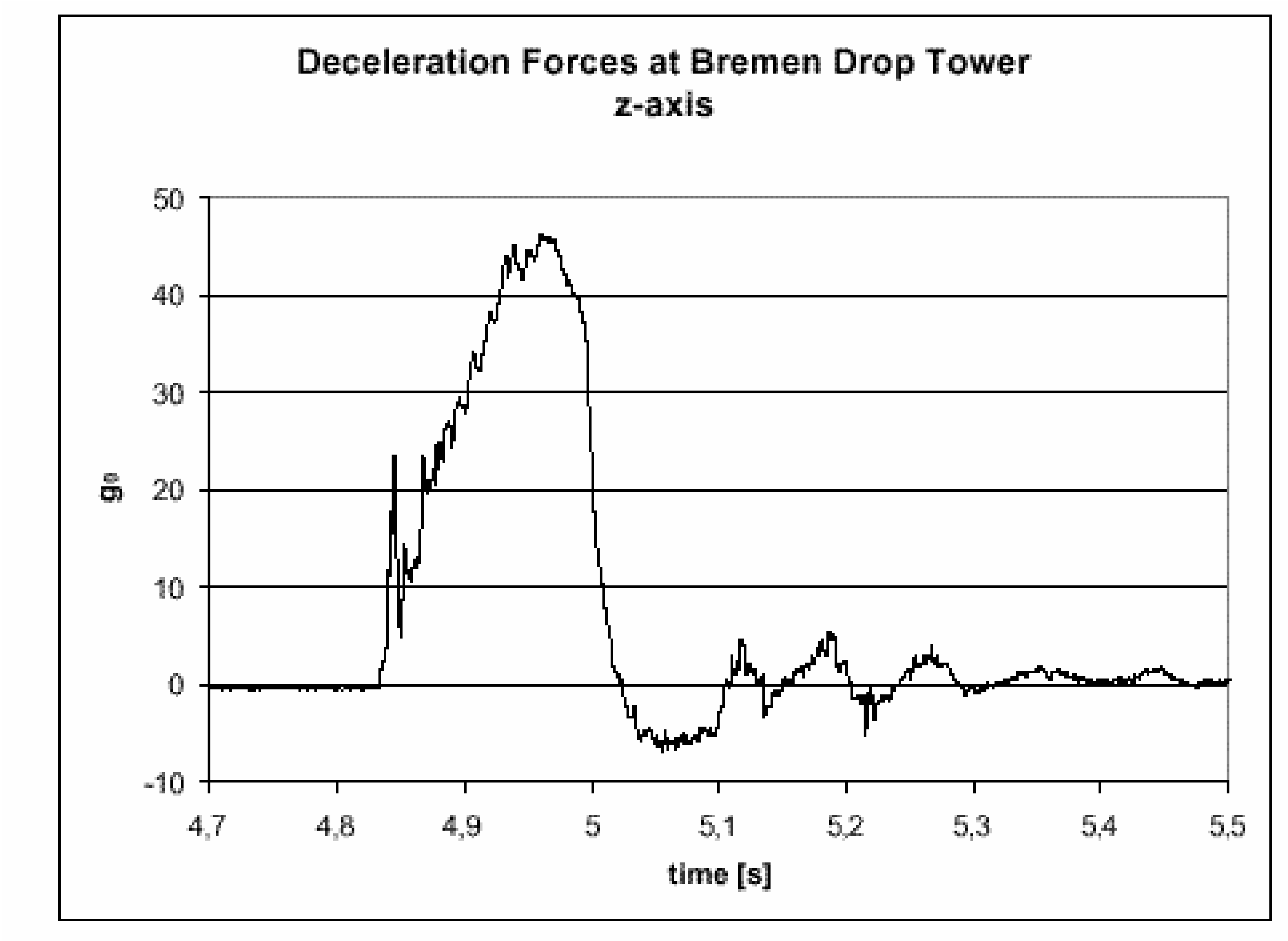
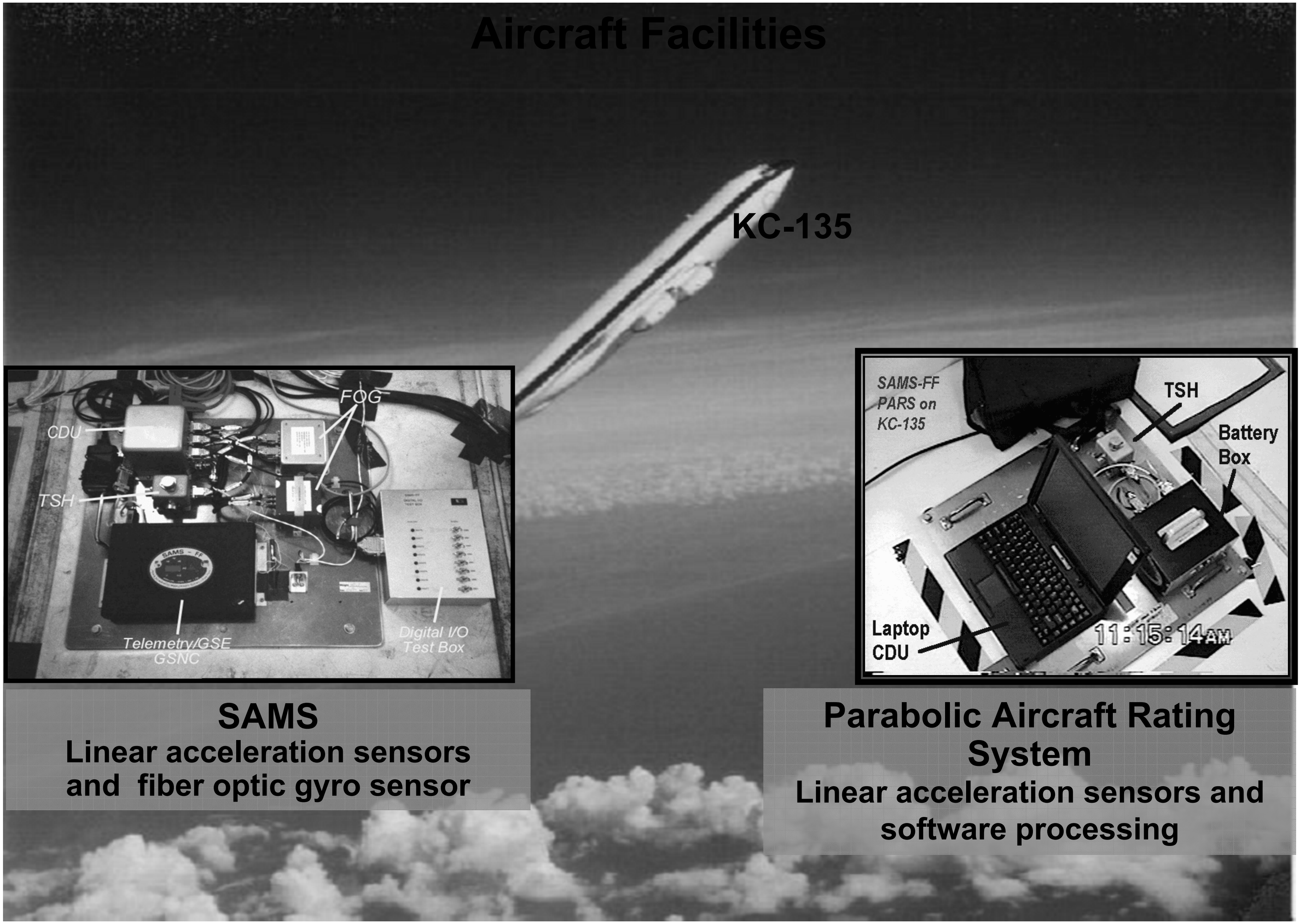


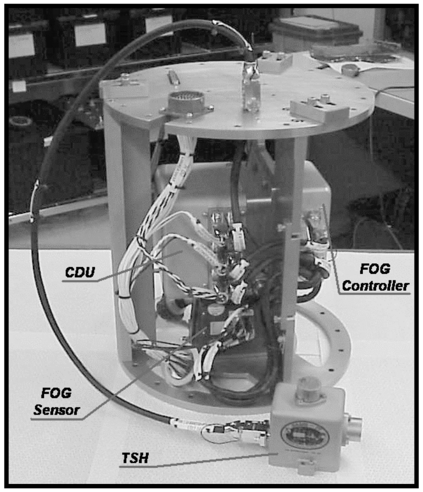
Figure 4: Deceleration at capture (ZARM)

Non-orbital flight platforms
(~ 300 kph horizontal velocity)

- "Parabolic" trajectory
  - In reality, an elliptical path
- 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
KC-135
FOG
CDU
TSH
Telemetry/GSE
GSNC
Digital I/O
Test Box
SAMS-FF
PARS on
KC-135
TSH
Battery
Box
Laptop
CDU
11:15:14AM
SAMS
Linear acceleration sensors and fiber optic gyro sensor
Parabolic Aircraft Rating System
Linear acceleration sensors and software processing

Sounding Rockets



SAMS
Linear acceleration sensors and fiber-optic gyro sensor

KC-135 Environment Characterization

- **Figure 5 illustrates the KC-135 overall environment over multiple parabolas during a typical campaign**
- **Figure 6 is a detailed plot of the KC-135 environment during the reduced gravity portion of the parabola**
- **Figure 7 is the acceleration environment of a KC-135 parabola for the Spread Across Liquids (SAL) experiment.**
  - **SAL test equipment was free-floated during the parabola**
  - **In that period, the acceleration environment was less than 0.15 milli-g, peak-to-peak**

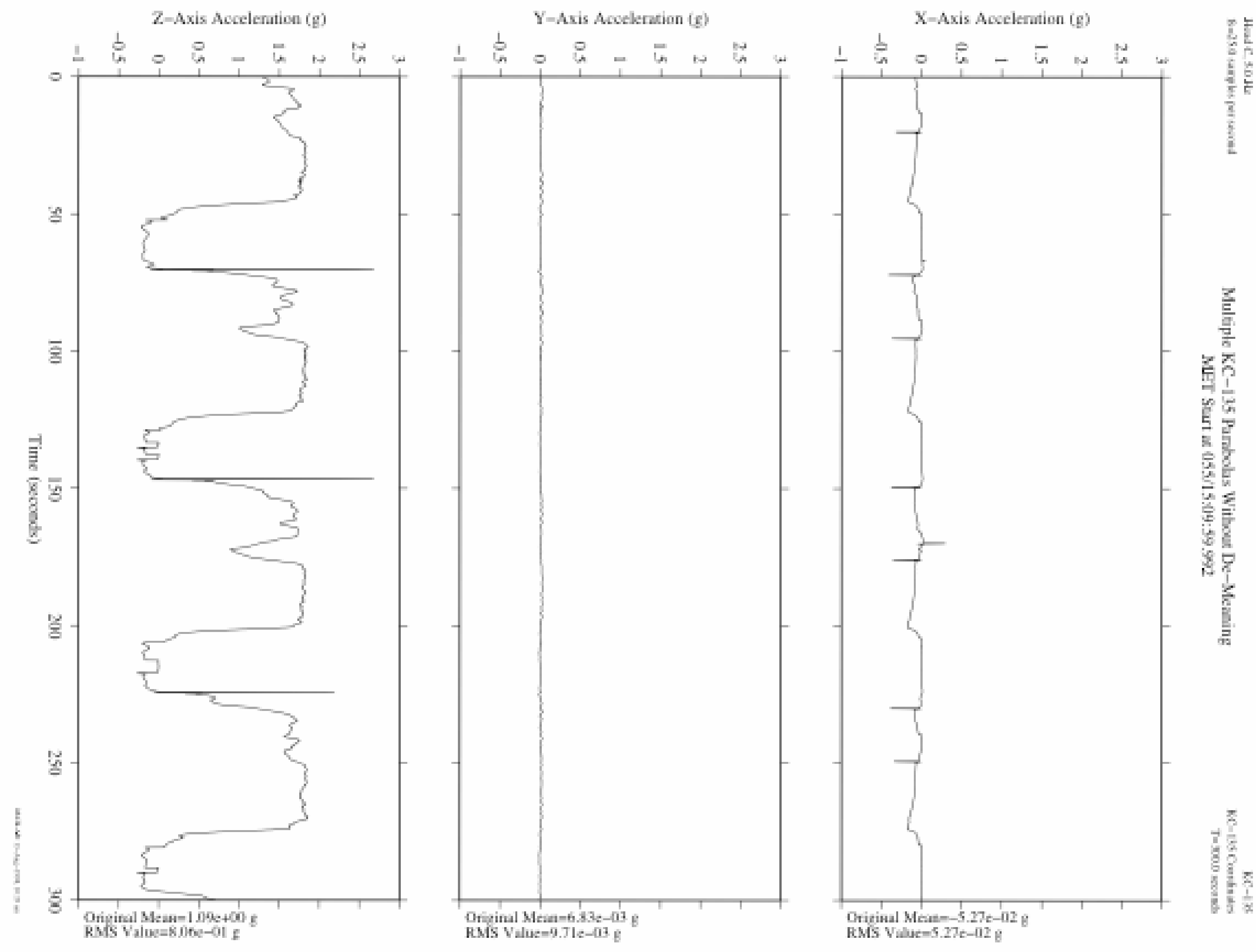


Figure 5 - KC-135 acceleration environment over several parabolas

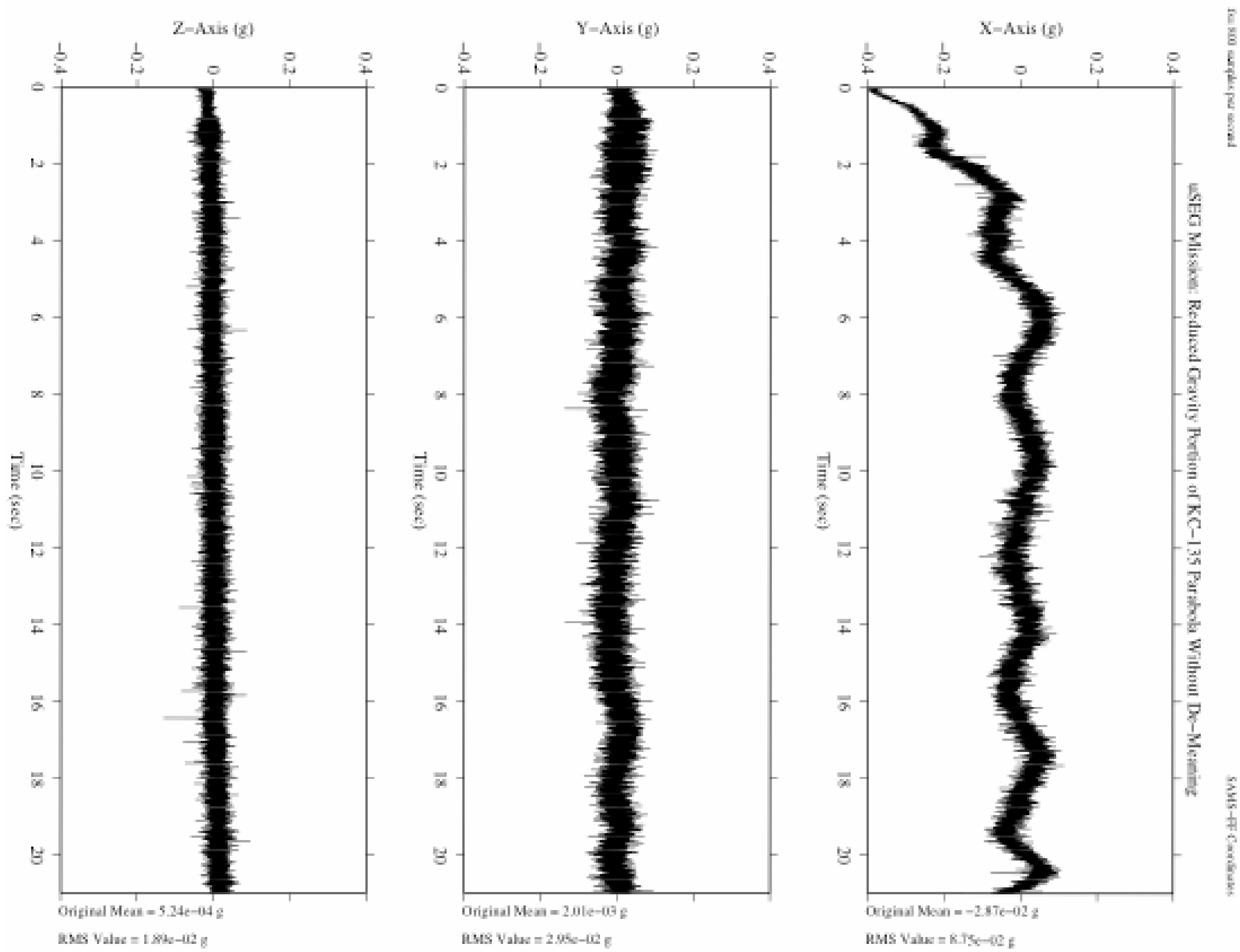


Figure 6 - Low-g portion of KC-135 parabola

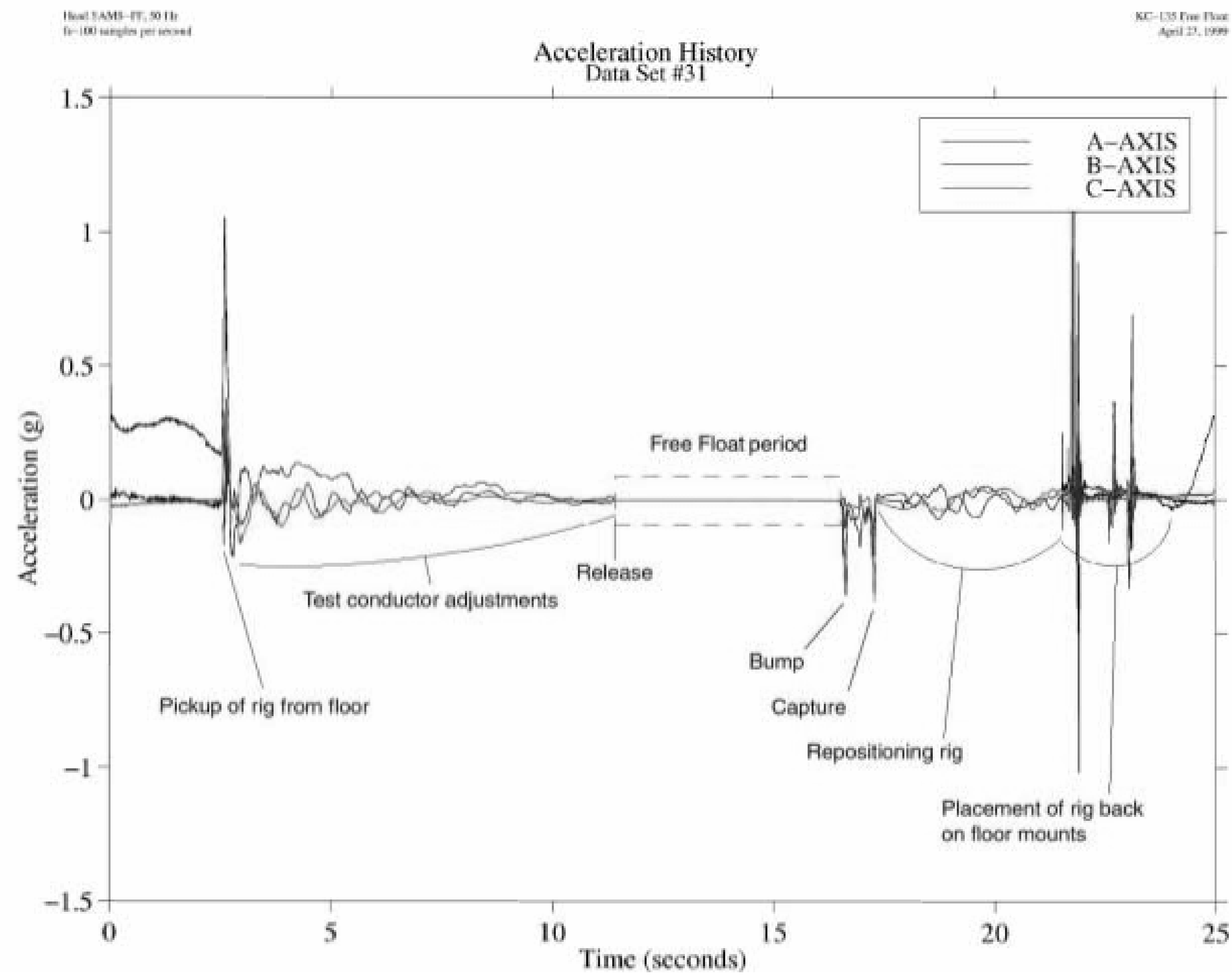


Figure 7 - Acceleration environment for parabola in which an experiment was free-floated

Sounding Rocket Environment Characterization

- **Terrier-Black sounding rocket flight**
  - **Flight timeline is shown in Figure 8**
  - **DARTFire combustion experiment payload**
  - **SAMS data rate adjusted during flight**
    - Maximize data acquisition for limited storage capacity
    - Acquisition according to science requirements for low-frequency measurements
- **For period when sample rate was 25 samples per second:**
  - **Environment was less than 30 μg root sum square (RSS)**
  - **RSS power spectral density is shown in Figure 9**
    - Frequency domain characteristics match known disturbance sources internal to the DARTFire equipment
      - Intensified Multispectral Imager filter wheel operates at 5 Hz
      - Infrared Imager filter wheel operates at 1 Hz

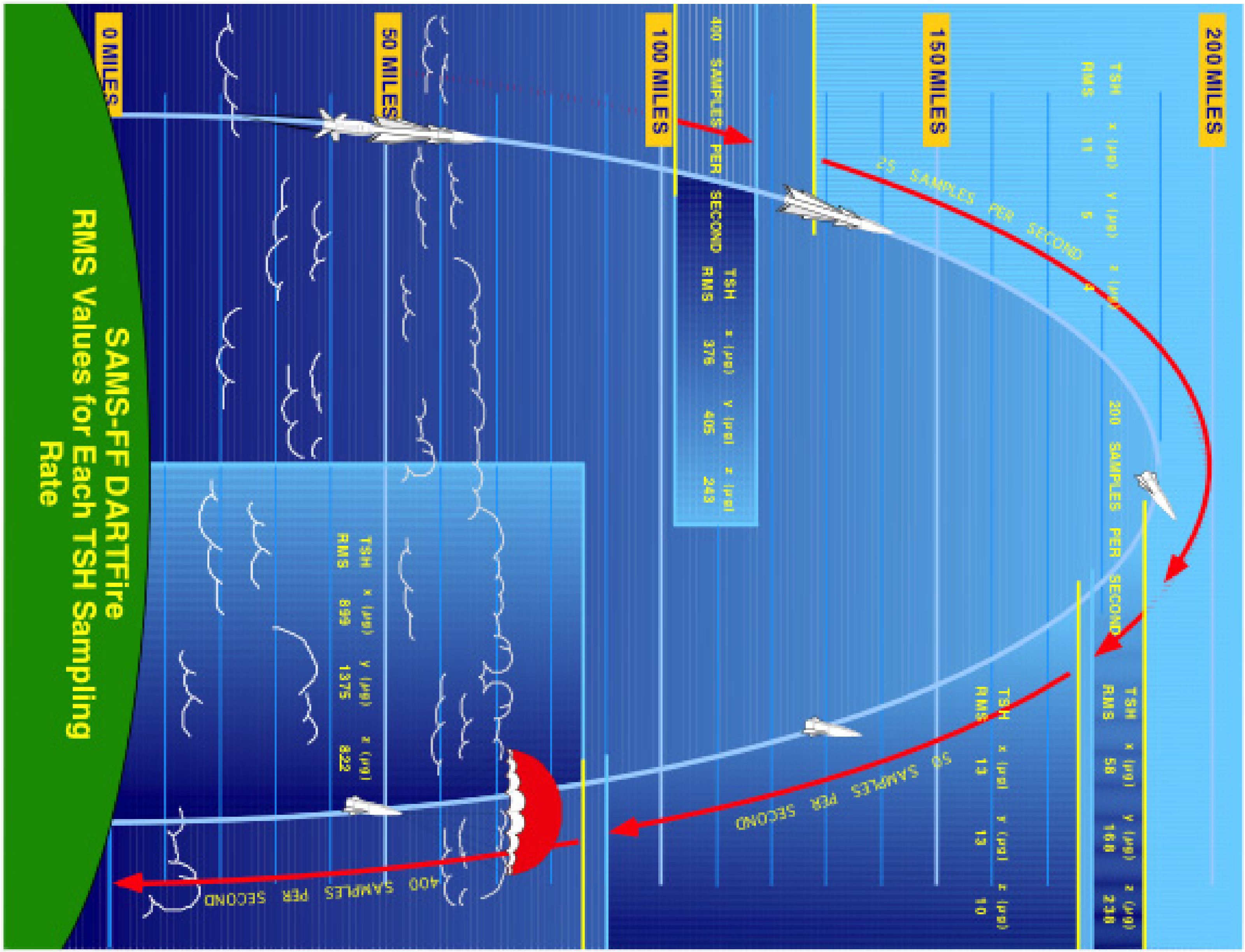


Figure 8 - Terrier-Black sounding rocket flight timeline

Terrior-Orion Sounding Rocket

Microgravity Levels during Flight of DARTFire

Altitude (miles)	Sample rate (samples / sec)	X (ug RMS)	Y (ug RMS)	Z (ug RMS)
102 to 118	400 s/s	376	405	243
118 to 190	25 s/s	11	5	4
190 to 175	200 s/s	58	168	238
175 to 85	50 s/s	13	13	10
85 to 0	400 s/s	899	1375	822

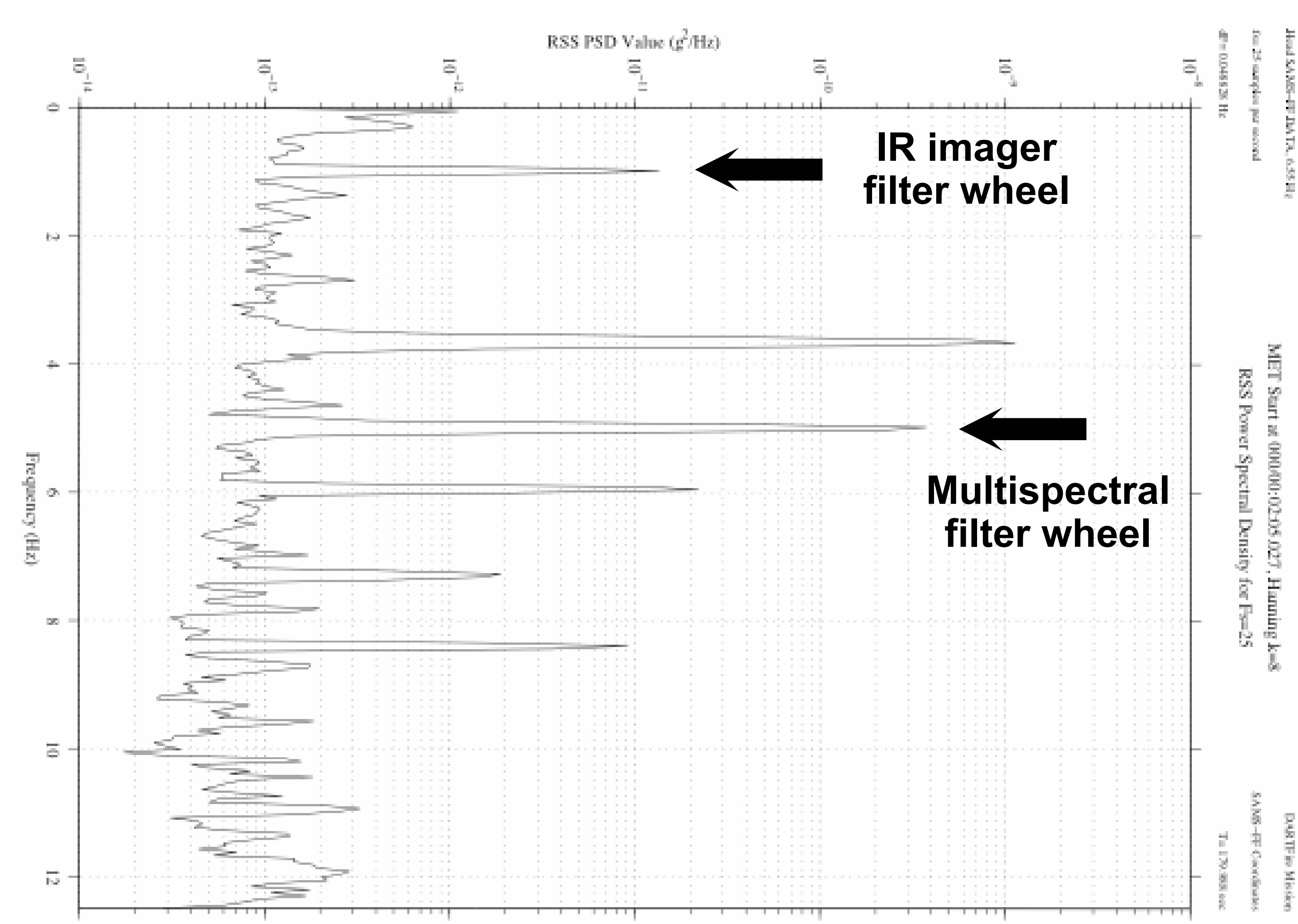


Figure 9 - Power spectral density during DARTFire experiment operations

Summary

- **Reduced-gravity environment**
  - **Does not have to be in space**
  - **Disturbances exist both in ground-based laboratories and in space**
- **Acceleration environment of experiments**
  - **Measure and understand during ground-based testing**
  - **Basis for comparison as acceleration environment improves**
    - For example, as experiment moves from lab testing to drop tower to KC–135 to ISS

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
- **Microgravity Carrier Summary**
  - http://microgravity.msfc.nasa.gov/NASA_Carrier_User_Guide.pdf
  - Ross, H. D. (2001) *Microgravity Combustion*, Academic Press