SECTION 2

Working in a Reduced Gravity Environment: “A Primer”

Kenol Jules

PIMS Project Scientist

NASA Glenn Research Center

March 5th, 2002

CONTENT

- Reduced Gravity Environment Description
  --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

- Earth-bound experiments are affected by normal gravity and vibrational forces, which exist in ground laboratories:
  - ¤ gravity, elevators, air conditioner, people and so on...
- Most microgravity experiments desire:
  - ¤ zero gravity, or
  - ¤ constant, uni-directional acceleration, or
  - ¤ constant conditions
- Taking experiments to orbit removes effects of gravity, but trades ground disturbances for other:
  - ¤ gravity gradient, aerodynamic drag, thrusters, other experiments disturbances, vehicle sub-systems and crew disturbances
- Experiments may be disturbed by accelerations from various sources

The reduced gravity acceleration environment of an orbiting spacecraft in a low earth orbit is a very complex phenomenon. Many factors contribute to form the overall environment. In general, it can be considered as made up of the following three components:

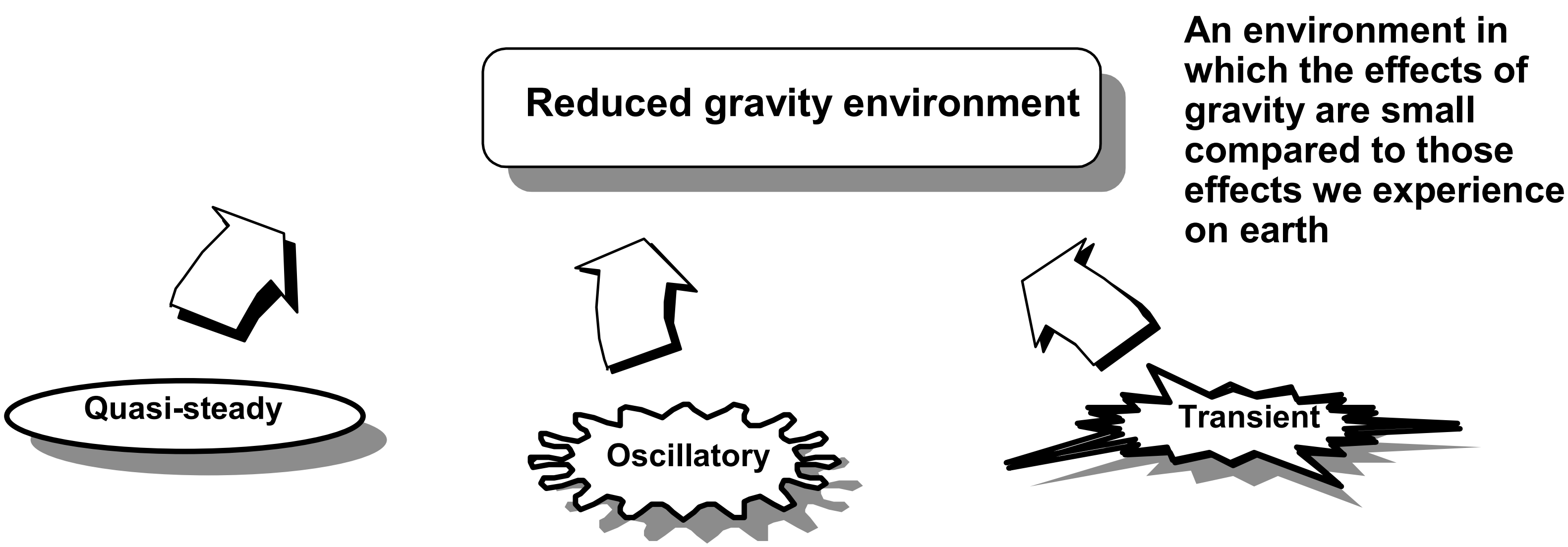
QUASI-STEADY: is composed of those accelerations that vary over long periods of time, typically longer than a minute for space-based platforms.

VIBRATORY: is composed of those accelerations that are harmonic and periodic in nature with a characteristic frequency.

TRANSIENT: is composed of those accelerations that last for a short period of time, and are non-repetitive.

What is a *“reduced gravity environment”* ?

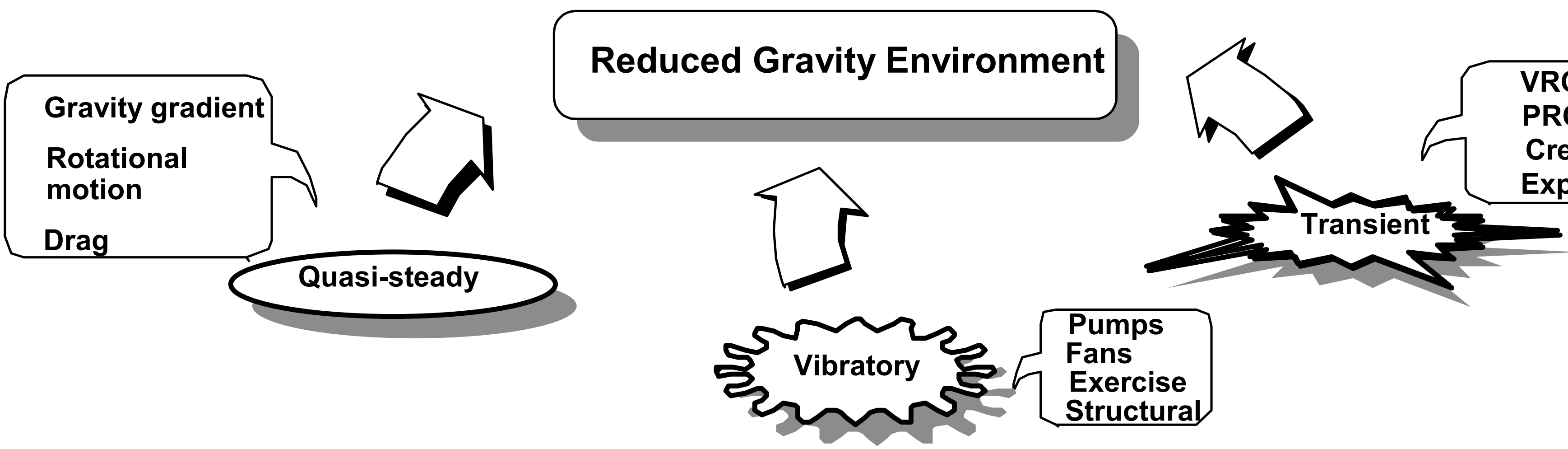
Major properties



What is a *"Reduced Gravity Environment"* ?

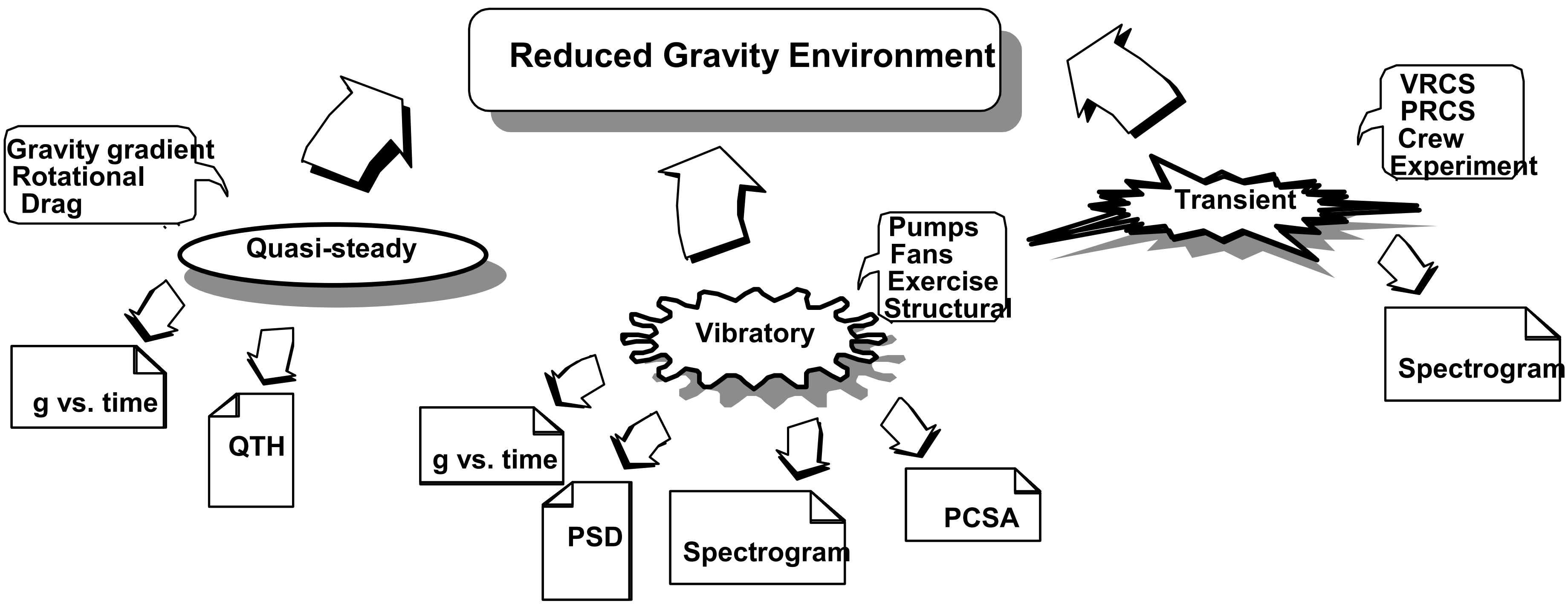
Major properties

What causes these accelerations?



What is a *"Reduced Gravity Environment"* ?

- **Major properties**
- **What causes these accelerations**
- **How do we display them?**



Definitions

- **Reduced Gravity Environment:** an environment in which the effects of gravity are small compared to those we experience on Earth
- **Vibratory:** term used to describe vibratory disturbances with frequency content greater than 0.01 Hz
- **Transient:** signals that are impulsive in nature; passing quickly into and out of existence. They are broadband.
- **Quasi-steady:** signal which varies at a very low frequency, typically below 0.01 Hz

Components of the Reduced Gravity Environment

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

Microgravity Environment

Component	Quasi-Steady	Vibratory	Transient
Frequency	$0 \leq f < 0.01$ Hz	$0.01 \leq f \leq 300$ 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

WHAT DO ALL THESE MEAN TO YOU?

- **The environment is <u>NOT</u> "zero-g"!**
- **Experiments may be affected by the reduced gravity environment**
- **This tutorial will explain to you what the environment is likely to be, how we measure it, how we interpret it, and will show you what impact the environment has had on some experiments.**

REDUCED GRAVITY ENVIRONMENT DESCRIPTION

Reduced gravity Facilities	Duration	Acceleration Levels	Notes
Drop Towers	< 10 seconds	10^{-3} g	NASA, Japan, Germany
Parabolic Aircraft	15 – 25 seconds	$1.5x10^{-2}$ g	~ 40 parabolas per campaign
Rockets	Up to 600 seconds	10^{-5} g	Various countries
SPACEHAB Module	Up to 16 days	< $5.5x10^{-4}$ g (for the combined three axes	Frequency range: 0.01 – 25 Hz
Spacelab Module (MPESS)	Up to 16 days	< $1.4x10^{-3}$ g (for the combined three axes)	Frequency range: 0.01 – 25 Hz
Spacelab Module	Up to 16 days	< $3x10^{-3}$ g (for the combined three axes)	Frequency range: 0.01 – 25 Hz
STS overall Quasi-Steady environment	Up to 15 days	< $1x10^{-6}$ g	Frequency range: 0.0 – 0.01 Hz. Average values for typical orbiter attitudes
STS overall vibratory environment	Up to 15 days	Tens to thousands μg_{RMS}	Depending on what activity is taking place
STS overall transient environment	Up to 15 days	Tens of µg peak	Depending on what activity is taking place

NOTE:

The acceleration level values listed in this table are NOT to be used as a nominal value of the reduced gravity environment of any specific platform. The environment is very dynamic in nature. They are listed here to illustrate the non-zero nature of the reduced gravity environment. The actual value for any of the platform listed here, at any moment in time, is frequency dependent (mission timeline activity dependent).

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

ISS Microgravity Environment Requirements

- Microgravity science researches perform on the ISS are science “requirement” driven, rather than vehicle “capability” driven

- Space Shuttle is used for microgravity experiments, but there are no Space Shuttle microgravity requirements

- ISS, on the other hand, DOES have microgravity requirement associated with the different regimes: Quasi-steady, Vibratory, Transient and time duration. These requirements are discussed in the next few charts

ISS Microgravity Environment Requirements

- The environmental requirement is specified as a "not to exceed" acceleration magnitude
  - Quasi-steady accelerations have directional requirements
  - Vibratory accelerations have RMS limits as a function of frequency
  - Transient accelerations have both magnitude limitation and integrated acceleration requirements
- These requirements must be met in minimum time intervals of 30 continuous days, with a cumulative time duration of not less than 180 days per year
- These must be achieved at 50% or more at the designated internal science locations (racks) on the station

ISS Microgravity Environment Requirements

- During the periods designated as "Microgravity mode", ISS will be operated to meet the microgravity environment requirements. Otherwise, ISS will be in what is called: "Non-microgravity mode"
  - ¤ These requirements applied only for ISS assembly complete
- Design requirements and operational constraints on ISS are intended to limit acceleration disturbances in three regimes:
  - Quasi-steady, $f \leq 0.01$ Hz
  - Vibratory, 0.01 Hz $\leq f \leq$ 300 Hz
  - Transient (short duration relative to an orbital period, non-periodic and broadband)

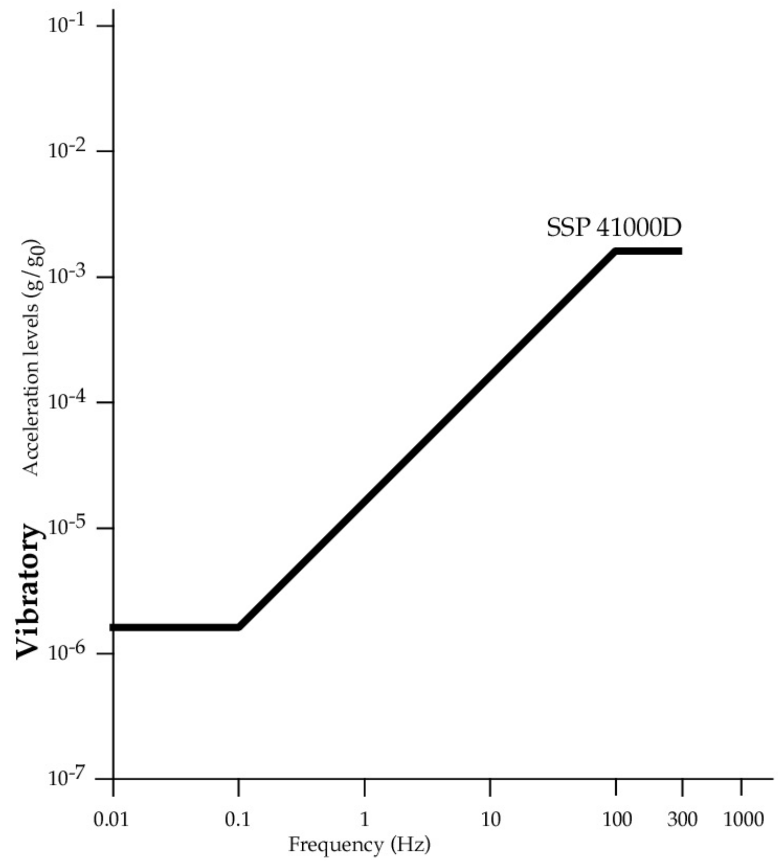
ISS Microgravity Requirements

Summary

Quasi-steady
- Steady state < f < 0.01 Hz
- g ≤ 1 μg_{rms}
- Stability: perpendicular g ≤ 0.2 μg_{rms}

Vibratory
- Levels in figure at structural mounting interfaces
- RMS acceleration magnitude in one-third octave averaged over 100 seconds
- Does not include crew disturbances

Transient
- g ≤ 1000 μg per axis
- g ≤ 10 μg-sec per axis (integrated over 10 sec)



ISS Microgravity Environment Requirements

ISS Microgravity Environment

THE Requirement for the International Space Station

DURATION · QUASI-STEADY · VIBRATORY · TRANSIENT

Mode: Microgravity - habitable

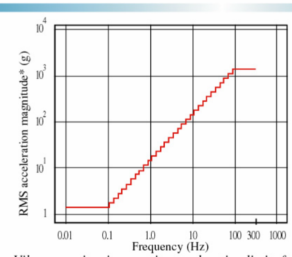
This mode consists of capabilities required for microgravity research by user payloads in a habitable environment. This mode does not include the effects of crew activity, but does include the effects of crew equipment, such as the operation of exercise devices and latched or hinged enclosures. Crew effects will be mitigated to the extent possible. This mode consists of the capabilities described in SSP 41000 and the following unique capability.

Capability: Support microgravity experiments

The purpose of this capability is to establish the required environment for microgravity experiments. The Space Station shall provide the following microgravity acceleration performance for at least 50 percent of the internal payload locations (excluding Nadir window payload location) for 180 days per year in continuous time intervals of at least 30 days:

a. At the centers of the internal payload locations, a quasi-steady (<0.01 Hz) acceleration
   (1) Magnitude less than or equal to 1 micro-g
   (2) Component perpendicular to the orbital average acceleration vector less than or equal to 0.2 micro-g
b. At the structural mounting interfaces to the internal payload locations
   (1) A vibratory acceleration limit as defined in the figure below
   (2) A transient acceleration limit for individual transient disturbance sources less than or equal to 1000 micro-g per axis
   (3) An integrated transient acceleration limit for individual transient disturbance sources less than or equal to 10 micro-g seconds per axis over any 10 second interval

The Space Station shall monitor and record the microgravity environment at selected locations.



for $0.01 \le f \le 0.1$ Hz: $a \le 1.6$ µg
for $0.1 < f \le 100$ Hz: $a \le f \times 16$ µg
for $100 < f \le 300$ Hz: $a \le 1600$ µg
where: f = frequency
a = acceleration

*NOTE: Root-mean-square acceleration magnitude 1/3 octave bands average over 100 seconds.

Vibroacoustic microgravity acceleration limits for the International Space Station vehicle

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- **Microgravity Disciplines Sensitivity Assessment**
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

Fundamental Physics

Quasi-steady
- A large quasi-steady level will destroy sample uniformity of critical fluid

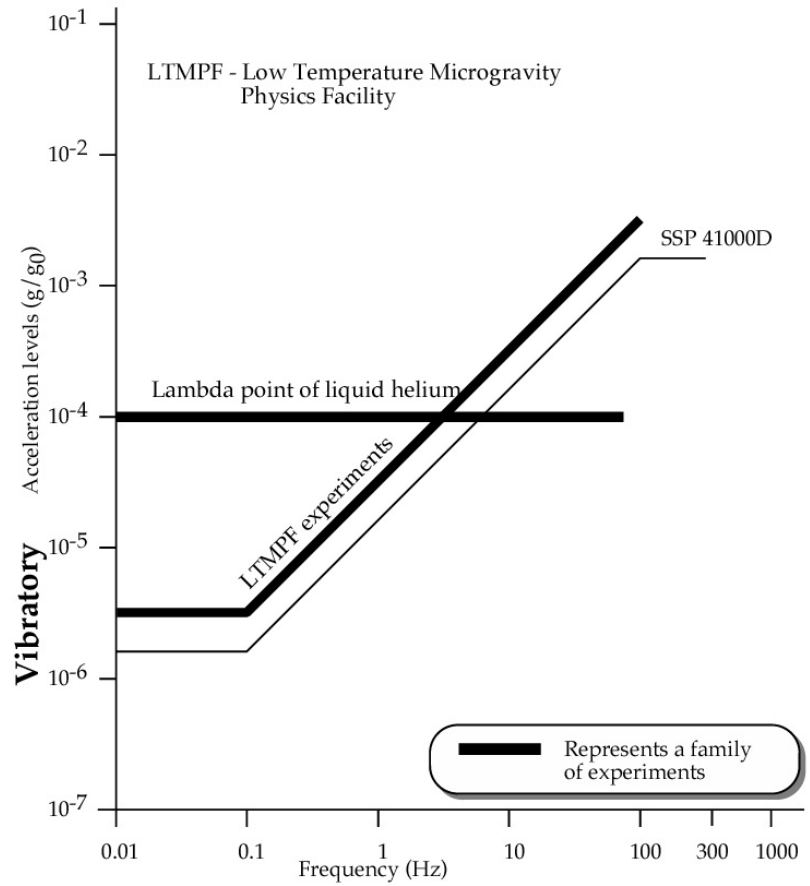
Vibratory
- Primary concern is vibratory heating of sample and destruction of sample uniformity

Transient
- Primary concern is vibratory heating of sample and destruction of sample uniformity

Rationale
- Low temperature physics experiments rely on establishment of highly uniform sample in microgravity

---

- NOTE: Many of these experiments are expected to be operated on the JEM-EF



Combustion Science

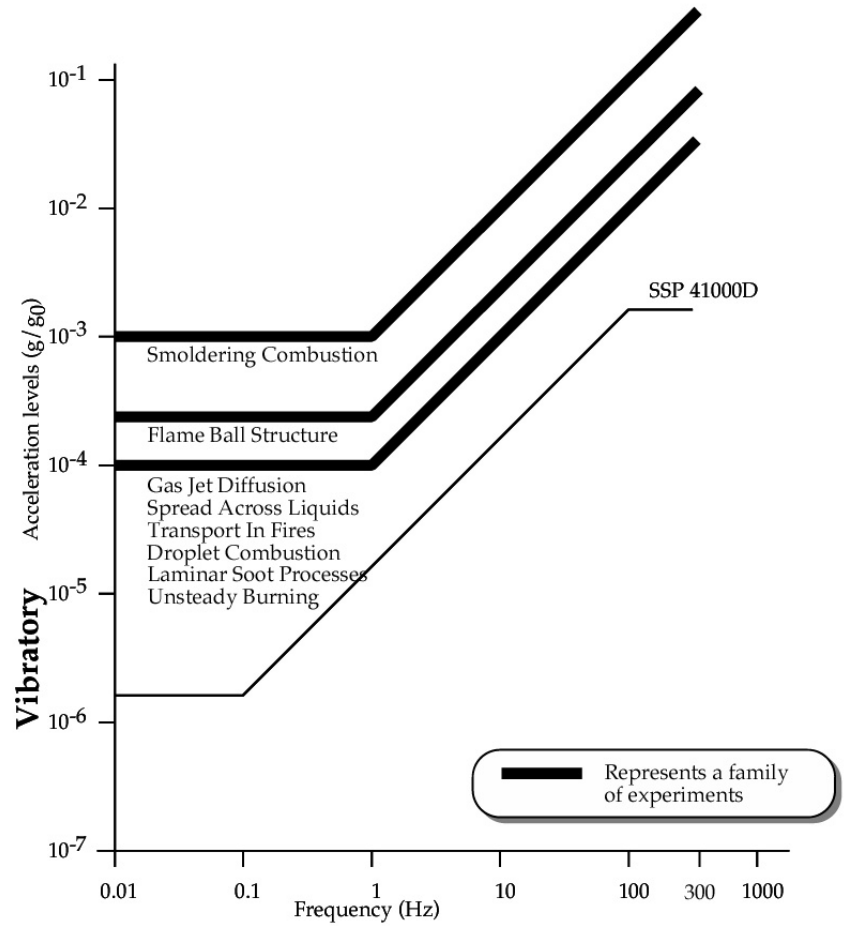
Quasi-steady
- Not a major concern (10^{-4} g_o)

Vibratory
- Typically low acceleration levels at low frequencies (< 1 Hz) disturb experiments
- Most experiments are above the ISS requirement curve but some are below the expected environment
- Low frequency g-jitter has been observed repeatedly to affect the combustion characteristics of a variety of flames, e.g., candle, gas jet, flame balls, etc.

    ref: Dr. H. Ross/NASA LeRC

Transient
- Tolerable for most experiments with time and magnitude restrictions on the disturbance

Rationale
- Microgravity conditions allow:
  - isolation of gravity-driven mechanisms;
  - influence of transport phenomena
  - creation of symmetry and/or boundary & initial conditions
  - new diagnostic probing or testing of similitude
- Microgravity environment has attracted widespread external peer advocacy for combustion science in space



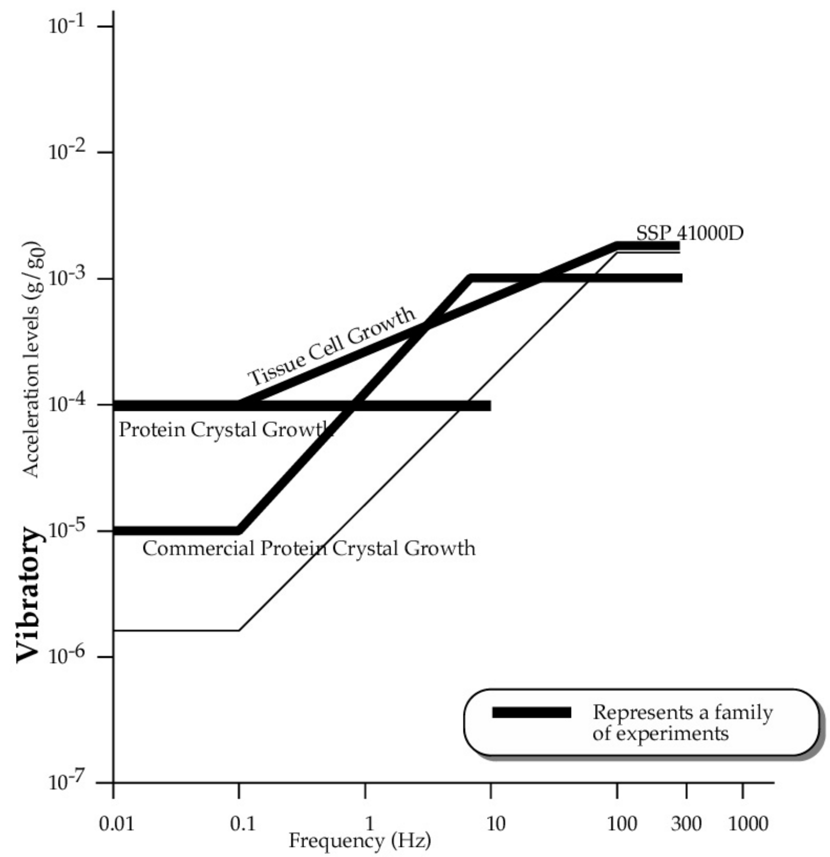
Biotechnology

Quasi-steady
- Not a major concern (10^{-3} to 10^{-4} g_o)

Vibratory
- Impact at higher frequencies of the desired operating level

Transient
- Primary concern is for large scale accelerations, such as Orbital Maneuvering System engines and crew disturbances

Rationale
- Large disturbances cause nucleations to occur in multiple sites destroying single crystal formation



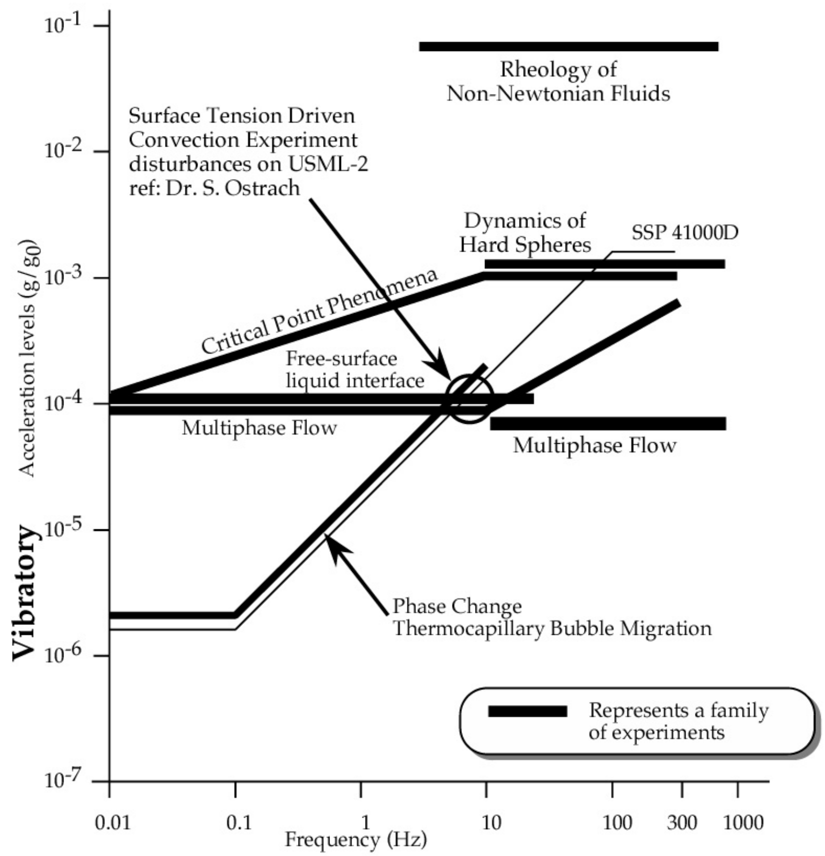
Fluid Physics

Quasi-steady
- Quasi-steady accelerations disturb most fluid experiments (2X10^{-6} g_o)

Vibratory
- Mid-range frequencies of expected environment will disturb fluid free surface experiments
- Some experiments require environment at lower levels than the ISS requirements curve
  e.g. Thin Film Fluid Flows at Menisci
- Surface Tension Driven Convection Experiment experienced surface distortion due to g-jitter frequently throughout the USML-2 mission
  ref: Dr. S. Ostrach/CWRU

Transient
- Transients disturb fluid experiments with lower viscosity fluids

Rationale
- Accelerations above a threshold cause interface instability, density settling, and density-driven convection & mixing



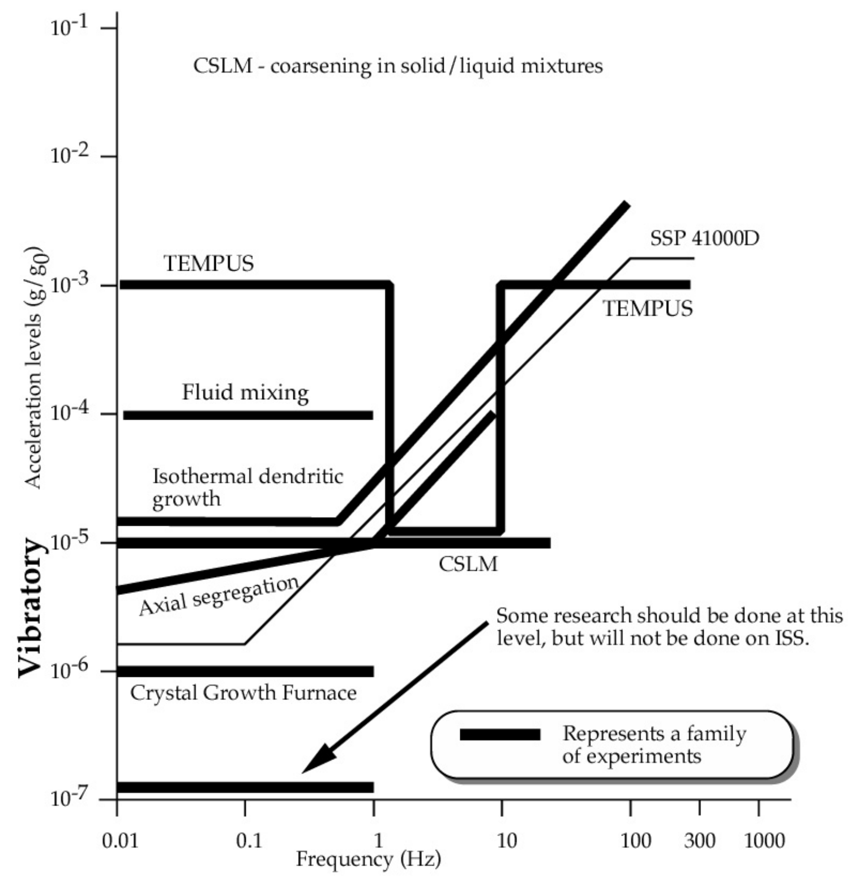
Materials Science

Quasi-steady
- Some samples and processes require very low quasi-steady acceleration levels (a < 0.1 micro-g)
  e.g., Stoke's settling, Bridgman growth, Float zone
- Residual acceleration direction and stability are important factors for crystallization processes
- A Crystal Growth Furnace sample was withdrawn from USML-2 due to a change in Orbiter attitude just before launch
  ref: Dr. S. Lehoczky/NASA MSFC

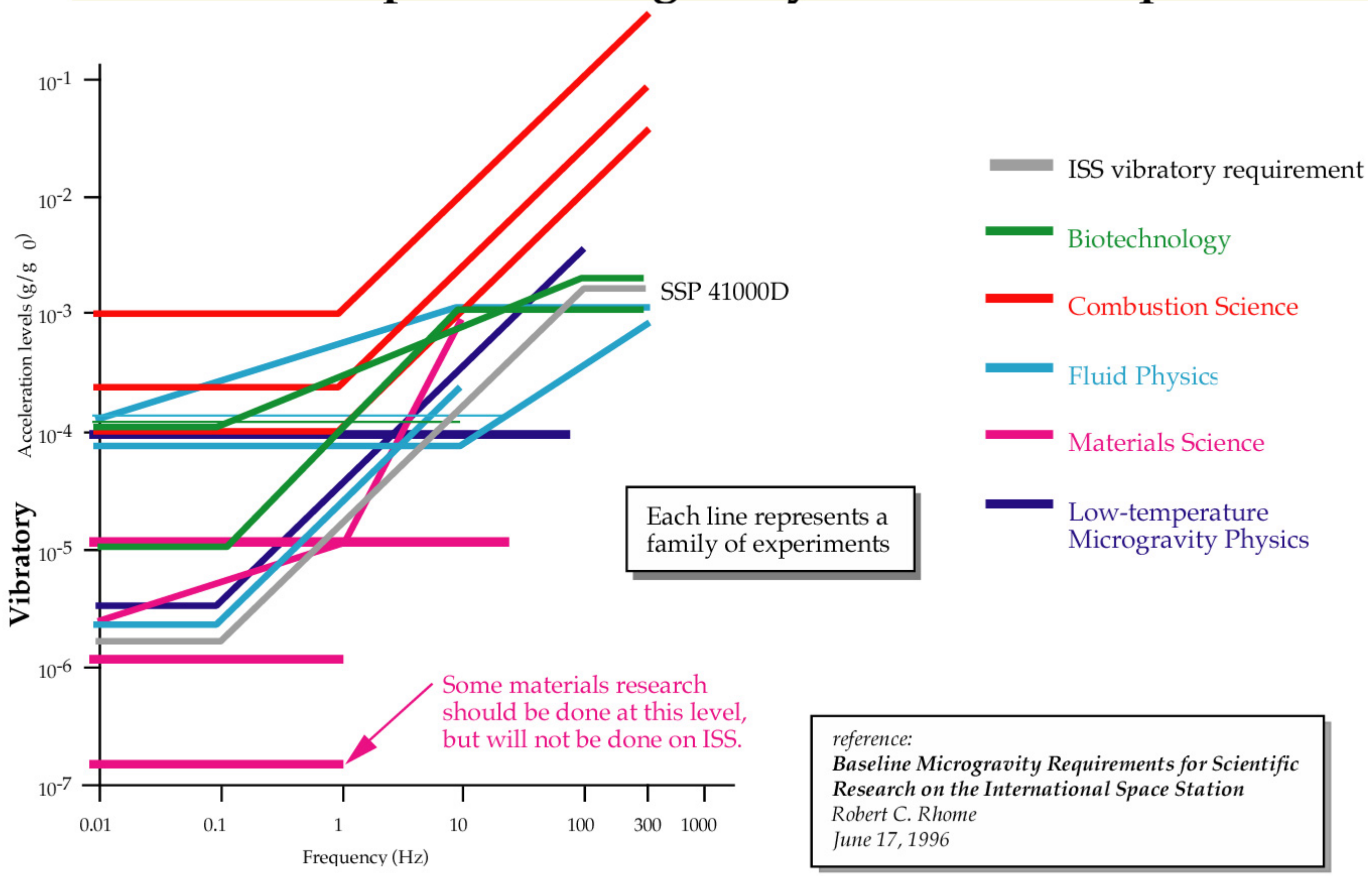
Vibratory
- Disturbances in various frequency ranges disturb experiments involving molten samples, suspended samples, etc.

Transient
- Some processes are very susceptible to transients such as thruster firings
- MEPHISTO (USMP-1 & USMP-3) experienced effects which lasted minutes from single thruster firings (0.01 g for 10 - 25 seconds)

Rationale
- Accelerations above a threshold cause thermo-solutal convection and interface instability



Science Discipline Microgravity Vibration Requirements



reference:
Baseline Microgravity Requirements for Scientific Research on the International Space Station
Robert C. Rhome
June 17, 1996

Measurement Needs By Disciplines

Experiment Type	Frequency Range	Measurement Level
Biotechnology	QS – 10 Hz	100 µg and above
Fluid Physics	QS – 300 Hz	1 µg to 1 mg
Combustion Science	QS – 50 Hz	10 µg and above
Fundamental Physics	QS – 180 Hz	0.1 µg and above
Material Science	QS – 300 Hz	0.01 µg and above

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- **Vibration Isolation--- Why?**
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

Vibration Isolation

MOTIVATION

- Ambient spacecraft acceleration levels often are higher than allowable from a science perspective, therefore:
  - Vibration isolation is used to reduce the acceleration levels to an acceptable level
  - Either passive or active isolation is used depending on the needs or requirements of a specific facility or experiments
  - These vibration isolation systems have flown on the Space Shuttle:
    - STABLE, MIM, and ARIS RME
  - The following vibration isolation systems will be on the ISS:
    - ARIS, MIM-2, g-LIMIT

Vibration Isolation

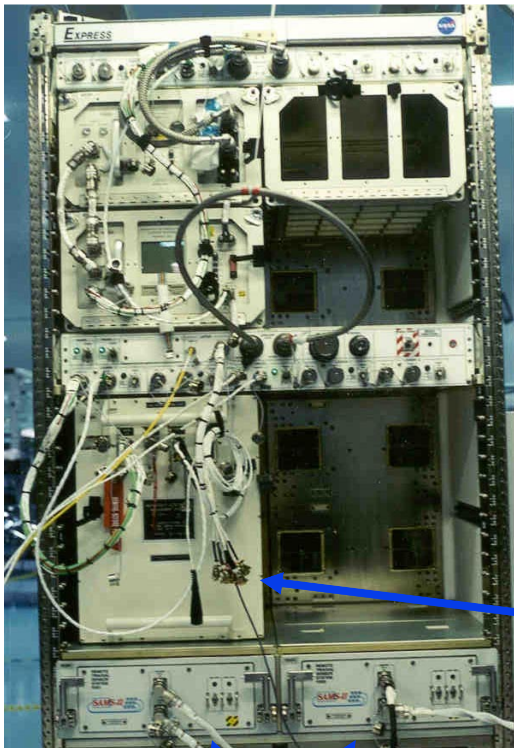
- Rack Level Isolation Systems:
  - Active Rack Isolation System– ARIS
    - ¤ ARIS provides rack-level reduction of acceleration levels
    - ¤ ARIS supplied by ISSP to meet the microgravity requirements
    - ¤ 16 racks will have ARIS installed

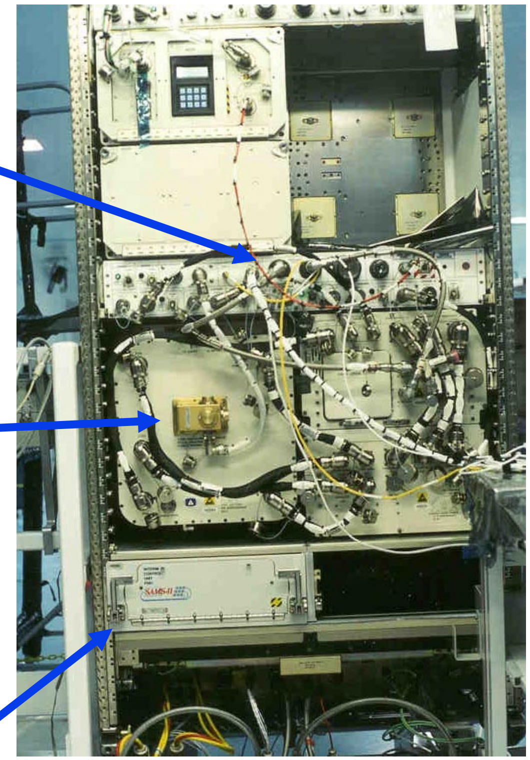
- Sub-rack Isolation Systems
  - STABLE / g LIMIT (Glovebox)
    - Marshall Space Flight Center
  - MIM/ MIM-2
    - Canadian Space Agency

EXPRESS RACK #1

Increment-2 Configuration

EXPRESS RACK #2





RTS-EE installed in EXPRESS rack behind panel
(standard in ARIS EXPRESS racks)

RTS-SE

MAMS

ICU DRAWER

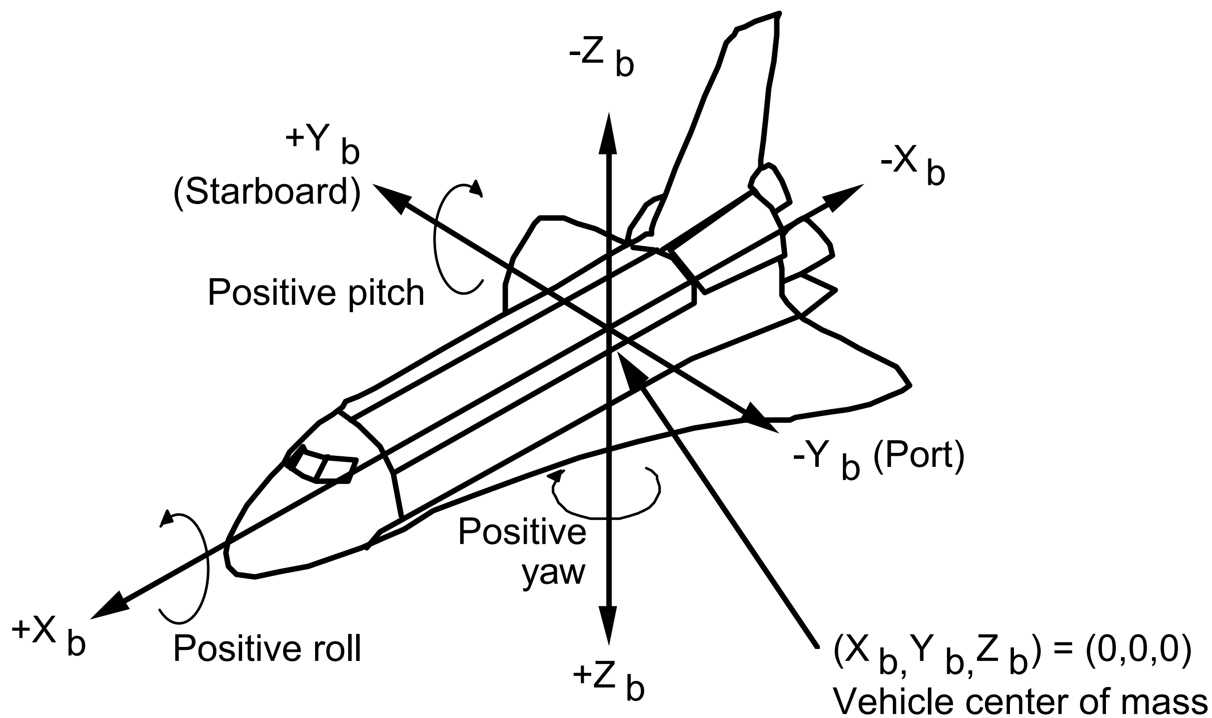
RTS DRAWERS

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

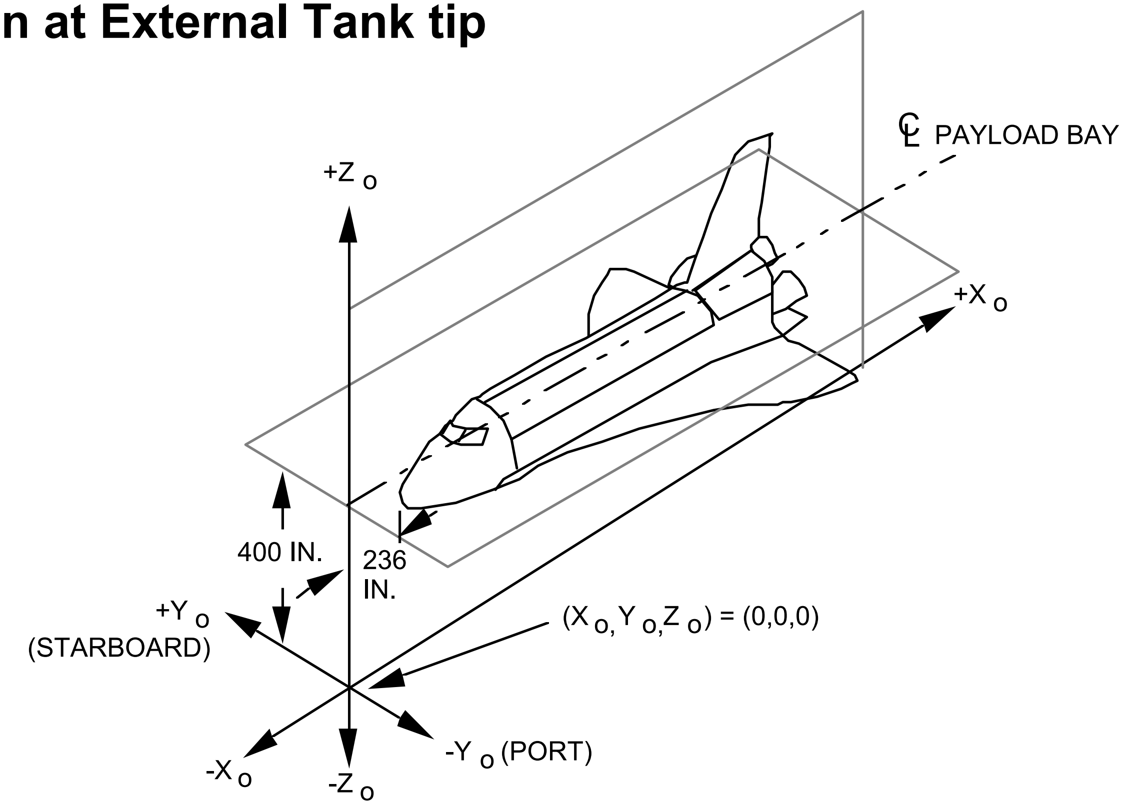
ORBITER

- **Body coordinate system**
  - **origin at vehicle center of mass**



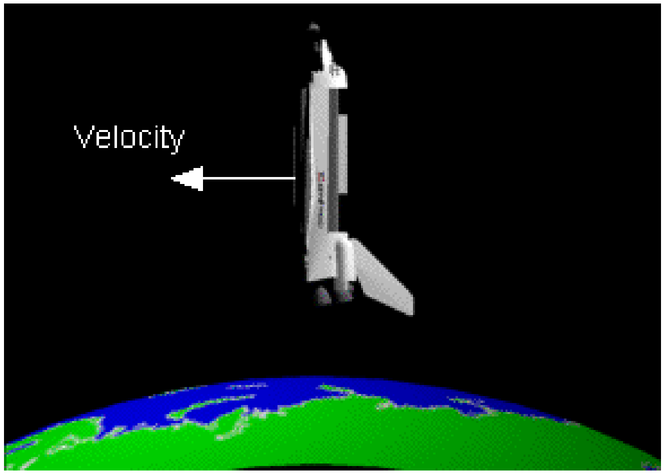
ORBITER

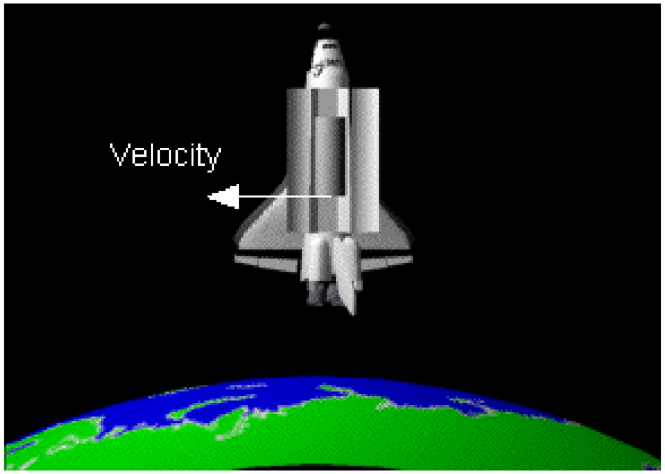
- **Structural coordinate system**
  - **origin at External Tank tip**



ORBITER

- Orbiter has two main attitudes
  - Local vertical / local horizontal (Earth oriented)
  - Inertial (quite often sun oriented)

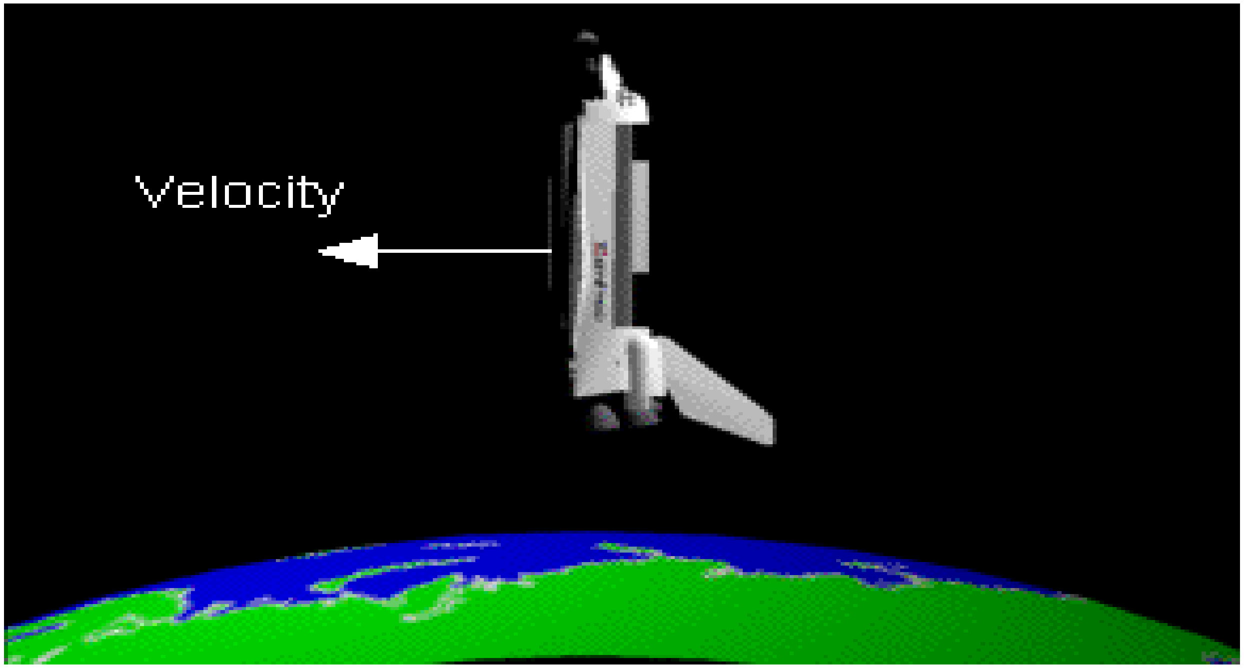




- Designation of attitudes
  - pitch / yaw / roll angle relative to airplane mode
    - e.g. PYR: 90°, 0°, 90°
  - body axes oriented to nadir (toward Earth) and flight direction
    - e.g. -XLV / +YVV

ORBITER

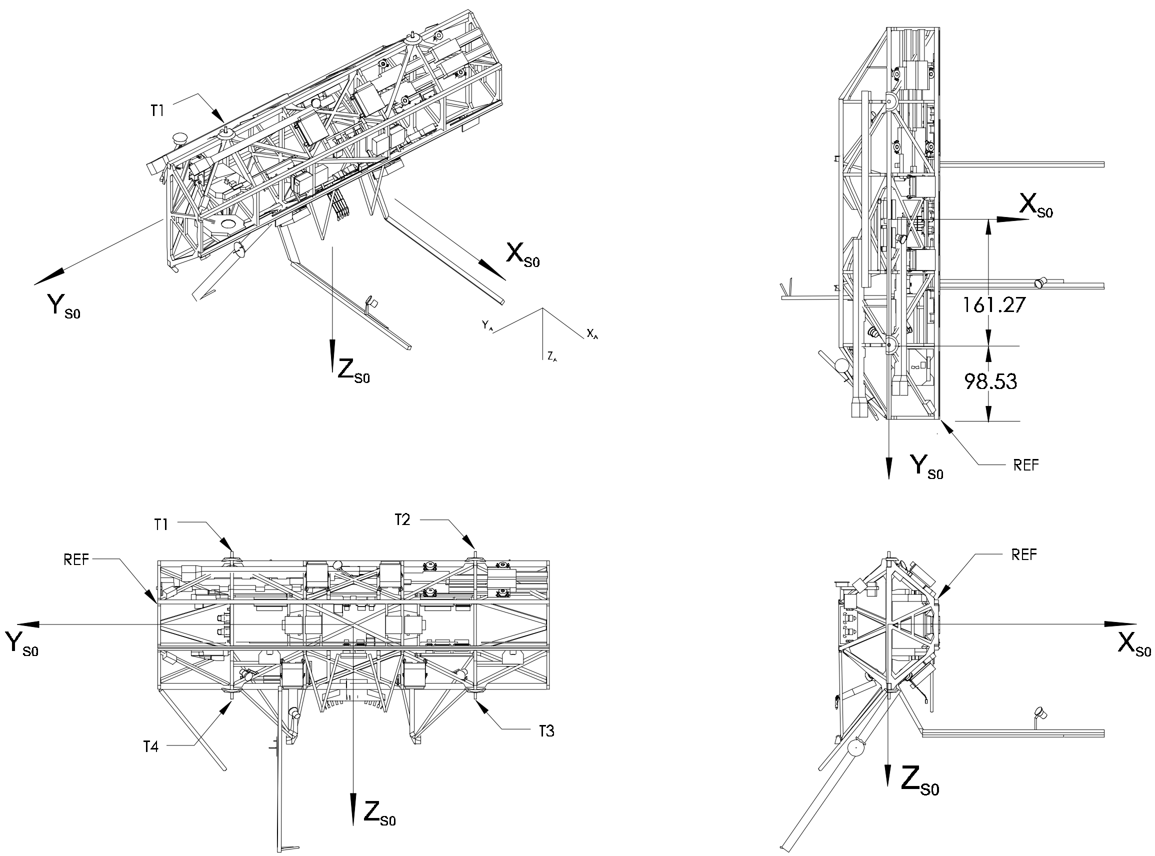
- **Fixed frame of reference determines sense of observed acceleration**
  - **Inertial reference frame: frame fixed with respect to inertial space**
  - **Science reference frame: frame fixed with respect to vehicle**



CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- **ISS Coordinates Systems**
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

ISS



Integrated Truss Segment S0 Coordinate System

Type

Right-Handed Cartesian, Body-Fixed

Description

This coordinate system defines the origin, orientation, and sense of the Space Station Analysis Coordinate System.

Origin

The YZ plane nominally contains the centerline of all four trunnion pins. The origin is defined as the intersection of two diagonal lines connecting the centers of the bases of opposite trunnion pins, running T1 to T3 and from T2 to T4.

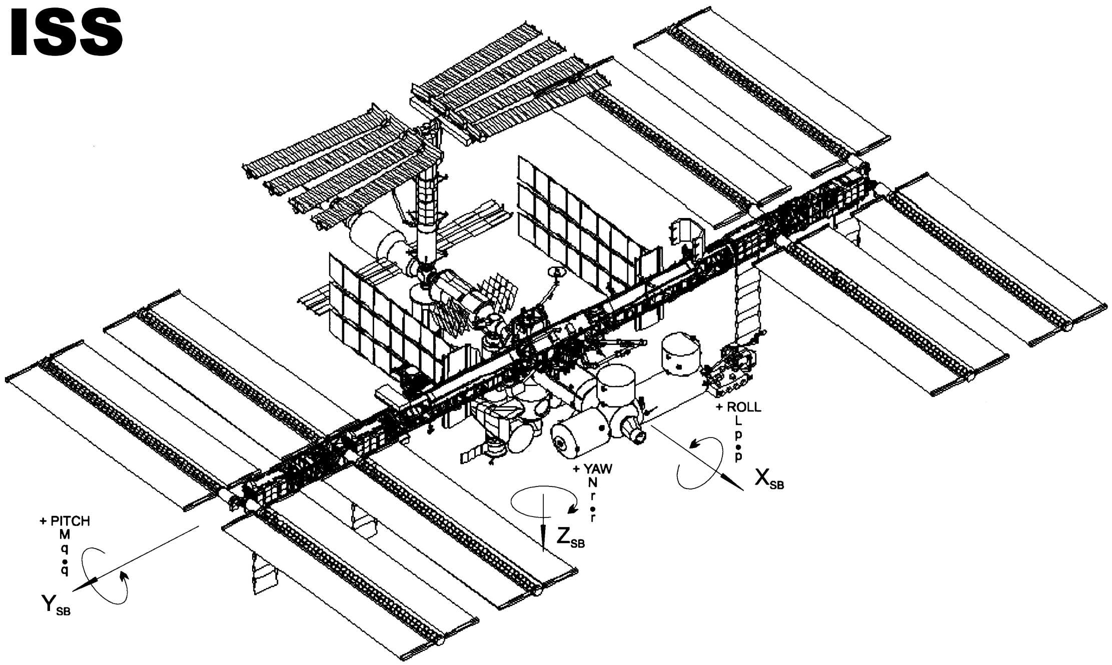
Orientation

X_{S0}: The X-axis is parallel to the vector cross-product of the Y-axis with the line from the center of the base trunnion pin T2 to the center of the base trunnion pin T3, and is positive forward

Y_{S0}: The Y-axis is parallel with the line from the center of the base of trunnion pin T2 to the center of the base of trunnion pin T1. The positive Y-axis is toward starboard.

Z_{S0}: The Z-axis completes the RHCS

ISS



SPACE STATION ANALYSIS COORDINATE SYSTEM

- **L, M, N are moments about X_A, Y_A and Z_A axes**
- **p, q, r are body rates about X_A, Y_A and Z_A axes**
- **pdot, qdot and rdot are angular body acceleration about XA, YA and XA axes**

Type

Right-Handed Cartesian, Body-Fixed

Description

This coordinate system is derived using the Local Vertical Local Horizontal (LVLH) flight orientation. When defining the relationship between this coordinate system and another, the Euler angle sequence to be used is a yaw, pitch, roll sequence around the Z_A, Y_A, and X_A axes, respectively.

Origin

The origin is located at the geometric center of Integrated Truss Segment (ITS) S_0 and is coincident with the S_0 Coordinate frame.

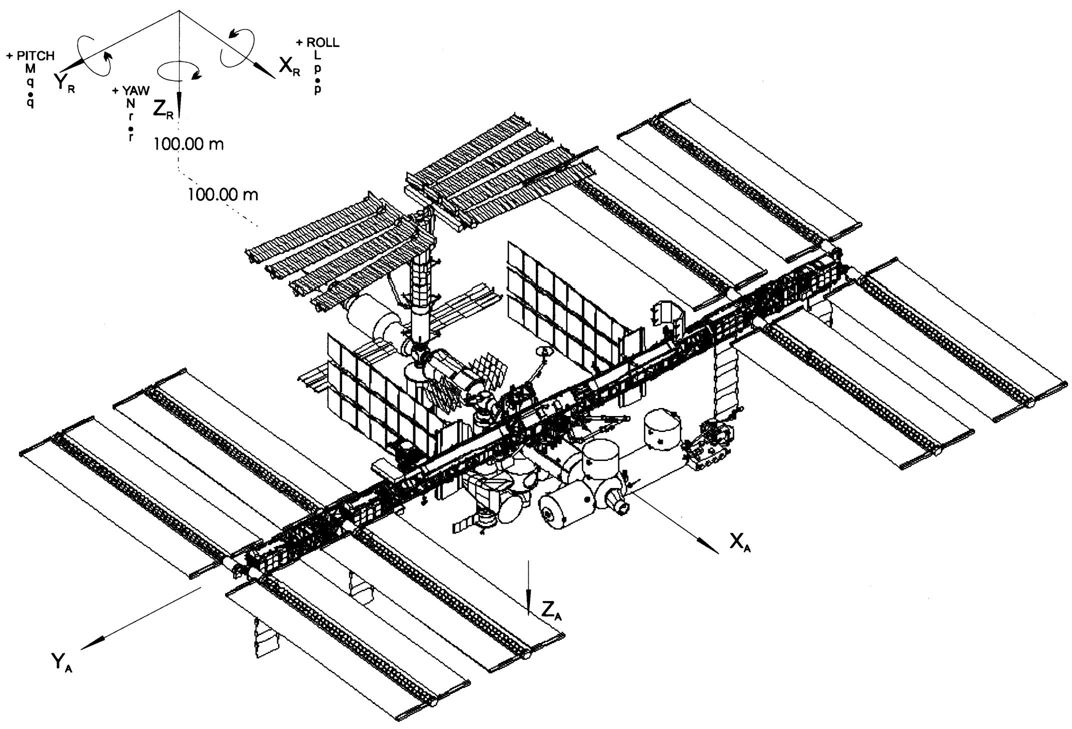
Orientation

X_A: The X-axis is parallel to the longitudinal axis of the module cluster. The positive X-axis is in the the forward direction

Y_A: The Y-axis is identical with the So axis. The nominal alpha joint rotational axis is parallel with YA. The positive Y-axis is in the starboard direction.

Z_A: The positive Z-axis is in the direction of nadir and completes the right-handed Cartesian system (RHCS).

ISS



SPACE STATION REFERENCE COORDINATE SYSTEM

Type

Right-Handed Cartesian, Body-Fixed

Description

This coordinate system is derived using the Local Vertical Local Horizontal (LVLH) flight orientation.

Origin

The datum point is located at the origin of the Space Station Analysis Coordinate System frame. The origin of the Space Station Reference Coordinate System is located such that the datum point is located at: $\mathbf{X_R=100}$, $\mathbf{Y_R=0}$, and $\mathbf{Z_R=100}$ meters

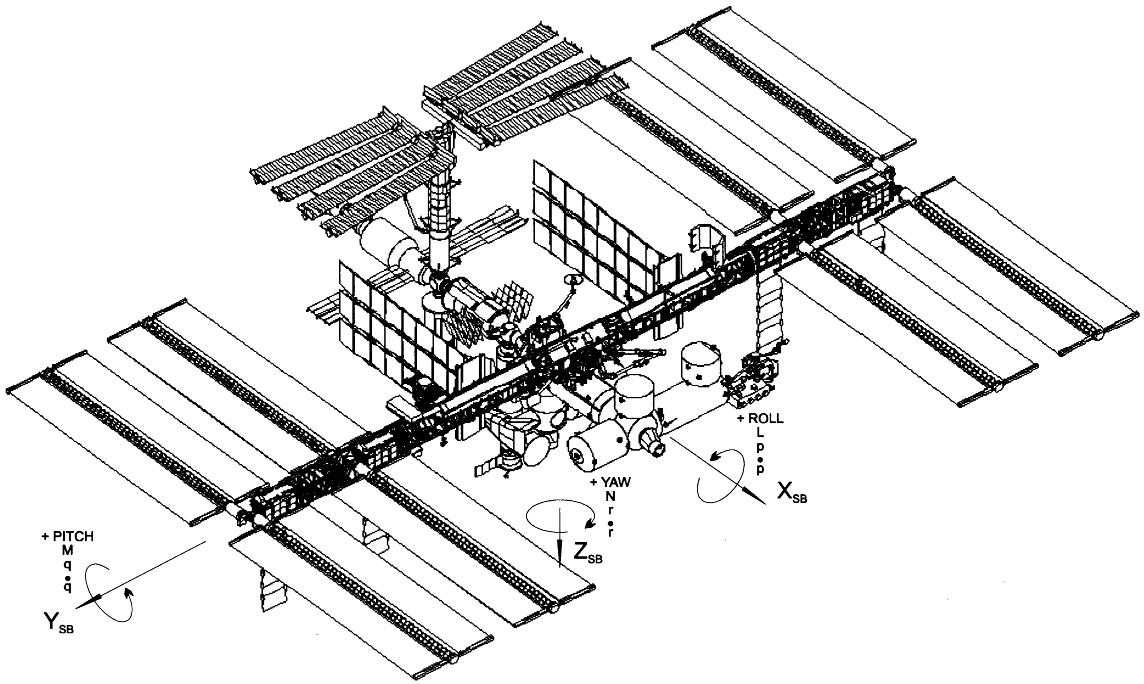
Orientation

$\mathbf{X_R}$: The X-axis is parallel to the X_A. The positive X-axis is in the forward direction

$\mathbf{Y_R}$: The Y-axis is coincident with the nominal alpha joint rotational axis, which is parallel to Y_A. The positive Y-axis is in the starboard direction.

$\mathbf{Z_R}$: The positive Z-axis is parallel to Z_A and is in the direction of nadir and completes the rotating right-handed Cartesian system.

ISS



SPACE STATION BODY COORDINATE SYSTEM

Type

Right-Handed Cartesian, Body-Fixed

Description

When defining the relationship between this coordinate system and another, the Euler angle sequence to be used is a yaw, pitch, roll sequence around the Z_{SB}, Y_{SB}, and X_{SB} axes, respectively

Origin

The origin is located at the Space Station center of mass.

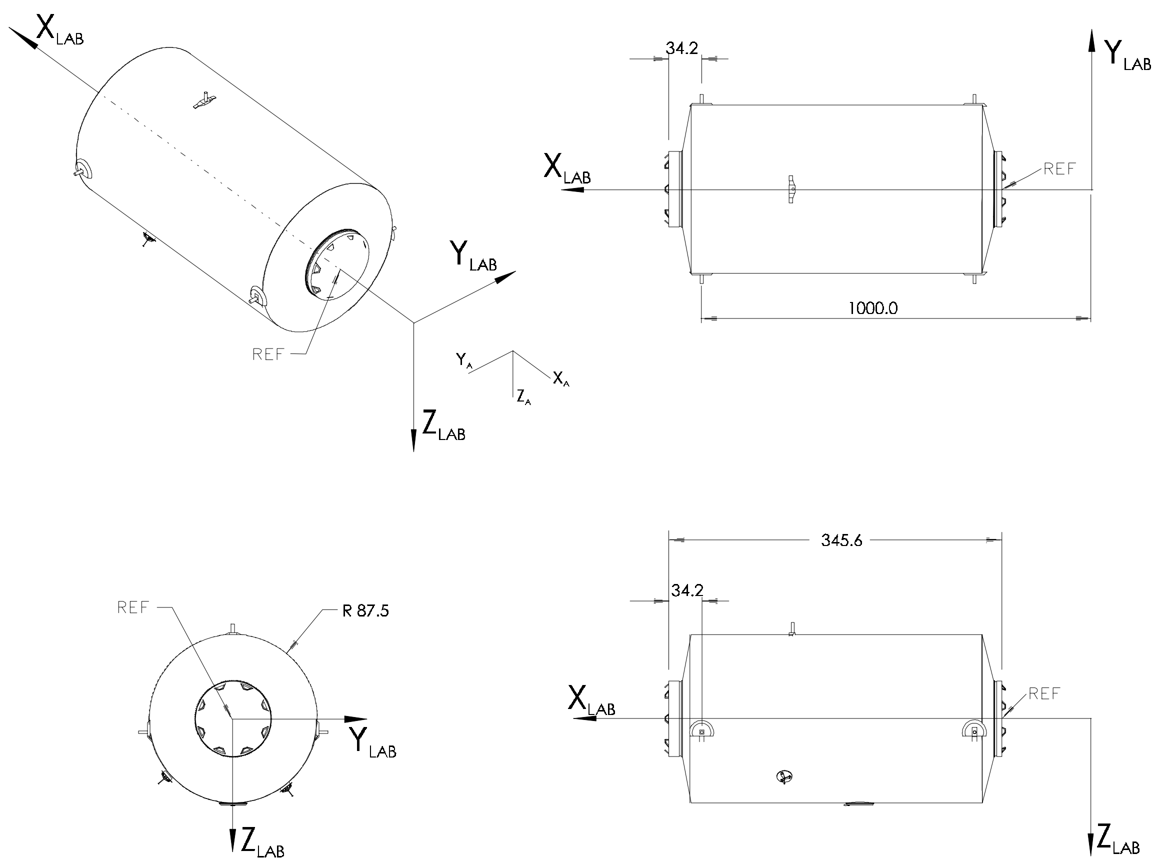
Orientation

X_{SB}: This axis is parallel to the X_A axis. Positive X_{SB} is in the forward flight direction.

Y_{SB}: This axis is parallel to the Y_A. Positive Y_{SB} is toward starboard.

Z_{SB}: This axis is parallel with the Z_A. Positive Z_{SB} is approximately toward nadir and completes the right-handed system: X_{SB}, Y_{SB}, Z_{SB}.

ISS



UNITED STATES LABORATORY MODULE COORDINATE SYSTEM

Type

Right-Handed Cartesian, Body-Fixed to the Pressurized Module

Origin

The origin is located forward of the pressurized module such that the center of the bases of the aft trunnions have X_{LAB} components nominally equal to 1000.000 inches.

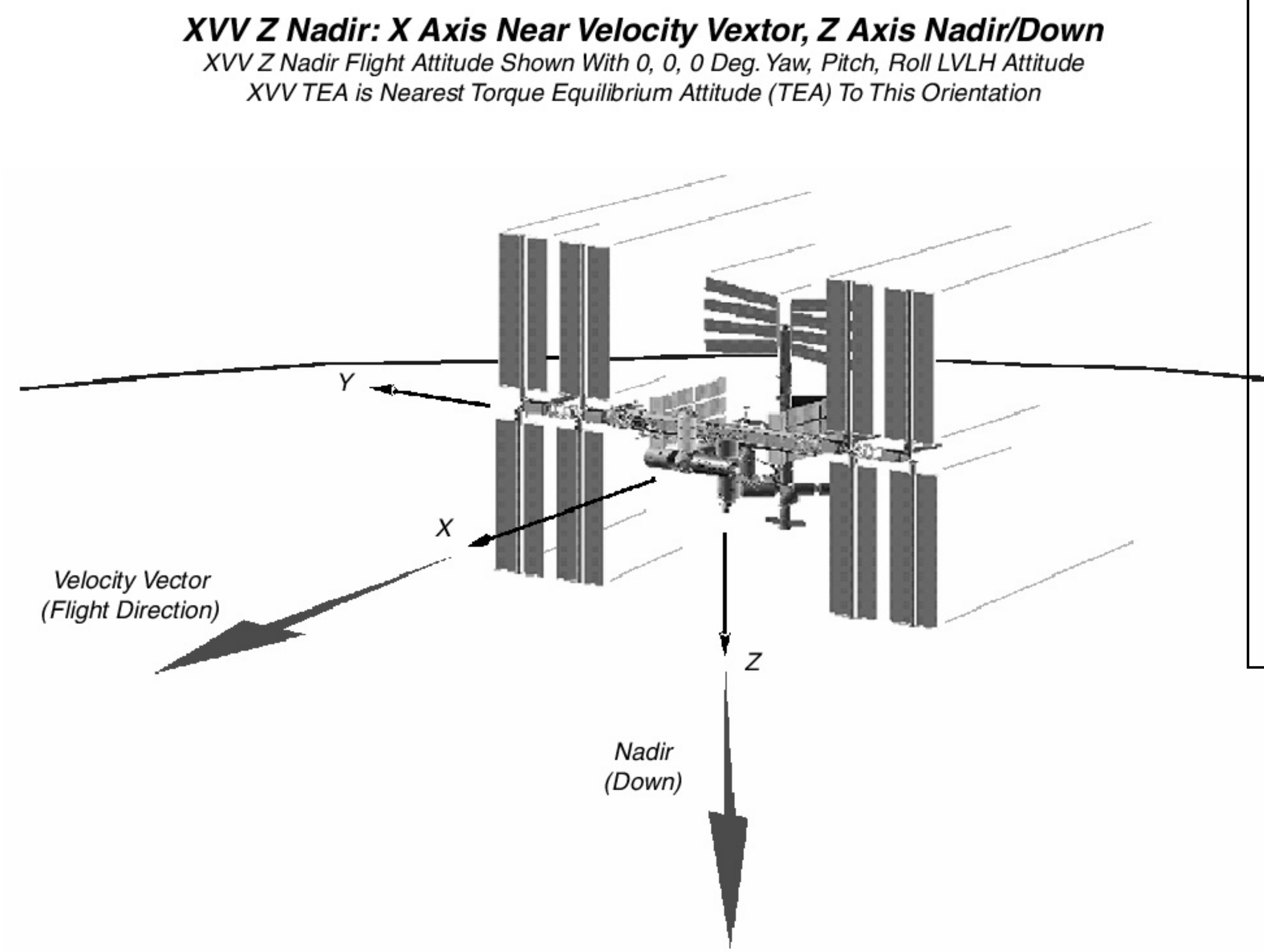
Orientation

X_{LAB}: The X-axis is perpendicular to the nominal aft CBM interface plane and pierces the geometric center of the array of mating bolts at the aft end of the pressurized module. The positive X-axis is toward the pressurized module from the origin.

Y_{LAB}: The Y-axis completes the right-handed Cartesian system (RHCS).

Z_{LAB}: The Z-axis is parallel to the perpendicular line from the X-axis to the center of base of the keel pin, and positive in the opposite direction as shown.

ISS-XVV Z Nadir



The basic flight attitude for ISS is called **XVV Z** Nadir. The vehicle design is optimized for this attitude. The **XVV** attitude:

- **places the most modules in the microgravity volume**
- **supports altitude reboosts**
- **service vehicle dockings**
- **minimizes aerodynamic drag**

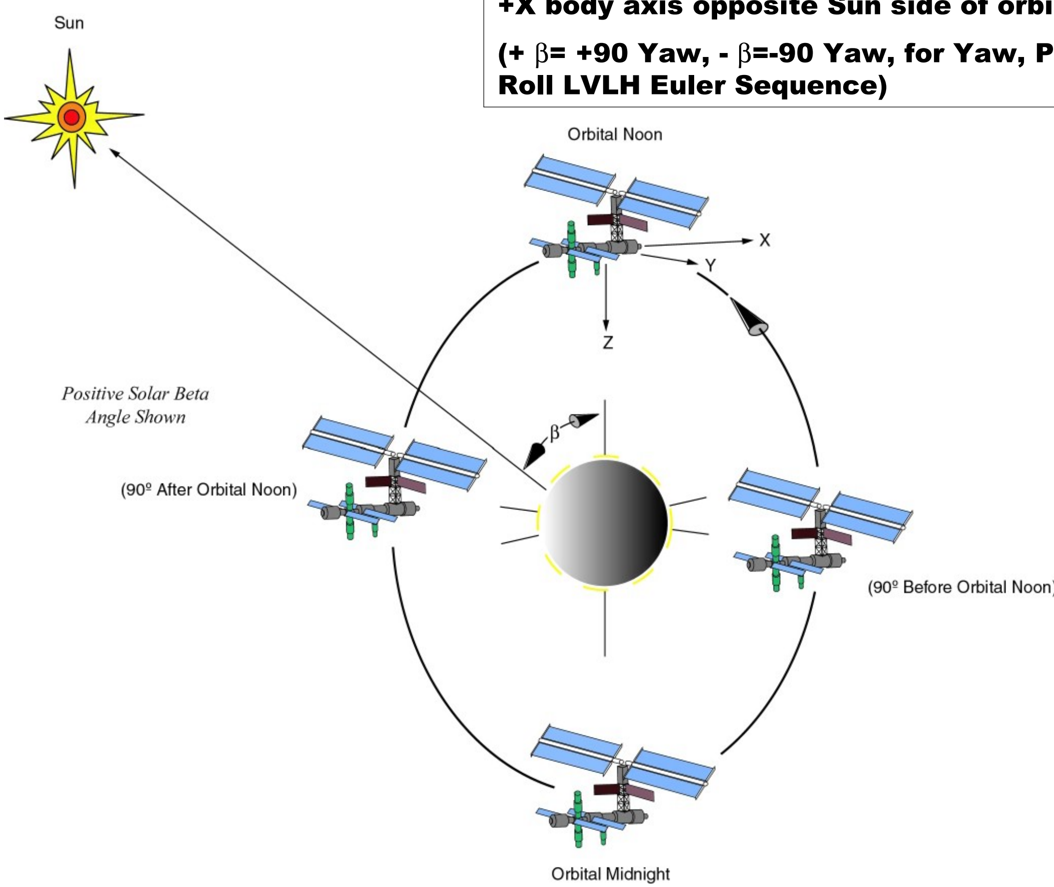
The ISS is designed to tolerate deviations from perfect XVV Z Nadir of +/- 15 degrees in each axis. This envelope was expanded to –20 deg in pitch.

ISS-XPOP

+ Z body axis is down/Nadir at orbital noon

+X body axis opposite Sun side of orbit plane

(+ β= +90 Yaw, - β=-90 Yaw, for Yaw, Pitch, Roll LVLH Euler Sequence)



- **Maximum power generation**
- **Minimizes vehicle gravity gradient torque**
- **Momentum manager provides CMG attitude control without propellant usage**

During the assembly stages (stages 2A through 12A.1), **ISS** will not be capable of generating enough power to sustain the required electrical loads in the **XVV** flight attitude at mid-to-high solar beta angles because these vehicle configurations have only a single solar array gimbal axis, which is aligned so that it only perfectly tracks the Sun when the solar beta angle is near zero. Therefore, **ISS** is designed to accommodate a second basic flight orientation for these increments.

XPOP: **X**-principal axis **p**erpendicular to the **o**rbit **p**lane, **Z** Nadir at orbital noon. The **XPOP** flight attitude sets up geometry between the ISS and the Sun so that the Sun stays close to the ISS/XZ body axis plane. This allows all the solar arrays to track the Sun regardless of the solar beta angle. **XPOP** also places the dominant inertia axis in the local horizontal to minimize gravity gradient torques and allow Control Moment Gyro (CMG) non-propulsive attitude control.

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- **Plots Header Description: Shuttle and ISS**
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

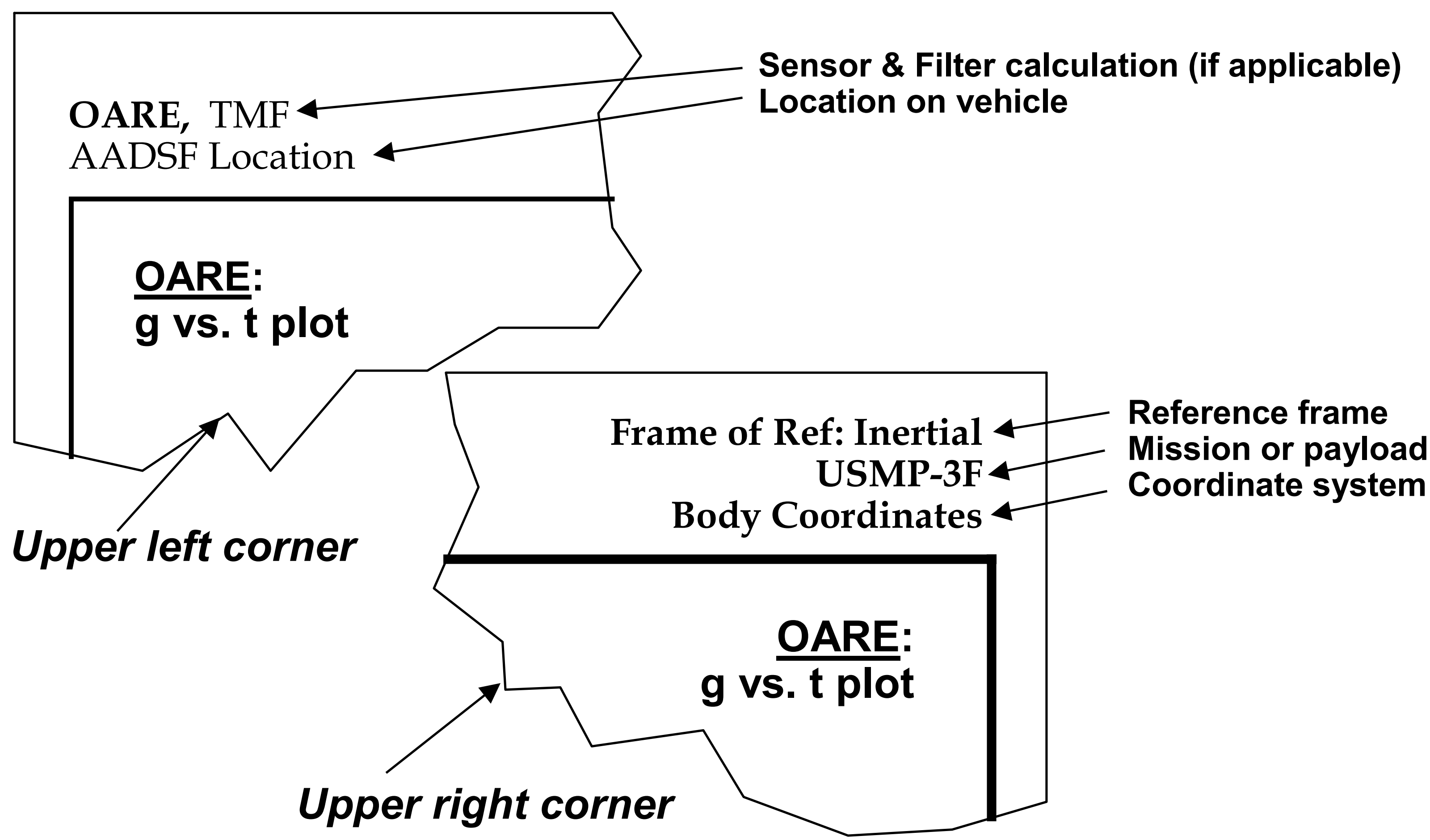
Acceleration Measurement Systems

- **OARE:** Orbital Acceleration Research Experiment - instrument which measures low frequency accelerations from DC up to 0.01 Hz
- **MAMS-OSS:** Microgravity Acceleration Measurement System – OARE SubSystems- instrument which measures the quasi-steady acceleration levels to characterize the ISS reduced gravity environment provided to users. MAMS measures accelerations from DC to 1 Hz.
- **MAMS-HiRAP:** Microgravity Acceleration Measurement System- High Resolution Acceleration Package- instrument which measures the vibratory accelerations from 0.01 to 100 Hz aboard the ISS
- **SAMS (RTS):** Second generation SAMS - instrument which measures the vibratory accelerations level from 0.01 to 300 Hz aboard the ISS.
- **SAMS (TSH):** - instrument for stand alone missions (e.g. sounding rockets), Shuttle, drop towers and KC-135, which measures vibratory acceleration levels from 0.01 to 200 Hz.

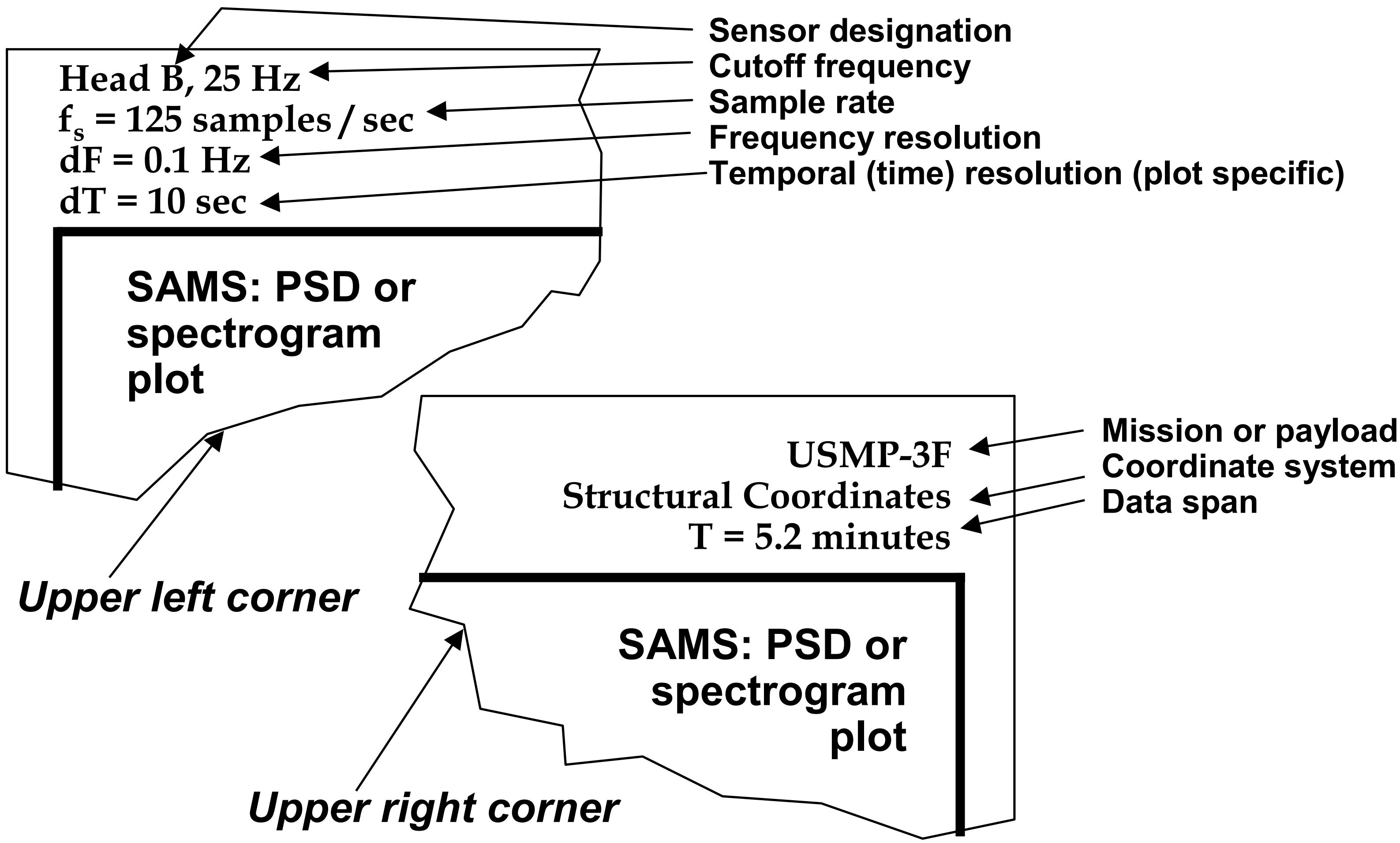
Definitions

- **Nyquist criteria:** sampling rate must be at least twice that of the highest frequency contained in the signal of interest
- **Cutoff frequency (f_c):** corner frequency in filter response; highest unfiltered frequency of interest
- **Sample rate (f_s):** rate at which an analog signal is sampled ($^{samples}/_{sec}$)
- **Power spectral density:** a function that quantifies the distribution of power in a signal with respect to frequency
- **Spectrogram:** a 3-D representation of the power spectral density as a function of frequency and time

OARE- SHUTTLE



SAMS- SHUTTLE



ISS QUASI-STEADY SAMPLE PLOTS INFORMATION

accelerometer system

sensor/data type

measurement location
[X_A Y_A Z_A] (in.)

mams, ossbtmf at LAB102,ER1,Lockers 3,4:[135,-10.68,132.2]
0.0625 sa/sec (0.01 Hz)
Time Span= 26.49 hours

sample rate (cutoff frequency)

data span (plot specific)

MAMS-OSS
g vs. t & QTH plots

Upper left corner

Increment: 2, Flight: 6A
SSAnalysis[0.0 0.0 0.0]

ISS Increment #, flight #

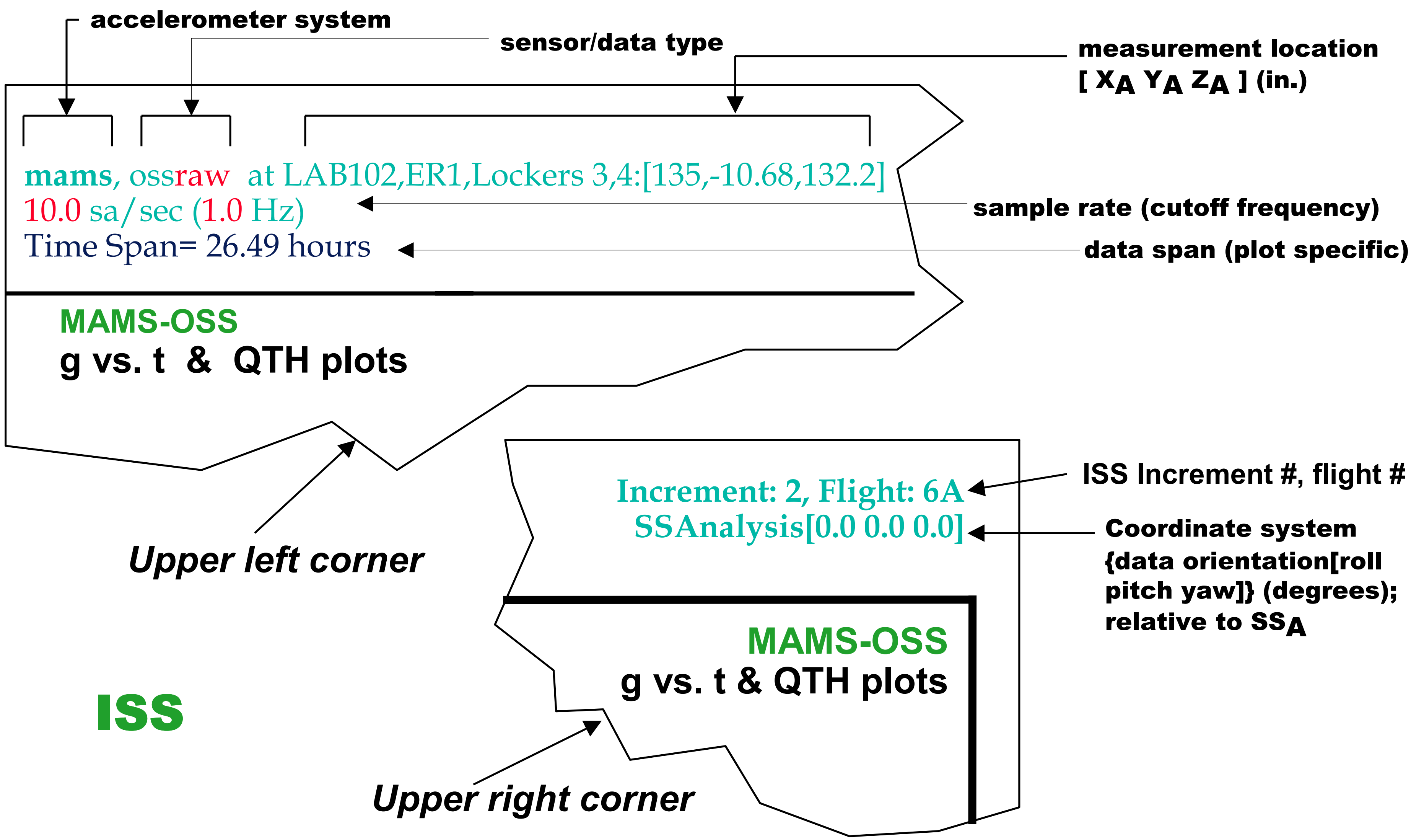
Coordinate system {data orientation[roll pitch yaw]} (degrees); relative to SS_A

MAMS-OSS
g vs. t & QTH plots

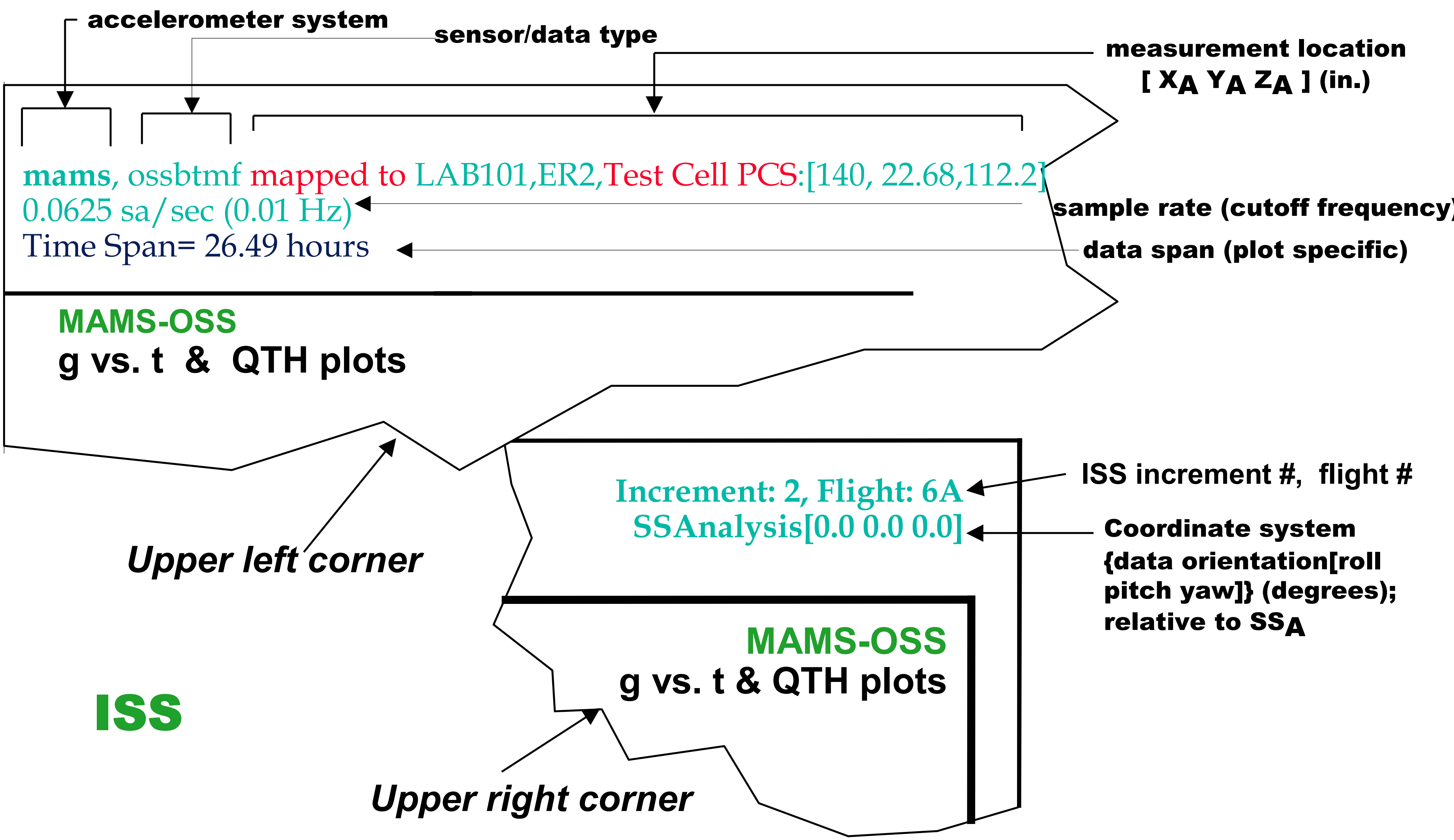
ISS

Upper right corner

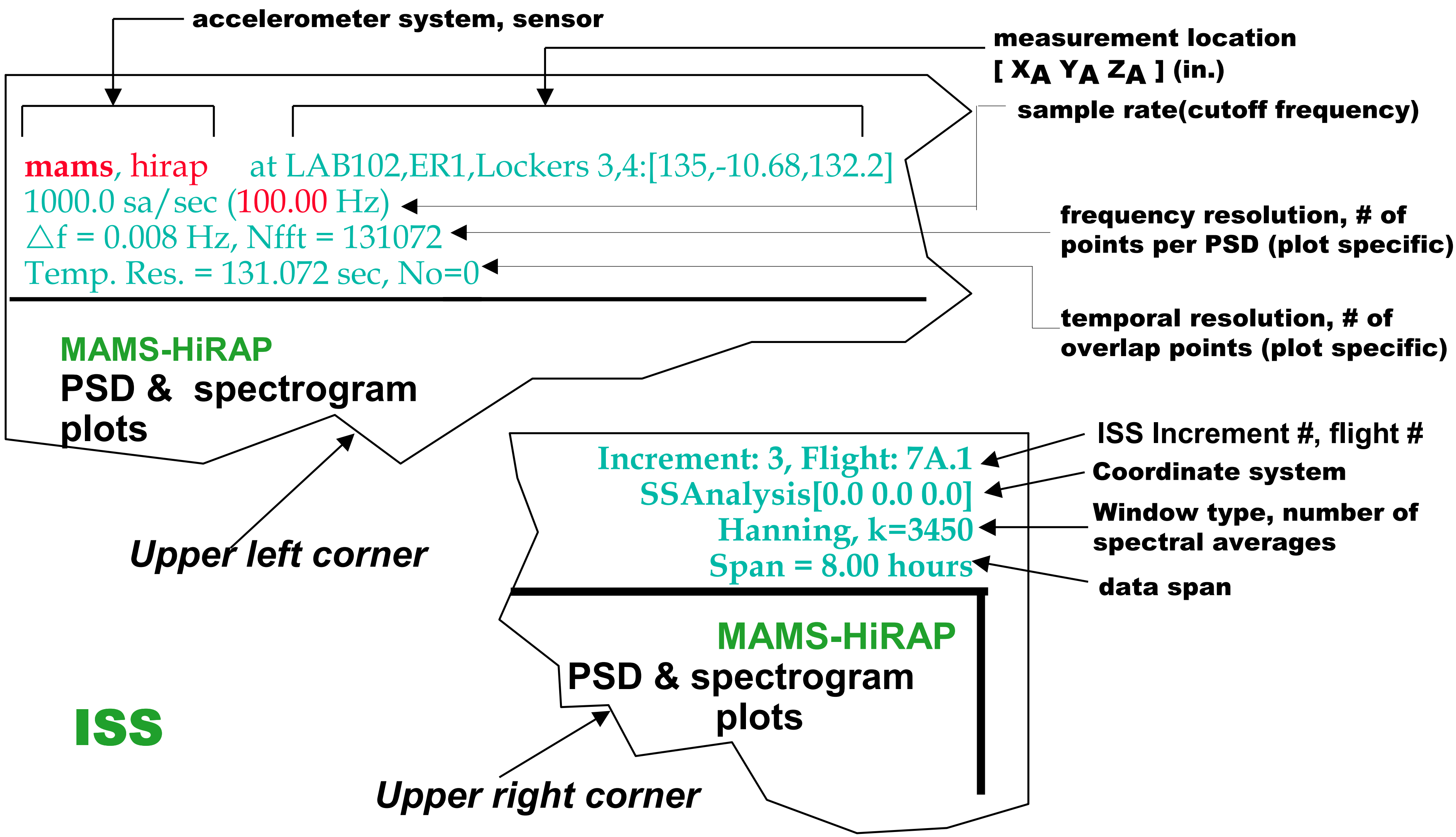
ISS QUASI-STEADY SAMPLE PLOTS INFORMATION



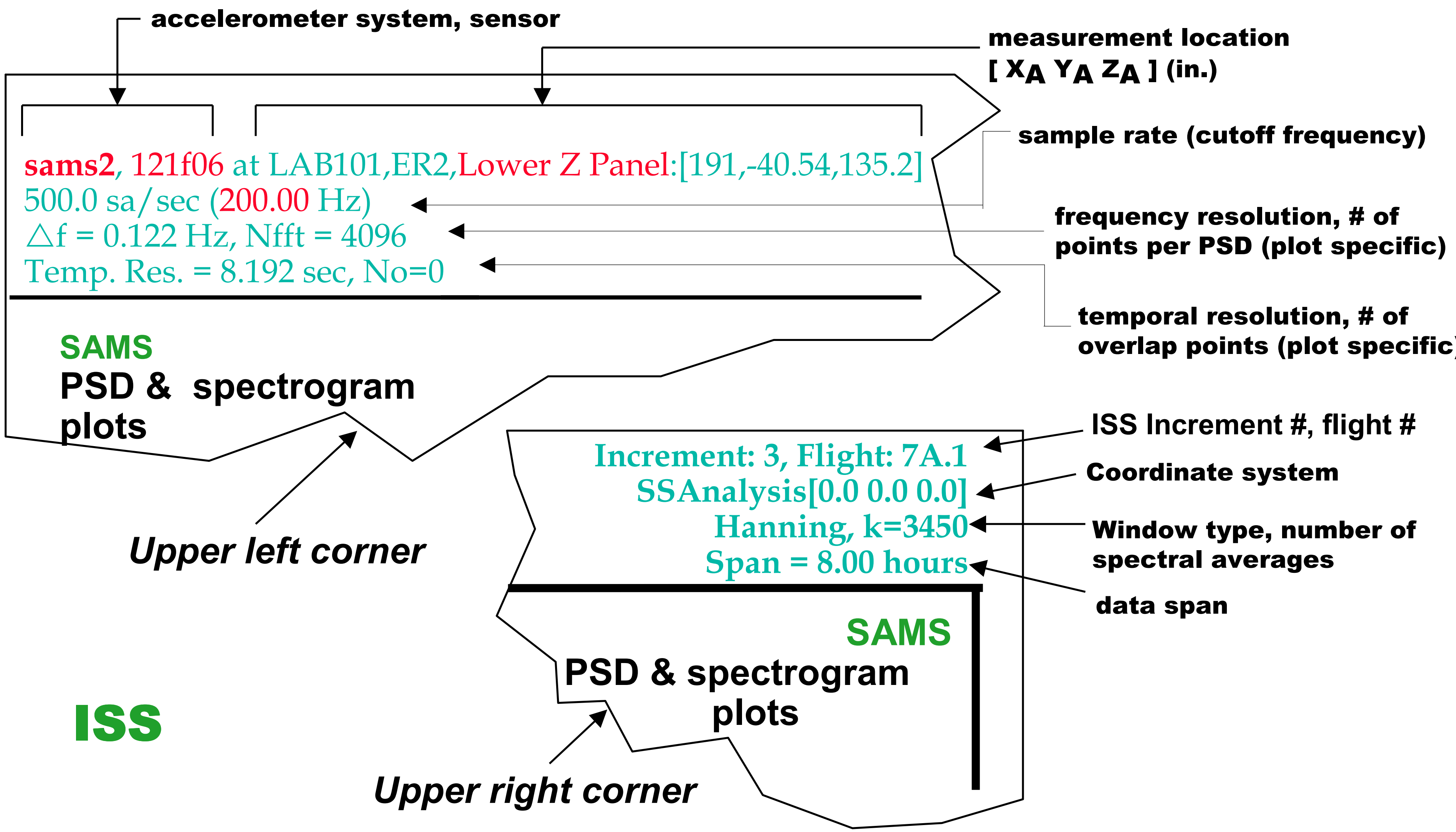
ISS QUASI-STEADY SAMPLE PLOTS INFORMATION



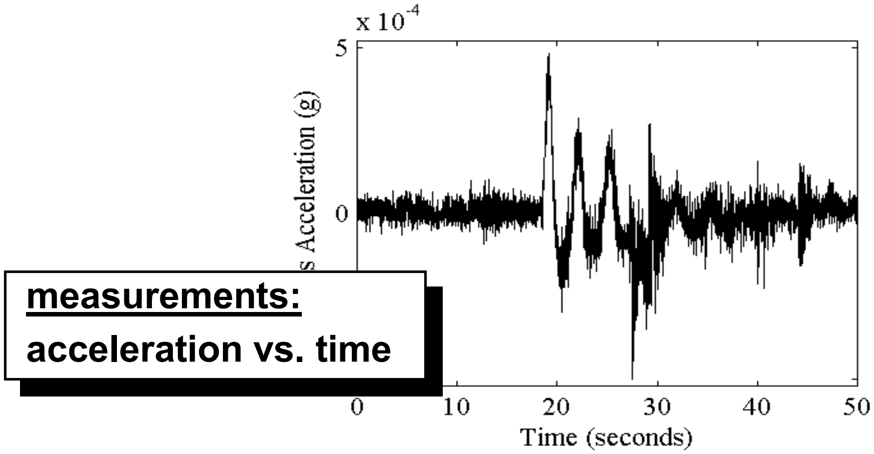
ISS VIBRATORY SAMPLE PLOTS INFORMATION

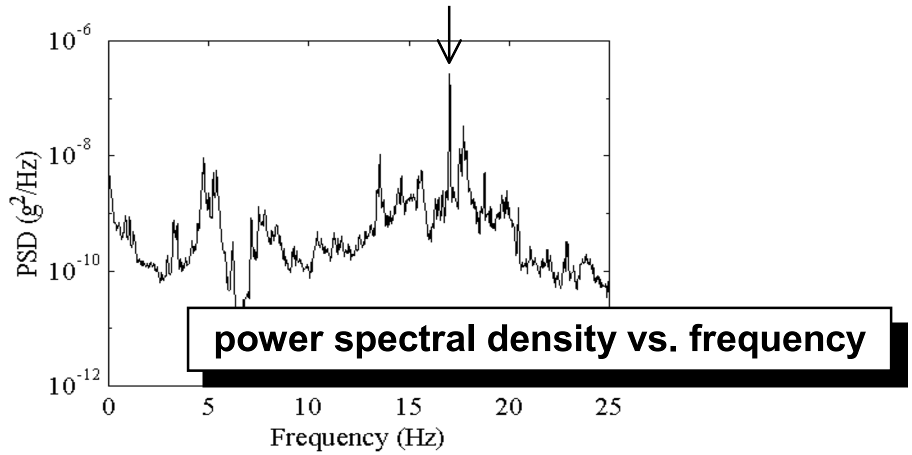


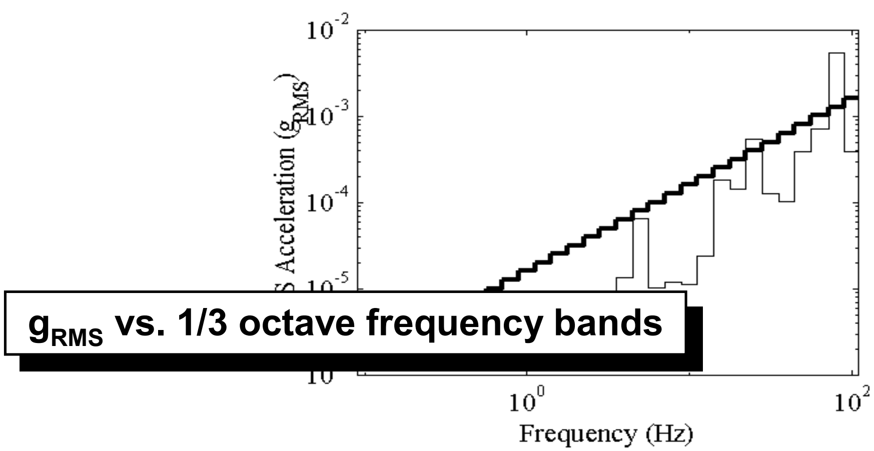
ISS VIBRATORY SAMPLE PLOTS INFORMATION

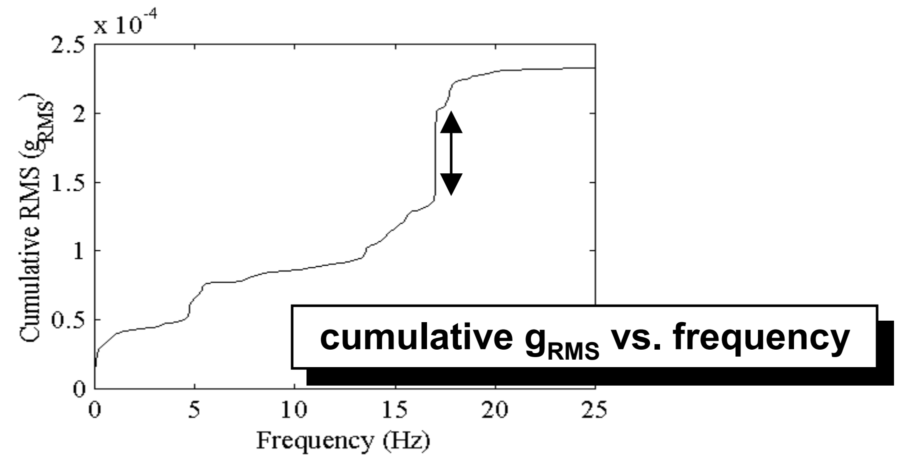


Plot Samples

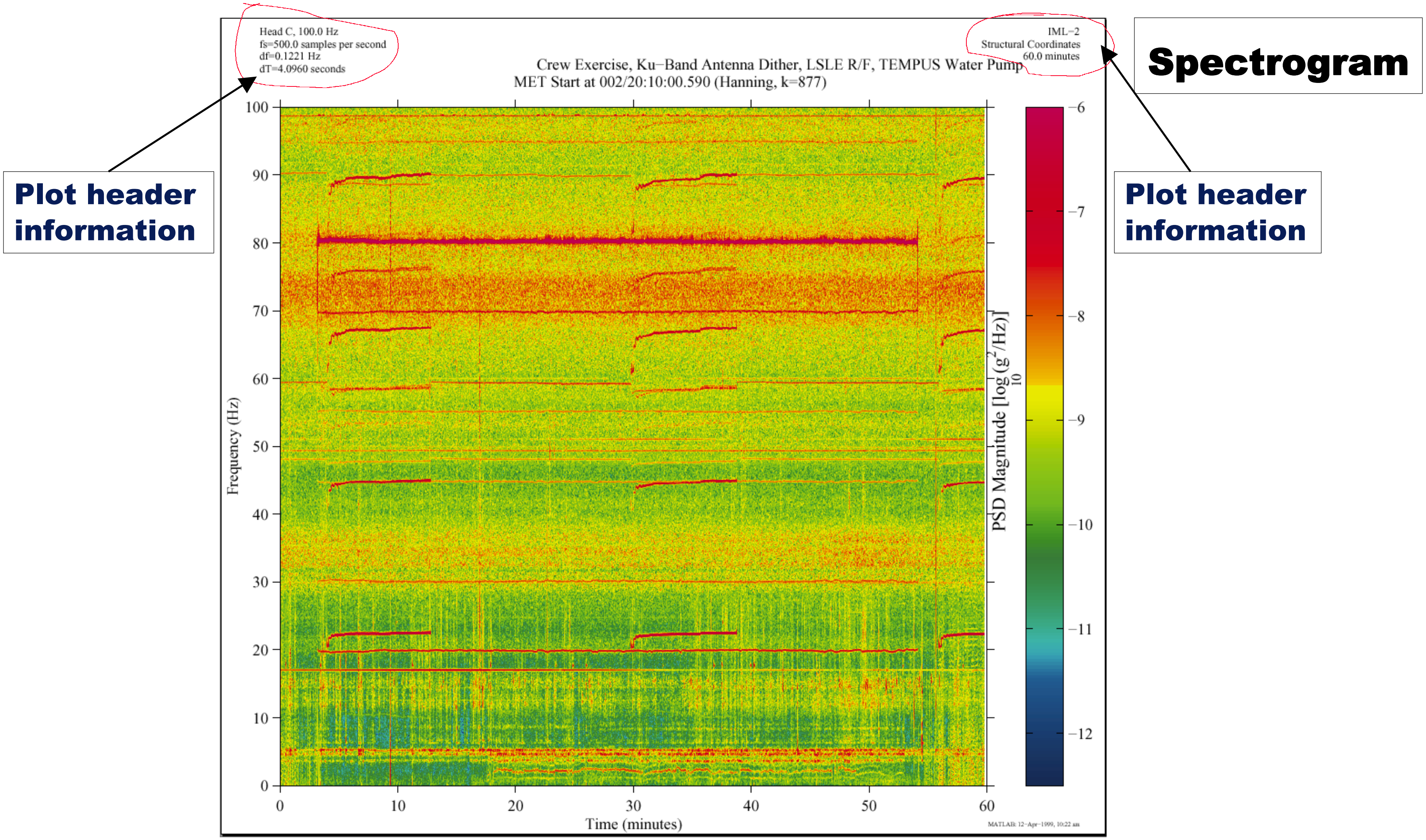








Plot Sample


Head C, 100.0 Hz
fs=500.0 samples per second
df=0.1221 Hz
dT=4.0960 seconds
IML−2
Structural Coordinates
60.0 minutes
Crew Exercise, Ku−Band Antenna Dither, LSLE R/F, TEMPUS Water Pump
MET Start at 002/20:10:00.590 (Hanning, k=877)
Frequency (Hz)
Time (minutes)
PSD Magnitude [log10(g²/Hz)]
MATLAB: 12−Apr−1999, 10:22 am
Plot header information
Plot header information
Spectrogram

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- **Experiment Planning and Execution**
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- Overall Summary

Available Reduced Gravity Carriers / Facilities

- STS Orbiters
- International Space Station (ISS)
- Sounding Rockets (Various Countries)
- Parabolic Flight Aircraft (KC-135)
- Free-Flyers (Russia)
- Drop Towers (US, Germany, Japan)
- Microgravity Emission Lab (MEL) @ NASA-GRC

Experiment Location and Orientation

- **Proximity to carrier / vehicle center of mass**
  - **sensitivity to quasi-steady variations**
- **Proximity to other equipment**
  - **sensitivity to vibration sources**
- **Alignment**
  - **sensitivity to quasi-steady acceleration direction**

Carrier Attitude

- Issues related to experiment location
  - gravity gradient effects
- Issues related to experiment orientation
  - design attitude that points experiment in desired direction
- Sensitivity to quasi-steady variations with time
  - atmospheric drag effects
  - local vertical / local horizontal attitudes versus inertial attitude

Accelerometer Selection

- Frequency Range
  - cutoff frequency based on experiment sensitivity
  - sampling rate and filter characteristics specified by accelerometer system team to provide frequency selected by experimenter
- Location and Alignment
  - close to experiment sensitive location
  - mounting technique
  - away from sources which may disturb accelerometer and mask disturbances of interest
  - knowledge of sensor orientation relative to experiment axes

Mission / Experiment Timeline

If at all possible, schedule your experiment operations to avoid any activities which might negatively impact it. Keep the following points in mind:

- **Experiment sensitivity to acceleration sources**
  - **quasi-steady, vibratory and transient**
- **Crew exercise**
- **Crew activity**
- **Thruster activity**
- **Other experiment operations**
- **Venting**

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- **Preflight Planning for Science Optimization**
- STS Ascent and Landing Profiles
- Overall Summary

Motivation

- Real-time replanning requires clear goals to be effective

- Decision makers may have no time to deeply consider the impacts in a crisis situation (it is after all your job– it is your experiment)

- PIs will fare better if they have a cohesive and rational plan (for-off nominal conditions)

Potential Success-level Definition

- **Technology demonstration:**
  - ¤ The level of success necessary to validate the hardware functionality and to observe critical science concepts (e.g. approach to steady state). The concept is that any follow-on experiment would benefit substantially from this level of testing.
- **Minimum Science:**
  - ¤ The level of success necessary to produce a scientifically interesting paper that is publishable in an important journal (or to meet minimal commercial goals).
- **Minimal achievement of experiment objectives**
  - ¤ The level of success necessary to satisfy a minimal number of the peer reviewed experiment objectives (or approved commercial goals). This is typically the level which, if it can not be assured, the hardware developer would not ship the hardware.

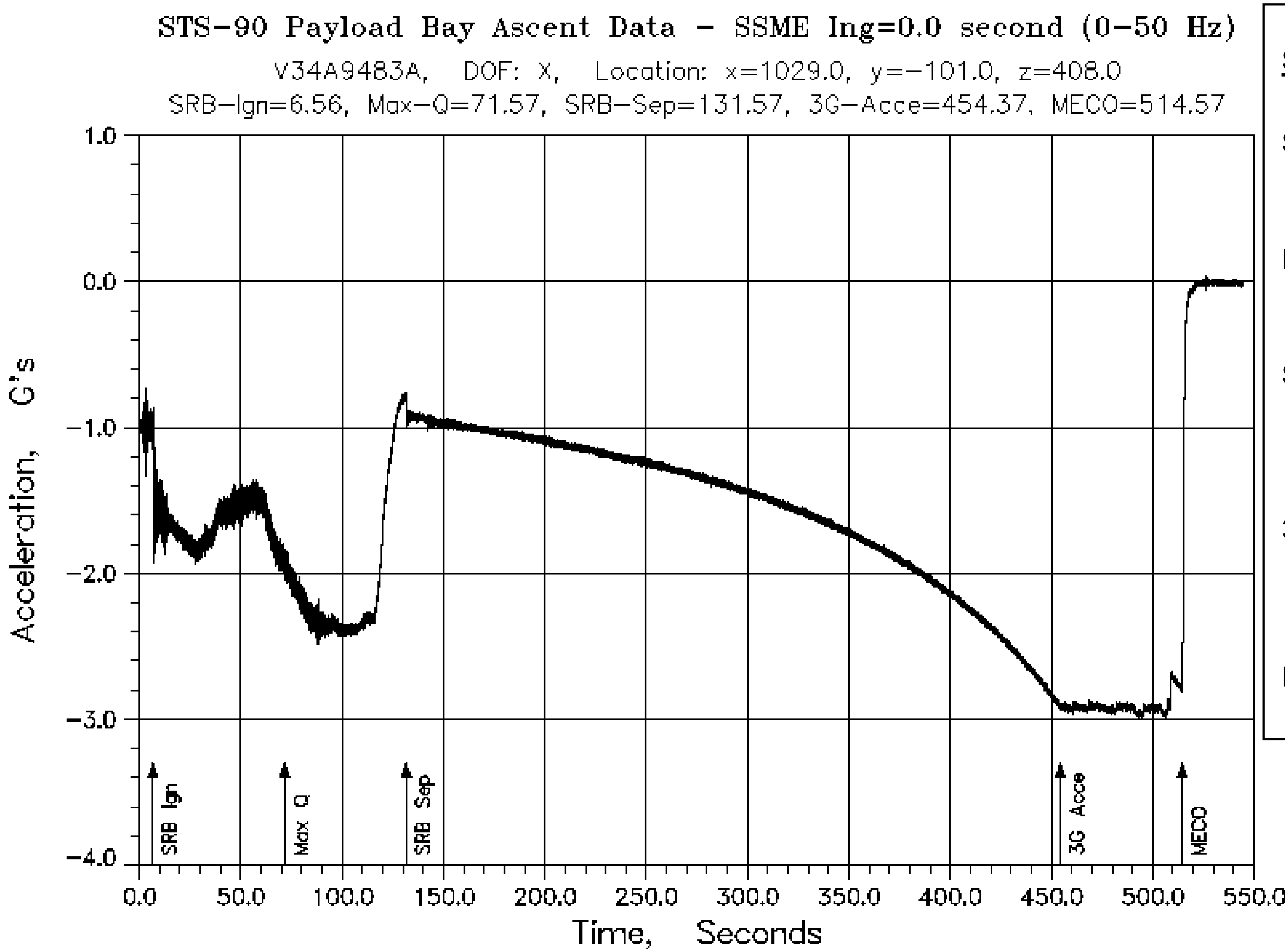
Planning Goals

- Plan for at least minimum science (in extreme situations)
- Plan to reach minimal achievement of the experiment objectives (in less extreme situations)
- Allow for equitable distribution of the timeline for both reduced and extra cases
- Write clear, concise, logical procedures (step by step) for the crew (astronauts) to follow, if crew is required

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- **STS Ascent and Landing Profiles**
- Overall Summary

STS ASCENT PROFILE



X-axis

<u>STS = Columbia</u>

SRB_{ign} = solid rocket boosters ignition

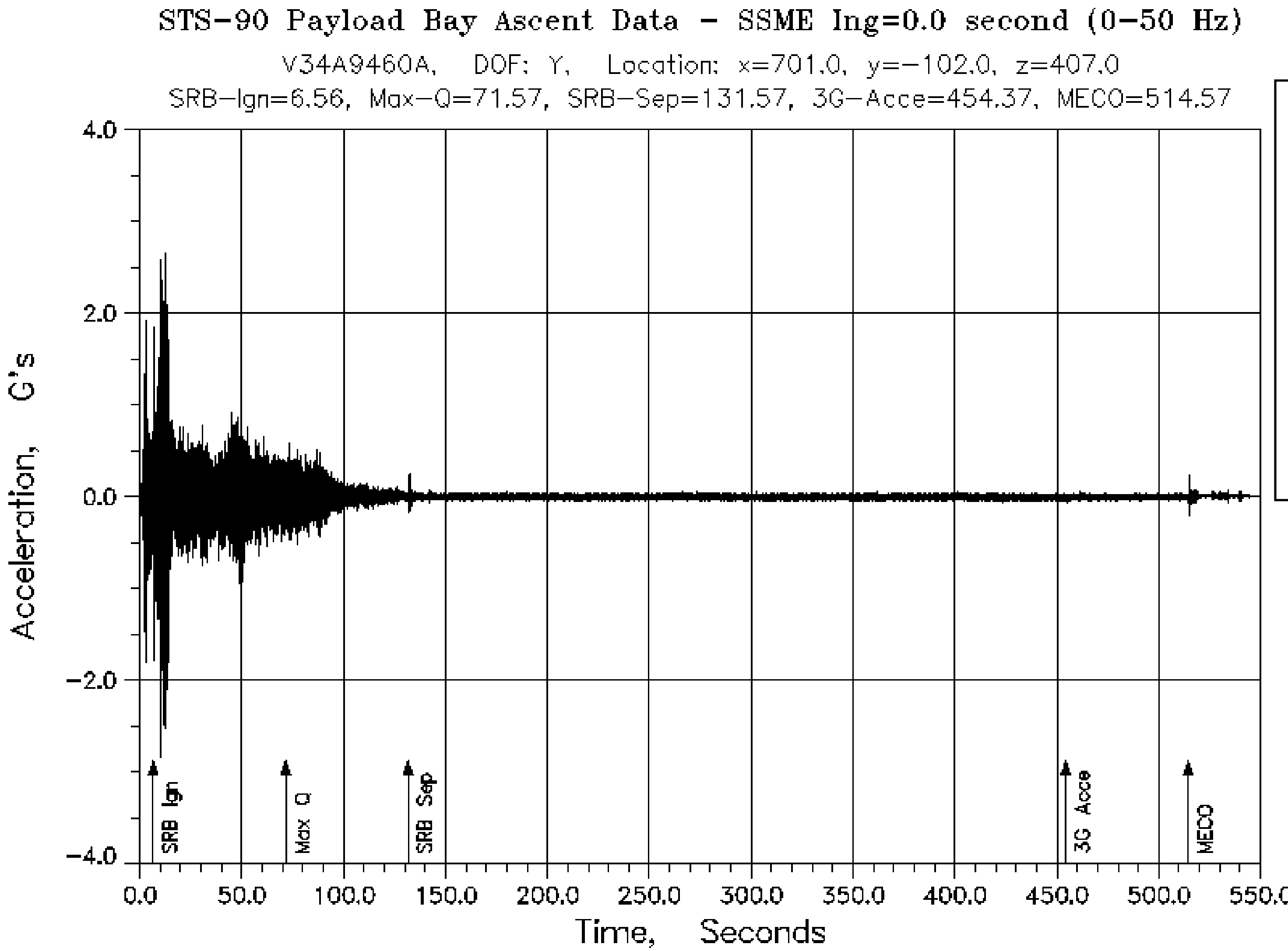
Max Q = time of maximum dynamic pressure

SRB_{Sep} = solid rocket boosters separation

3G Acce = time at which 3g acceleration is reached

MECO = main engine cutoff

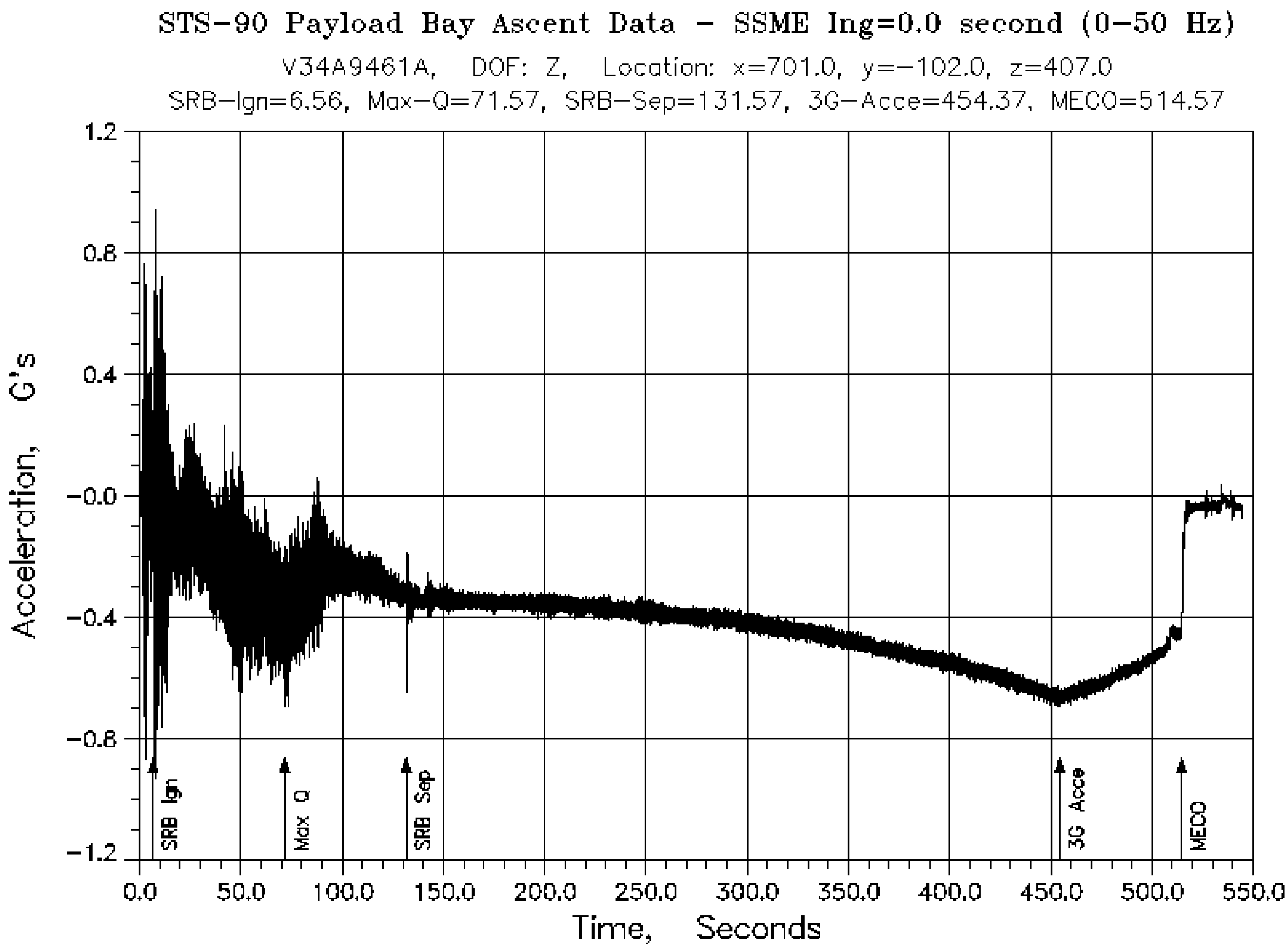
STS ASCENT PROFILE



- **Sensor dynamic responses:**
  -10 to + 10 G range
- **Frequency response:**
  0 – 50 Hz
- **Sampling rate:**
  500 samples per sec.
- **Coordinate system:**
  Orbiter structural system

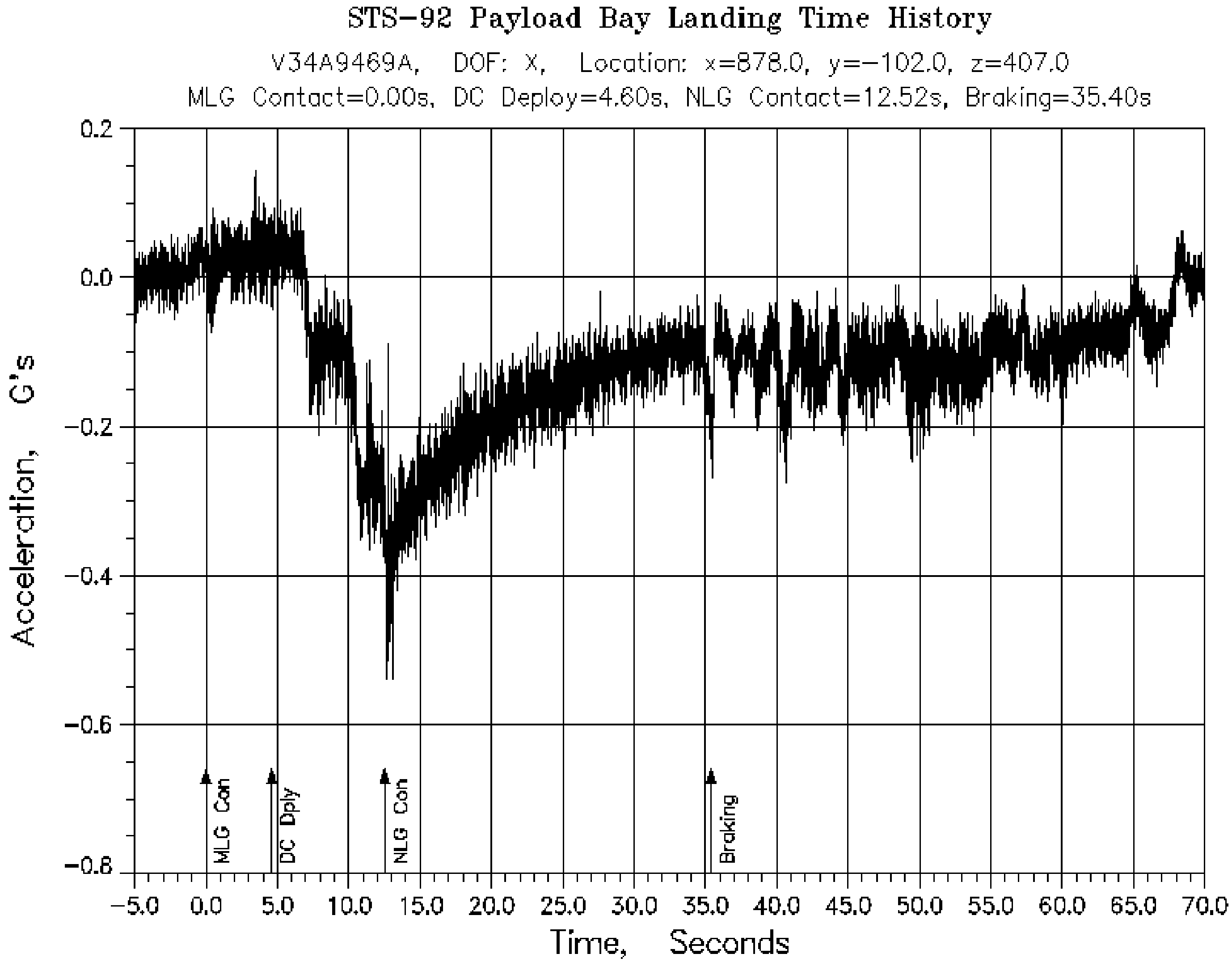
Y-axis

STS ASCENT PROFILE



Z-axis

STS LANDING PROFILE



STS = Discovery

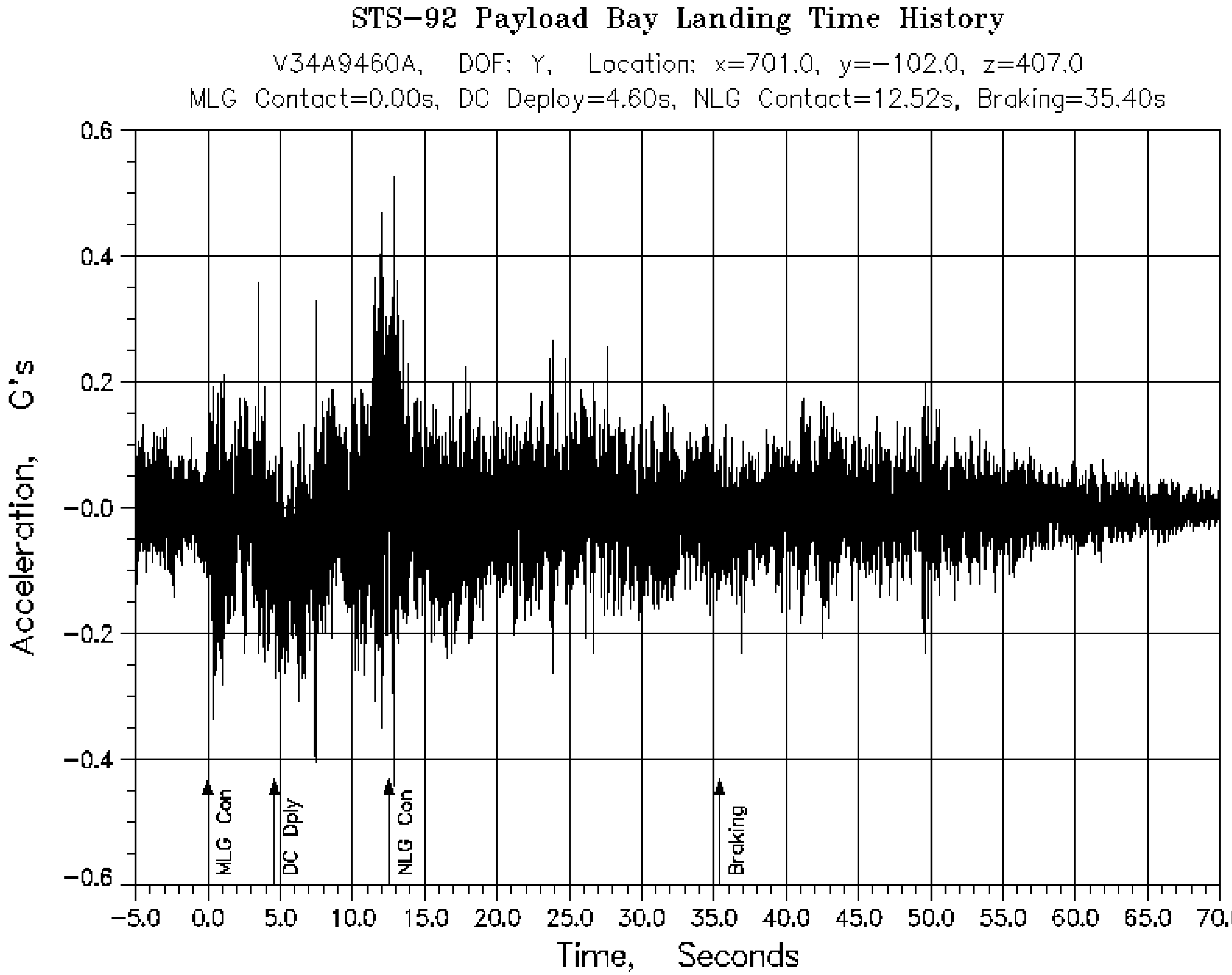
MLG$_{cont}$= main landing gear ground contact

DC$_{deploy}$ = drag Chute deployment

NLG$_{CONT}$ = nose landing gear ground contact

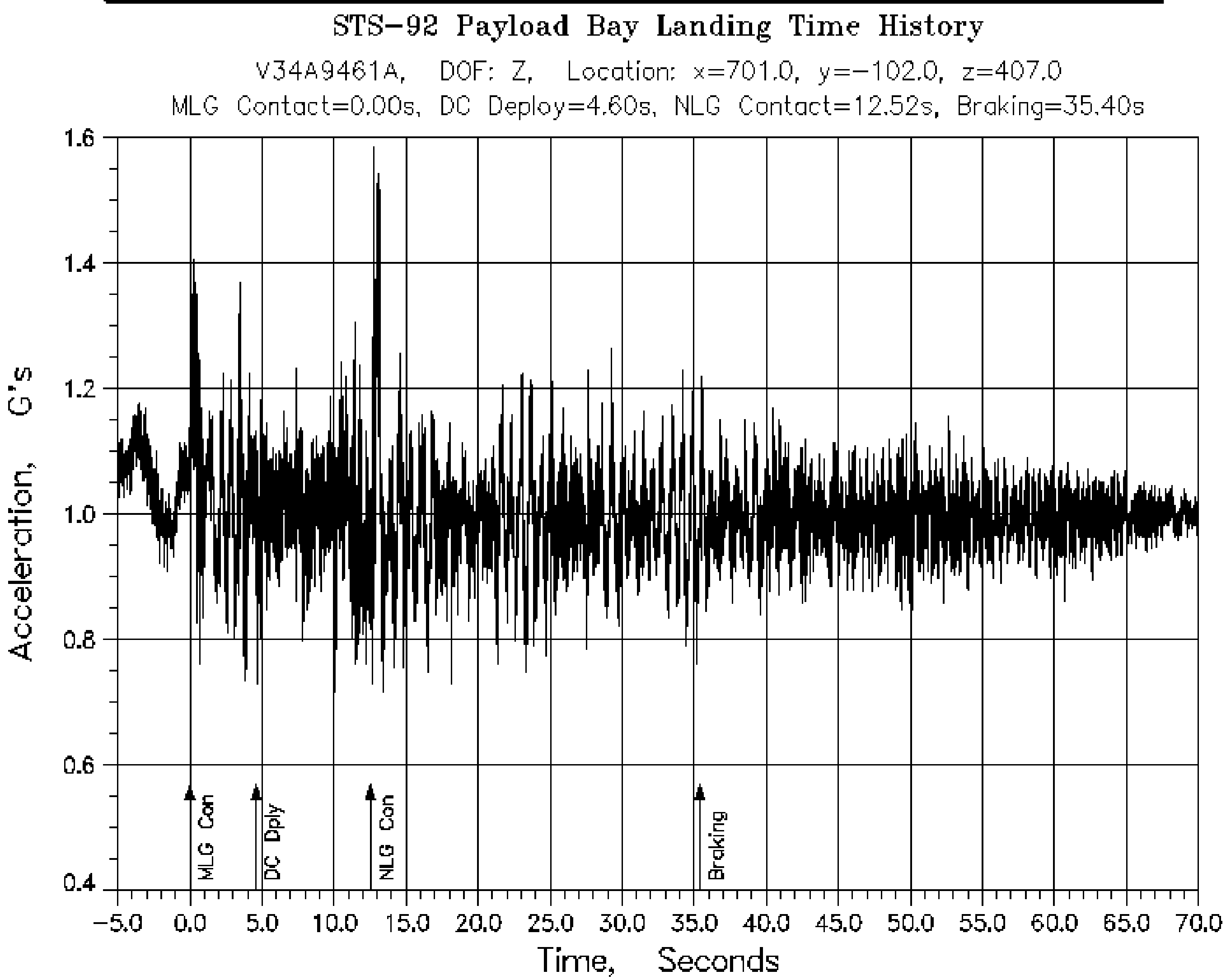
X-axis

STS LANDING PROFILE



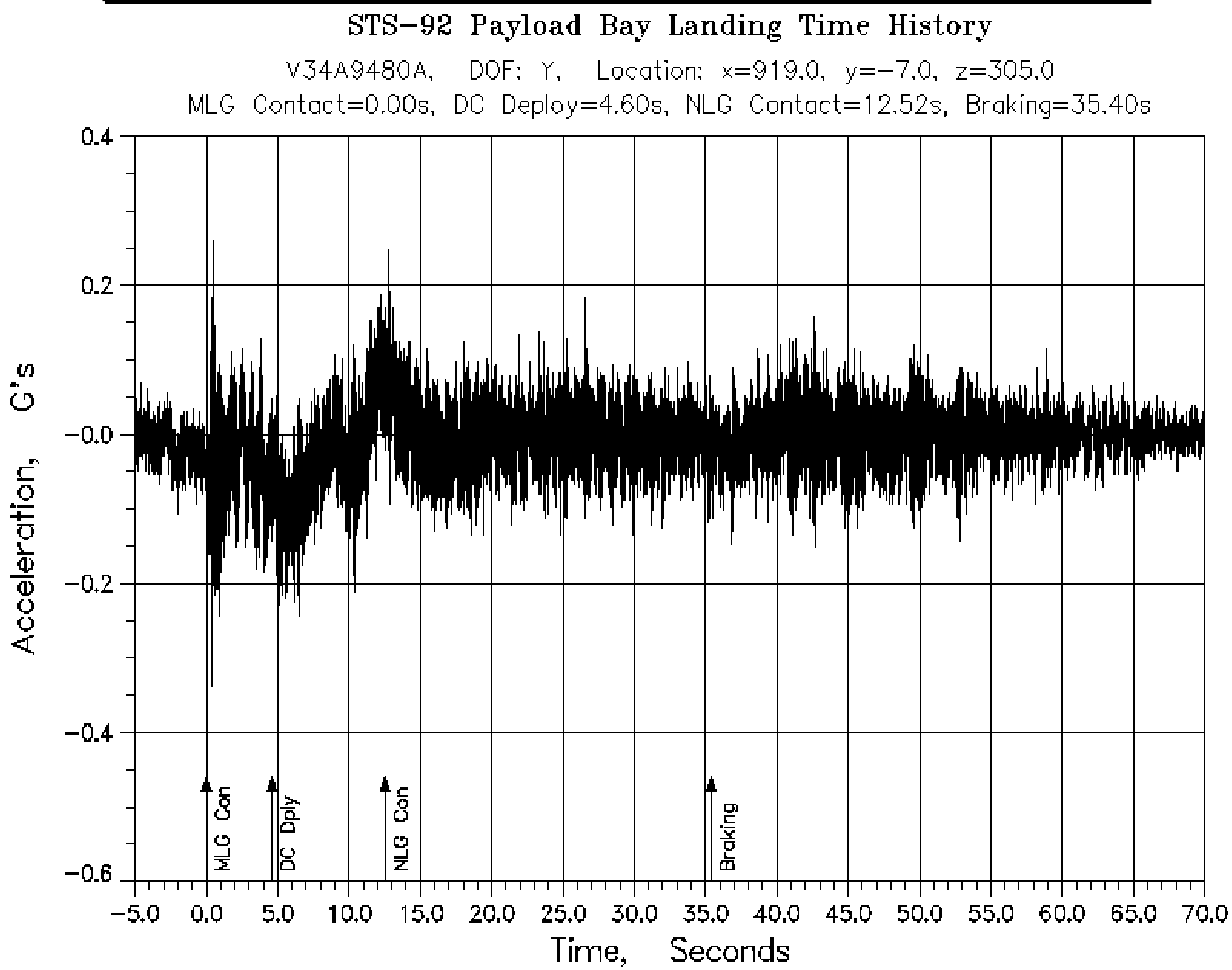
Y-axis

STS LANDING PROFILE



Z-axis

STS LANDING PROFILE



Y-axis

CONTENT

- Reduced Gravity Environment Description --- Overview
- ISS Microgravity Environment Requirements
- Microgravity Disciplines Sensitivity Assessment
- Vibration Isolation--- Why?
- Shuttle Coordinate Systems
- ISS Coordinates Systems
- Plots Header Description: Shuttle and ISS
- Experiment Planning and Execution
- Preflight Planning for Science Optimization
- STS Ascent and Landing Profiles
- **Overall Summary**

OVERALL SUMMARY

- The reduced gravity environment is not “zero-g” or even “zero-acceleration”. It is dynamic.
- The carrier environment may (and will) influence the results of a science experiment:
  - ¤ Carrier hardware
  - ¤ Experiment hardware
  - ¤ Crew effects
  - ¤ Water dump / Venting
  - ¤ Carrier attitude
  - ¤ Carrier altitude
  - ¤ Jet firings

OVERALL SUMMARY

- **Analyses and/or tests should be performed before flight to investigate the sensitivity of an experiment to the reduced gravity environment.**
- **Environments of past missions should be considered in planning future experiments (PIMS is a good source for that)**
- **Experiment teams MUST understand their own experiment hardware both for sensitivities and potential disturbance sources they may be causing to the environment with (for example) moving parts from their experiments or / and required crew actions (observe the “good neighbor policy”)**

REFERENCES

- DeLombard, R.: "Compendium of Information for Interpreting the Microgravity Environment of the Orbiter Spacecraft." NASA TM-107032, 1996.
- Rogers, M. J. B., Hrovat, K., McPherson, K., Moskowitz, M. E., and Reckart, T.: Accelerometer Data Analysis and Presentation Techniques, NASA TM-113173, September 1997.
- DeLombard, R.; McPherson, K.; Hrovat, K; Moskowitz, M.; Rogers, M. J. B.; and Reckart, T.: Microgravity Environment Description Handbook, NASA TM-107486, 1997.
- Sutliff, T. J.: Requirements and Development of an Acceleration Measurement System for International Space Station Microgravity Science Payloads, NASA TM-107484, June 1997.
- "International Space Station Flight Attitudes" D-684-10198-06 DCN-002, Dec. 1999.
- Robert C. Rhome.: "Baseline Microgravity Requirements for Scientific Research on the International Space Station", June 1996.
- "System Specification for the International Space Station", SSP 41000E, July 1996.
- Melissa J. B. Rogers.: " Planning Experiments for a Microgravity Environment", Sept. 1998.
- "Space Station Reference Coordinate Systems", SSP 30219, Revision E, Nov. 1998.
- "Microgravity Control Plan", SSP 50036RB, March 2000.
- Bao, Nguyen.: "STS-92 Payload Bay Flight and Analytical Ascent Data Assessment" MSAD-01-0140, Jan. 2001, Lockheed Martin Space Operation