SECTION 10

Working in a Reduced Gravity Environment: A Primer

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March 3nd, 2004

CONTENT

INTRODUCTION

- 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

REDUCED GRAVITY ENVIRONMENT DESCRIPTION

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 (frequency content is typically below 0.01 Hz)

VIBRATORY: is composed of those accelerations that are harmonic and periodic in nature with a characteristic frequency (frequency content greater than 0.01 Hz)

TRANSIENT: is composed of those accelerations that last for a short period of time and are non-repetitive (frequency content is broadband)

Quasi-steady

- **Frequency content: DC to 0.01 Hz**
- **Three main components of QS Vector**
  - **Aerodynamic Drag (Spacecraft wetted surface area)**
    - Attitude
    - Atmospheric density (time and altitude dependent)
    - ISS Configuration
  - **Rotational Effects (Spacecraft rotating about its center of mass-CM)**
    - Attitude
    - Angular velocity
    - Position relative to ISS Center of Mass
  - **Gravity Gradient (Experiment not necessarily located at the CM)**
    - Attitude
    - Position relative to ISS Center of Mass

- **Disturbances in the Quasi-Steady Environment**
  - **Crew Activity Effects**
  - **Air and Water Venting**
  - **EVA/SSRMBS Operations**
  - **Miscellaneous**

Vibratory

- **Crew**
  - Sleep/Wake
  - Exercise
- **Vehicle**
  - Docking
  - Air conditioner [SKV]; Система Кондиционирования Воздуха (СКВ)
  - Vehicle structural modes
  - Etc …
- **Experiment**
  - Experiment of Physics of Colloids in Space (EXPPCS)
  - ADVanced AStroCulture (ADVASC)
  - Gas Analysis System for Metabolic Analysis of Physiology (GASMAP)
  - Microencapsulation Electrostatic Processing System (MEPS)
  - Characterization Experiment (ARIS-ICE) Hammer Test
  - Active Rack Isolation System International Space Station (ARIS-ICE)
  - Etc …

REDUCED GRAVITY ENVIRONMENT DESCRIPTION

WHAT DO ALL THESE MEAN TO YOU?

- **The environment is NOT "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 it is measured and interpreted and will also illustrate the impact the environment had on past experiments and how experiment operations (and other factors…) affect the environment as well.**

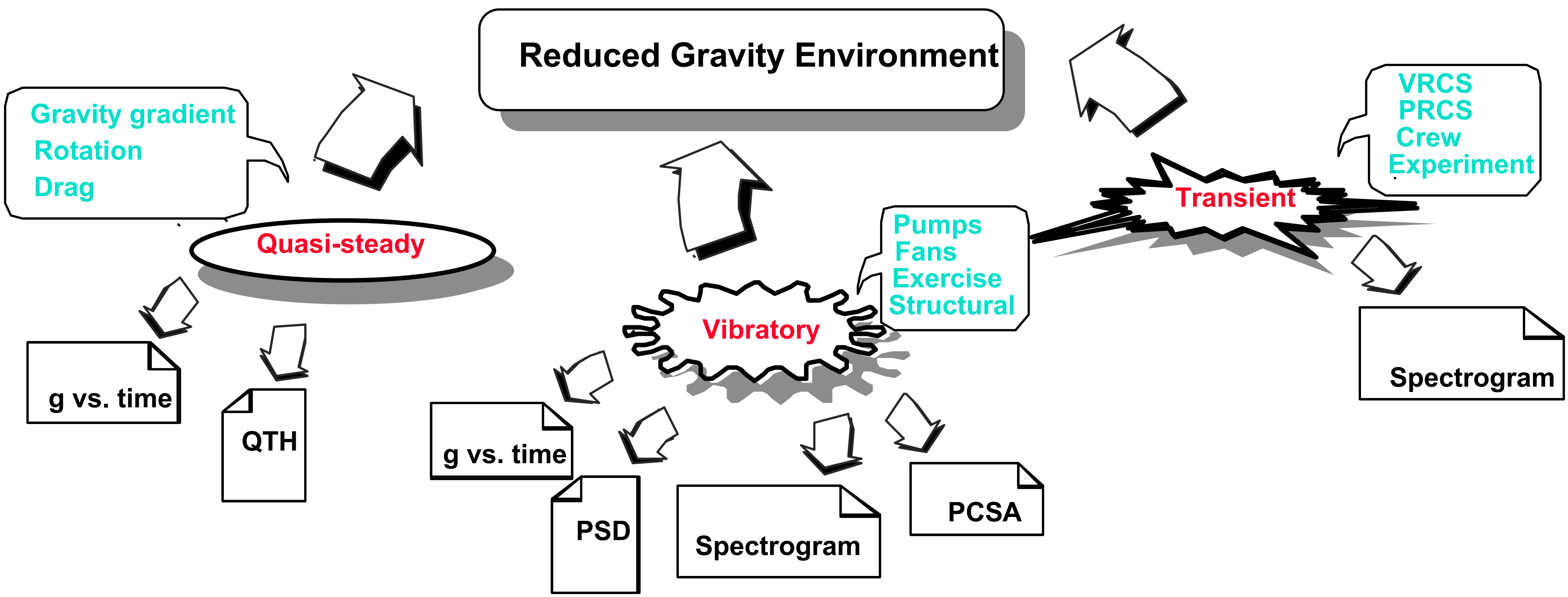
REDUCED GRAVITY ENVIRONMENT DESCRIPTION

What is a *"Reduced Gravity Environment"* ?

Major properties

What causes these accelerations

How do we display them?



MISCONCEPTION ABOUT "A MICROGRAVITY ENVIRONMENT"

- **Microgravity Environment (or better yet, a Low-gravity Environment):** is an environment in which the effects of gravity are small (NOT ZERO) compared to those we experience on Earth. The environment is not 1×10^{-6}g per se, the magnitude level is a function of time, frequency, location, duration, vehicle systems and configurations as well as crew and experiments. It is dynamic.
- The effect of earth's gravity on an object can be reduced to very small levels in a number of ways:
  - ¤ At a sufficiently large distance away from the earth's surface
  - ¤ Placing the object in free fall

A common misconception is that the effects of gravity are reduced in an orbital spacecraft due to its distance (i.e., low earth orbit) away from the earth's surface. That is not the case.

MISCONCEPTION ABOUT "A MICROGRAVITY ENVIRONMENT"

- The weight, W, of an object is the resultant gravitational force exerted on the body by all bodies in the universe. At or near the earth's surface, the force of the earth's attraction is so much greater than any other body in the universe that all other attracting forces can be ignored (with little error). The weight, W_e, of the object on the earth's surface can be approximated as:

$$\boxed{W_e = Gmm_e/r_e^2 \qquad (1)}$$

Where: m = mass of the object, G = $6.67\times10^{-11}Nm^2kg^{-2}$ (Cavendish's constant), me = mass of the earth (5.98×10^{24}kg) and r_e = radius of the earth (6370 km on average)

- If the object falls freely, its weight is the force accelerating it towards the earth. The acceleration is solely due to the earth gravity, defined as:

$$\boxed{g_e = Gm_e/r_e^2 \qquad (2)}$$

Substituting the above values for G, m_e and r_e → $g_e = 9.8\ ms^{-2}$

Substituting (2) into (1) → $\boxed{W_e = mg_e \qquad (3)}$

MISCONCEPTION ABOUT "A MICROGRAVITY ENVIRONMENT"

- The International Space Station (ISS) orbits about 300 km above the earth and since its contents are farther away from the center of gravity of the earth, orbiting at $r > r_e$, there is some reduction in gravity and weight. From equations (1-3):

$$W / W_e = g / g_e = r_e^2 / r^2$$

- So, at about 300 km above the earth's surface (r = 6670 km),

$$W / We = g / g_e = 0.91$$

- This is just about 9% reduction in the weight of gravity level. And of course, this reduction is not enough for the apparent weightlessness of astronauts and objects within the ISS or the Shuttle.

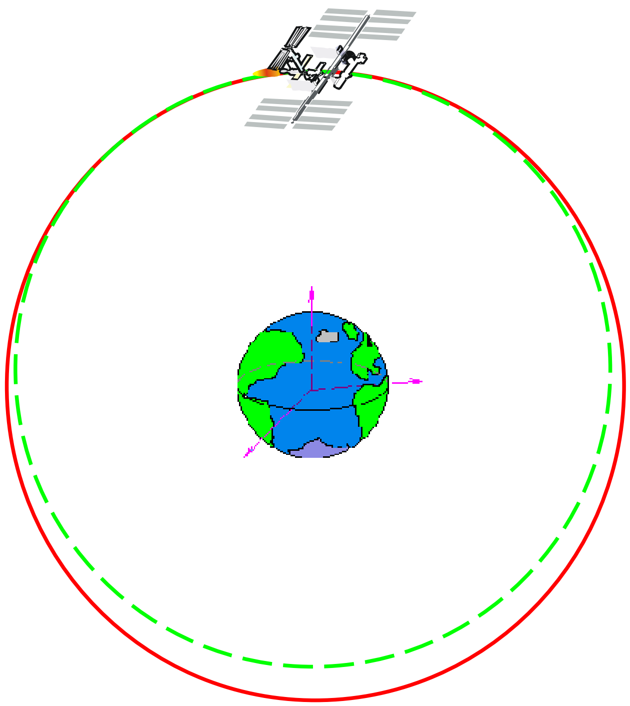
- In order to achieve microgravity ($g / g_e = 1\text{x}10^{-6}$) based strictly on distance from the surface of the earth, the ISS will have to be located away from the earth's surface at a distance of: 1000 times the earth's radius:

$$r = 6.37\text{x}10^6 \text{ km}$$

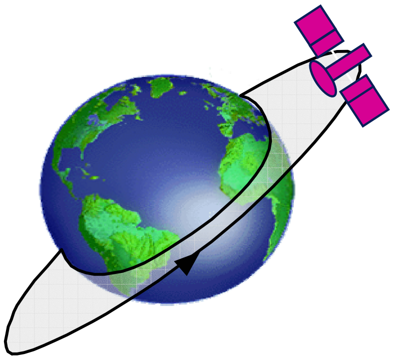
About 17 times farther than the moon is from the earth.

MISCONCEPTION ABOUT "A MICROGRAVITY ENVIRONMENT"

- Therefore, the ISS (or Shuttle) and its contents will have weight while in orbit. The apparent weightlessness they experience is due to a common acceleration while in free fall due to gravity with the sum of all other forces being zero. The ISS and its contents are freely falling towards the earth due to earth's gravity as show in these graphics:



Freely falling



ISS Microgravity Environment Requirements

- **Microgravity science research conducted on the ISS are science "requirement" driven, rather than vehicle "capability" driven**

  - **Space Shuttle was used for microgravity experiments, but there were no Space Shuttle microgravity requirements**

  - **ISS, on the other hand, DOES have microgravity requirements 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, $0.01 \text{ Hz} \leq f \leq 300$ Hz
  - Transient (short duration relative to an orbital period, non-periodic and broadband)

ISS Microgravity Environment Requirements

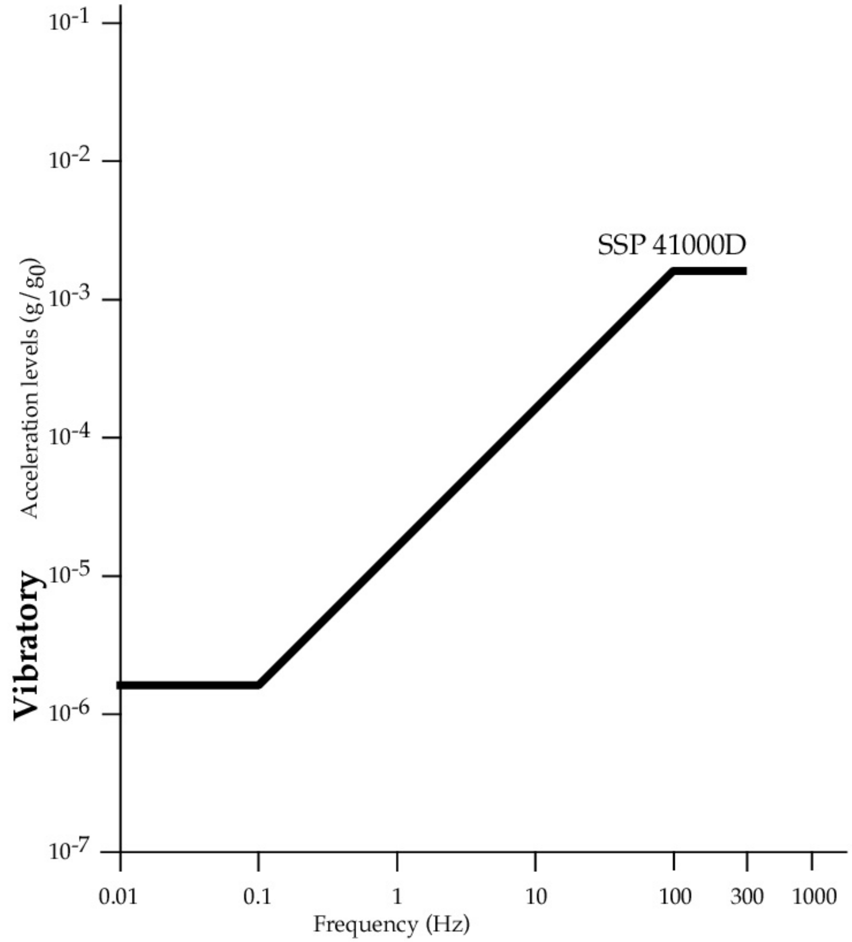
ISS Microgravity Requirements

Summary

Quasi-steady
- Steady state < f < 0.01 Hz
- $g \leq 1\ \mu g_{rms}$
- Stability: perpendicular $g \leq 0.2\ \mu g_{rms}$

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
- $g \leq 1000\ \mu g$ per axis
- $g \leq 10\ \mu g$-sec per axis (integrated over 10 sec)



For $0.01 \leq f \leq 0.1$ Hz : $a \leq 1.6^{*}\ \mu g$ or **$1.8^{\S}\ \mu g$**

For $0.1 < f \leq 100$ Hz : $a \leq f \times 16\ \mu g$ or **$18\ \mu g$**

For $100 < f \leq 300$ Hz : $a \leq 1600\ \mu g$ or **$1800\ \mu g$**

Where: f = frequency
a= acceleration

*** Vehicle alone**
§ Vehicle + payload

EXPERIMENT SENSITIVITY ASSESSMENT

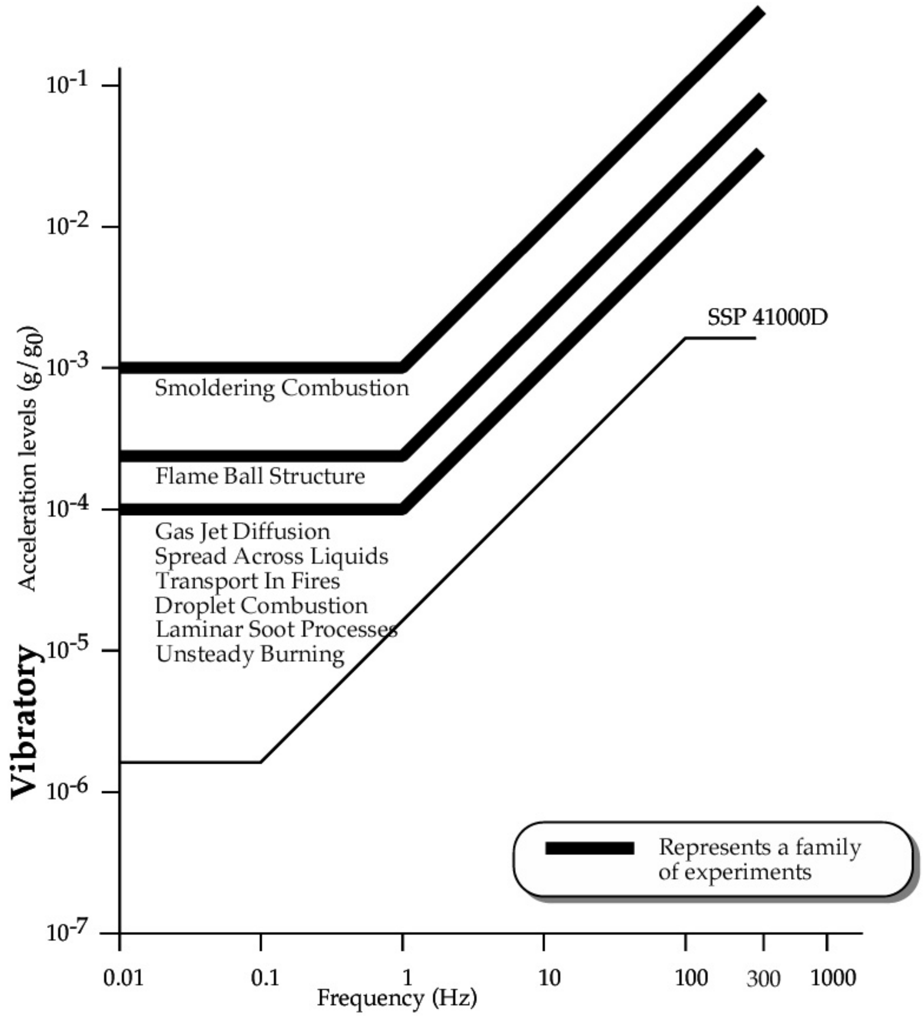
Combustion Science

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

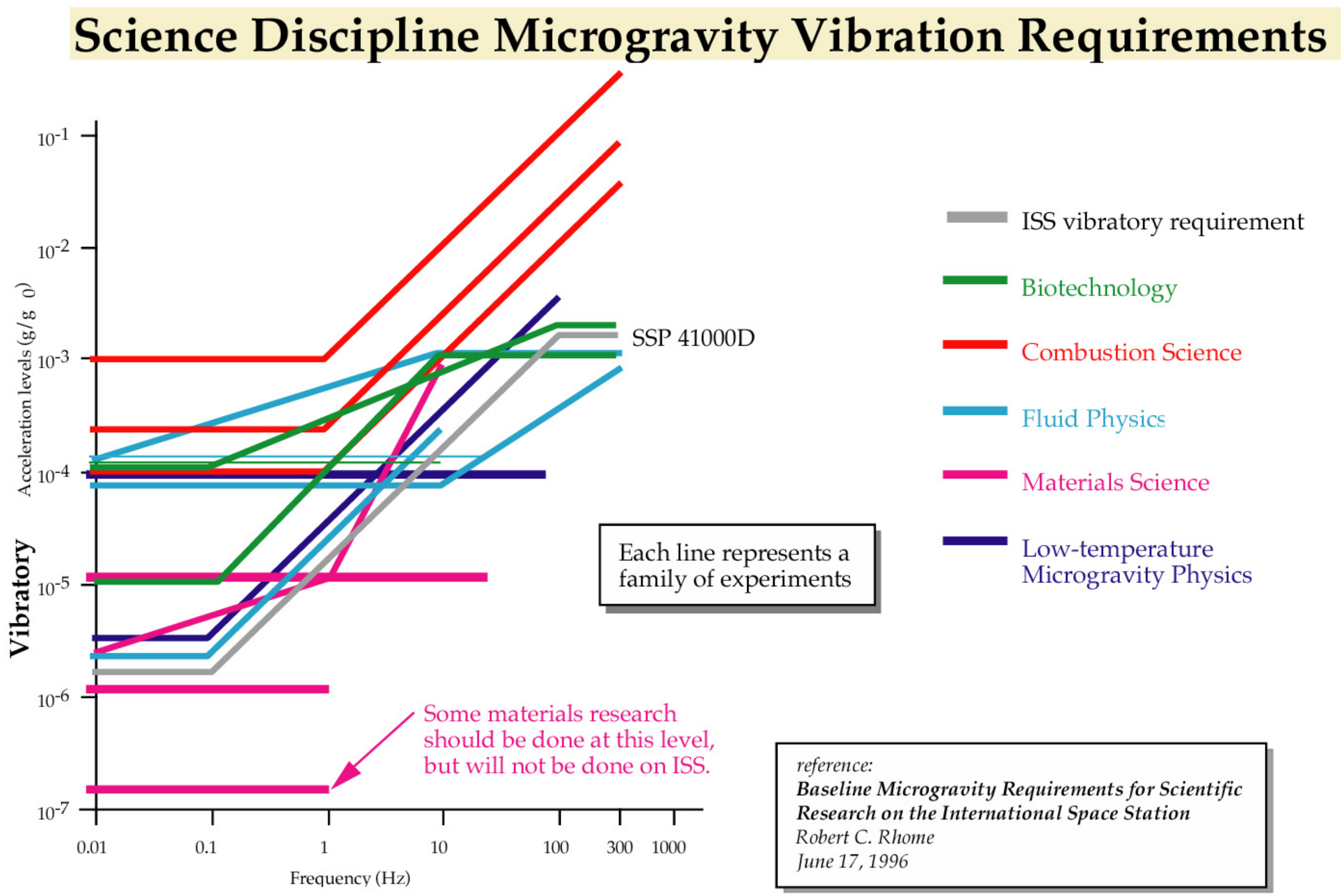
Vibratory
- Typically low acceleration levels at low frequencies (< 1 Hz) disturb experiments
- Most experiments are above the ISS requirement curve but some are below the expected environment
- Low frequency g-jitter has been observed repeatedly to affect the combustion characteristics of a variety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



EXPERIMENT SENSITIVITY ASSESSMENT



EXPERIMENT SENSITIVITY ASSESSMENT

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

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 are (or will be) on the ISS:**
    - **ARIS, MIM-2, g-LIMIT and PaRIS**

Vibration Isolation

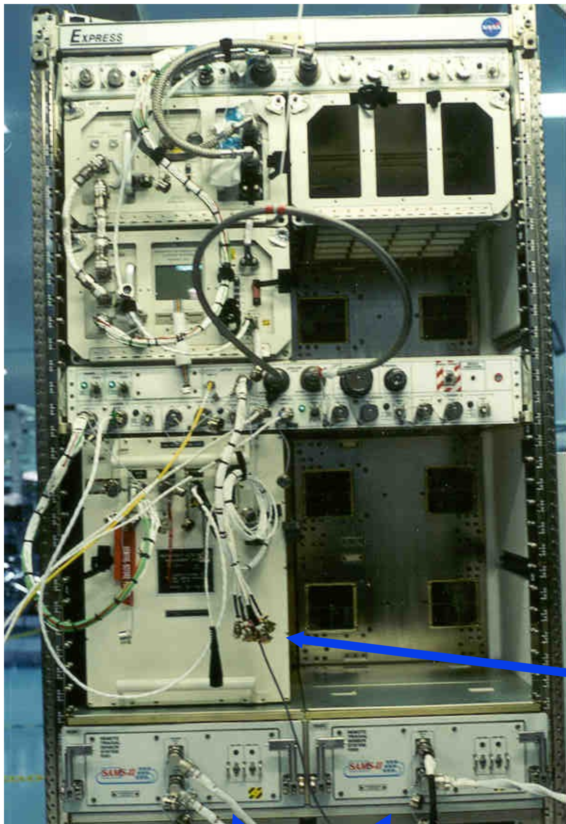
- Rack Level Isolation Systems:
  - Active Rack Isolation System– ARIS
    - ¤ ARIS provides rack-level reduction of acceleration levels
    - ¤ ARIS supplied by ISSP to meet the microgravity requirements
    - ¤ 6 racks (?) will have ARIS installed
  - Passive Rack Isolation System-- PaRIS
    - ◊ Provides passive isolation from 0.5 - 2.0 Hz. Up to 300 Hz.
    - ◊ Will be used on 3 racks (?): 2 HHRs and CIR
- Sub-rack Isolation Systems
  - STABLE / g LIMIT (Glovebox)
    - Marshall Space Flight Center
  - MIM/ MIM-2
    - Canadian Space Agency

ISS Rack Facilities

EXPRESS RACK #1

Increment-2 Configuration

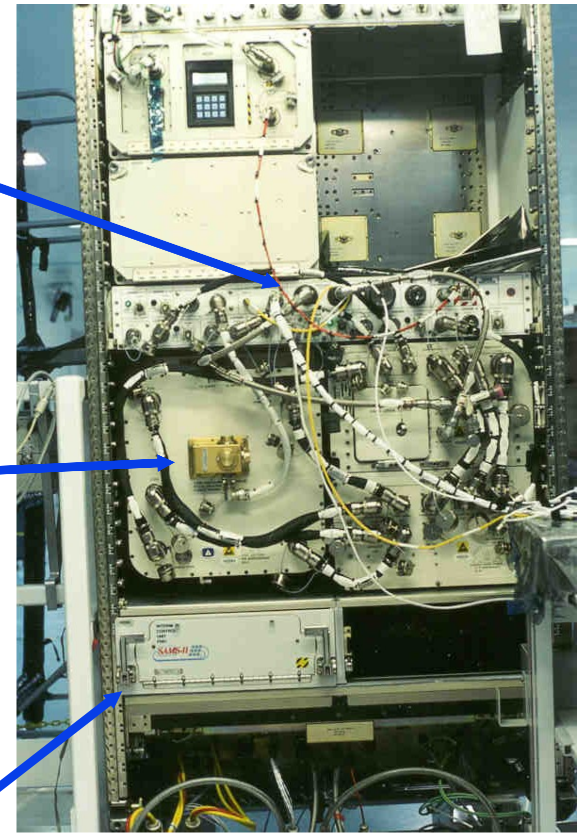
EXPRESS RACK #2



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

RTS-SE

MAMS

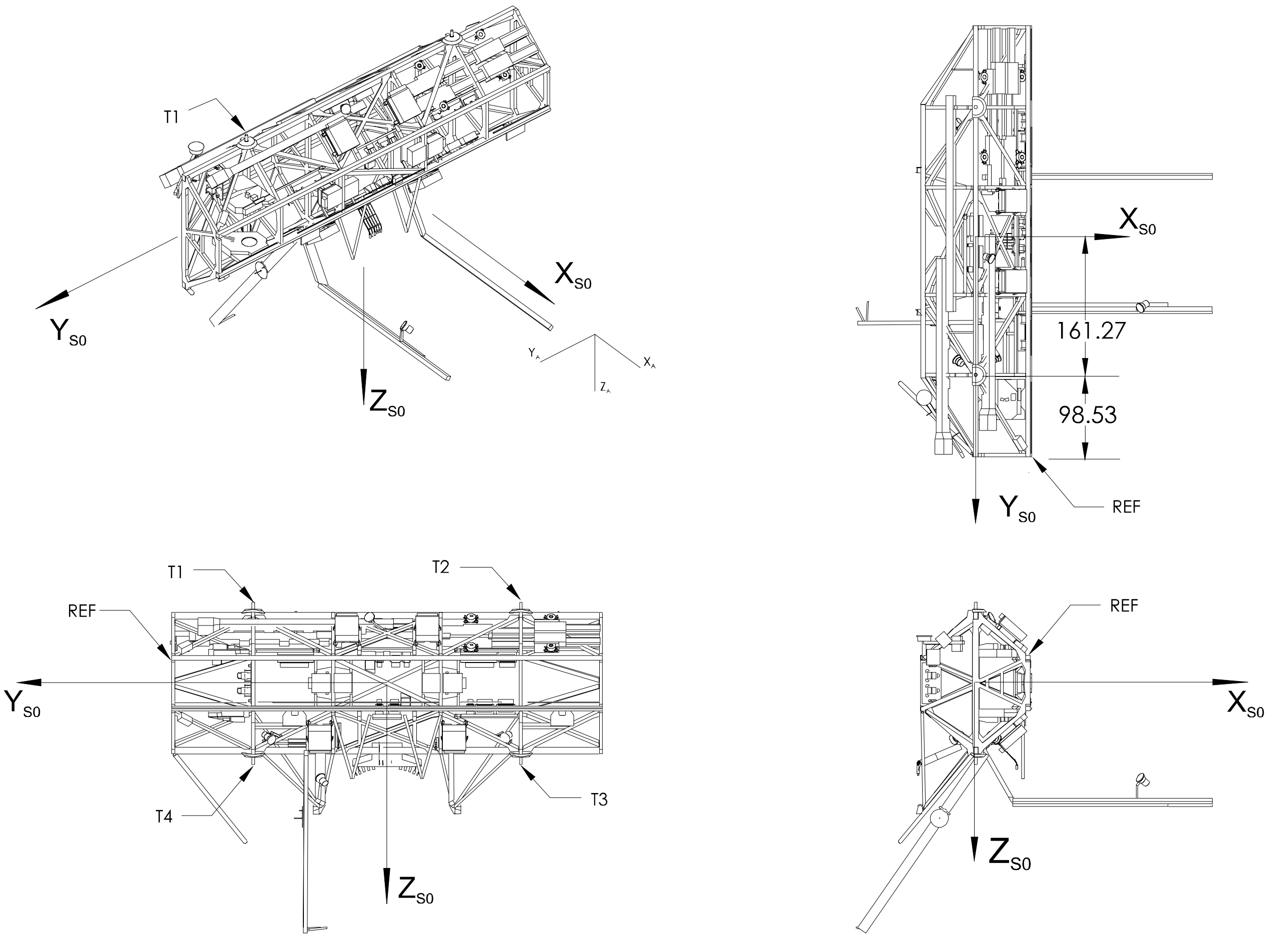


RTS DRAWERS

ICU DRAWER

COORDINATE SYSTEMS

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.

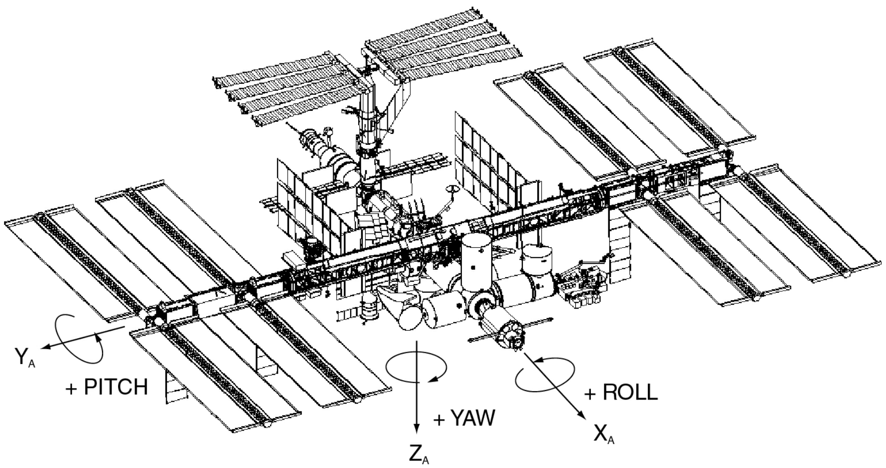
Orientation

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

COORDINATE SYSTEMS



SPACE STATION ANALYSIS COORDINATE SYSTEM

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.

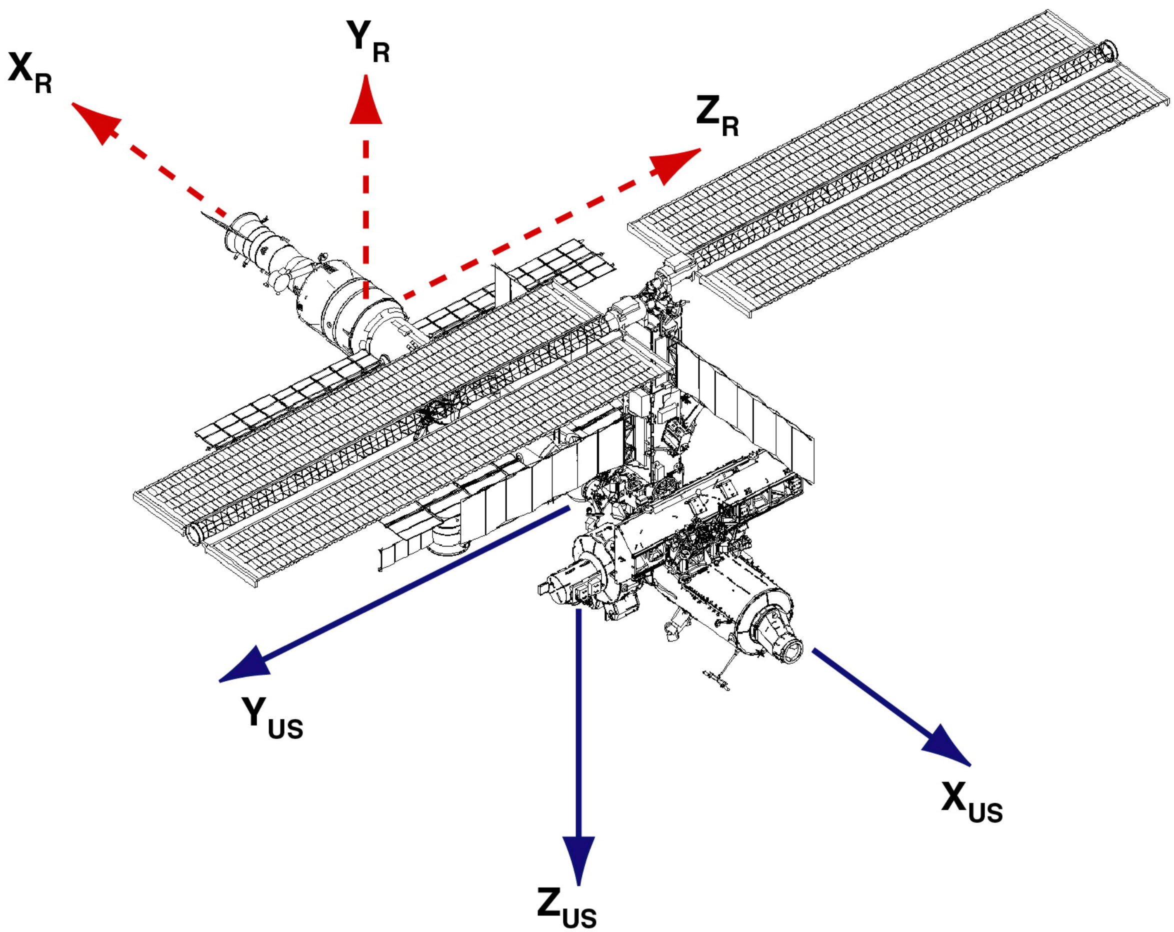
Orientation

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

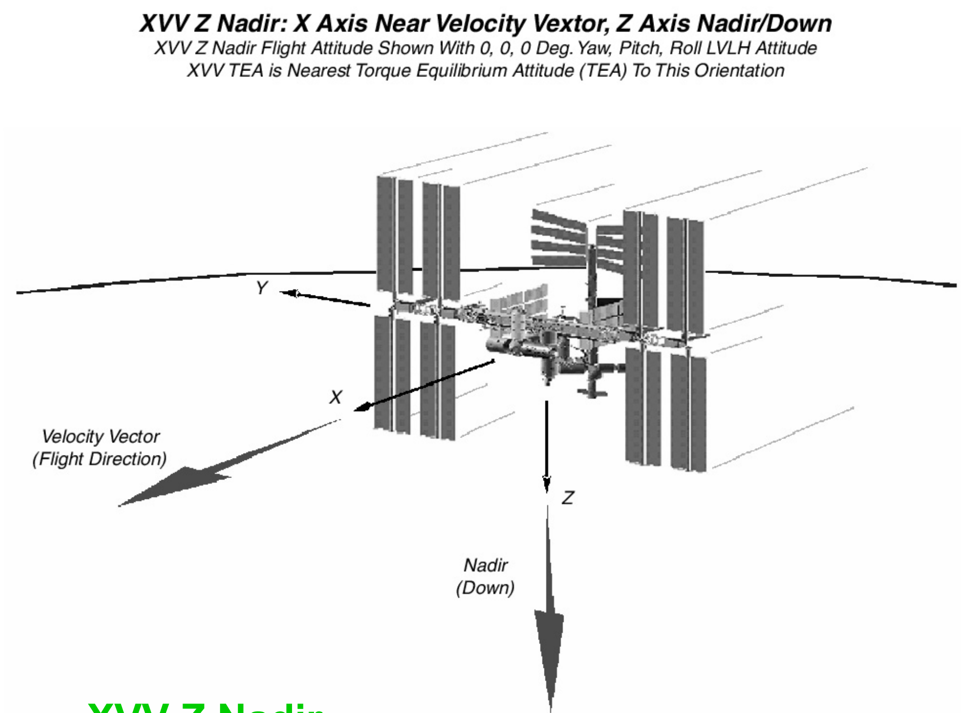
Y_A: The Y-axis is identical with the So axis. The nominal alpha joint rotational axis is parallel with YA. The positive Y-axis is in the starboard direction.

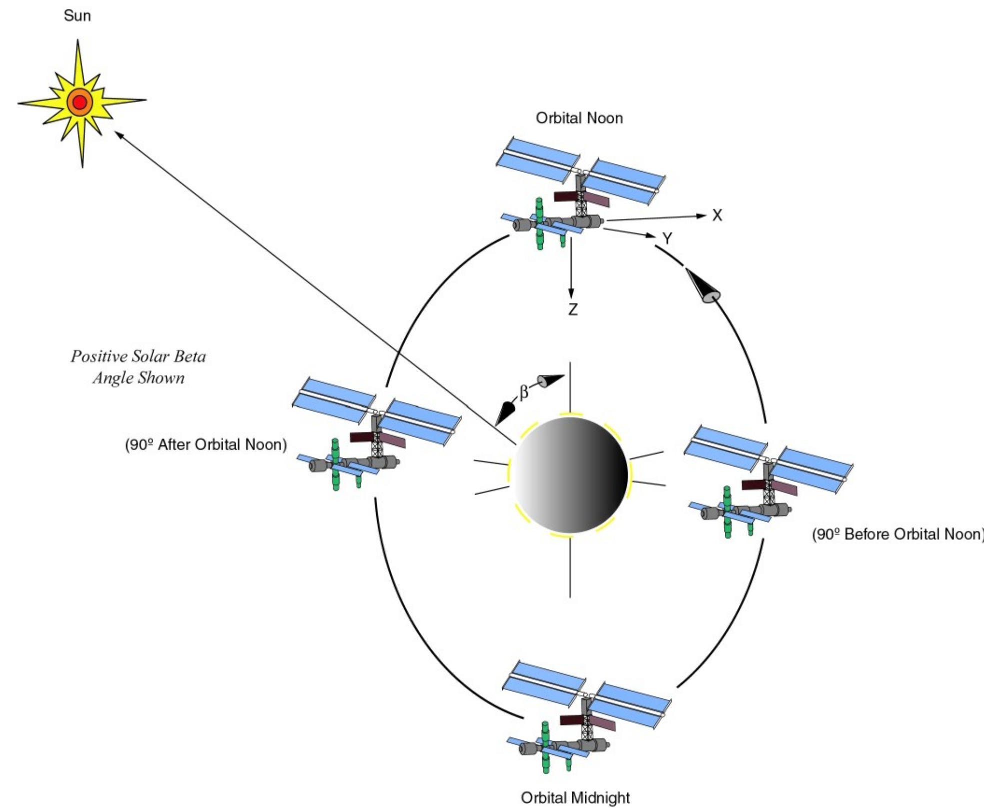
Z_A: The positive Z-axis is in the direction of nadir and completes the right-handed Cartesian system (RHCS).

ISS-USOS / ROS Analysis Coordinate Systems



FLIGHT ATTITUDES: LVLH vs. XPOP





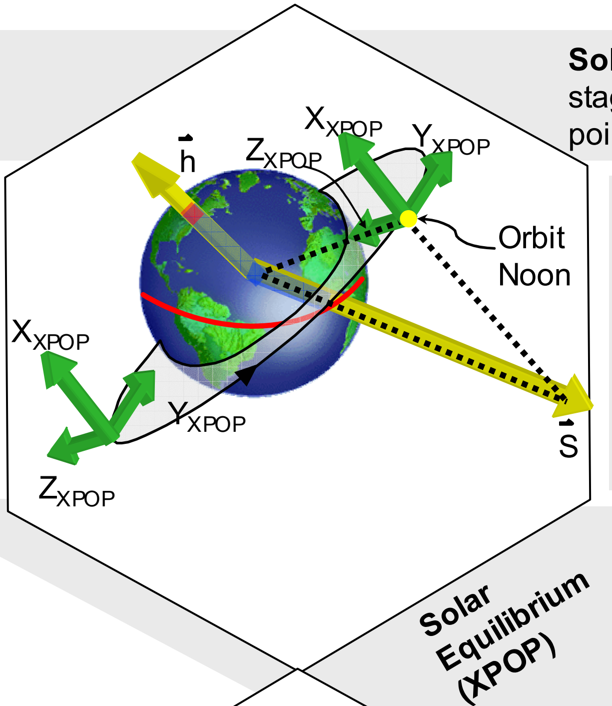
XVV Z Nadir

- is the basic flight attitude of ISS
- places the most modules in the microgravity volume
- supports altitude reboosts
- service vehicle dockings
- minimizes aerodynamic drag
- tolerates angular deviations of +/-15˚ in each axis

XPOP

- maximizes power generation
- minimizes vehicle gravity gradient torque
- momentum manager provides CMG attitude control without propellant usage
- Allows all the solar arrays to track the sun regardless of the solar beta angle

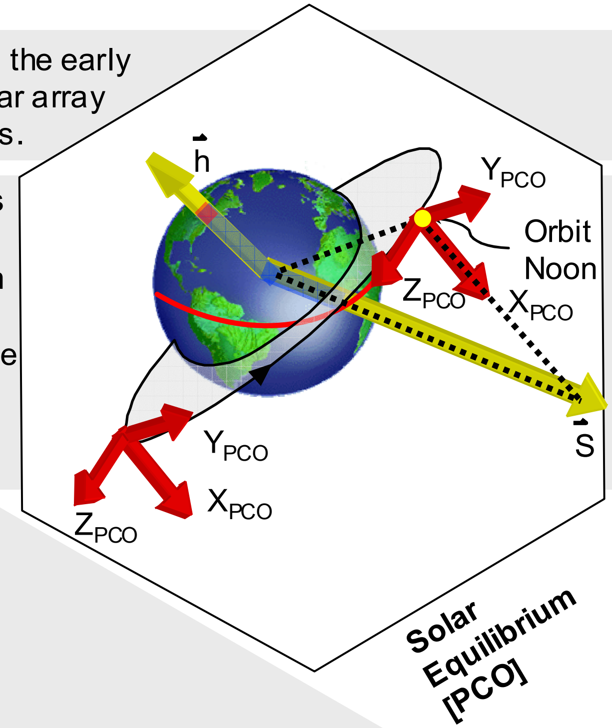
Flying Attitudes: Solar Equilibrium-- US (XPOP) vs. RS (XPOP)



Solar Equilibrium (XPOP, [PCO]) - Used during the early stages of station assembly (<12A) to improve solar array pointing during very high and very low beta angles.

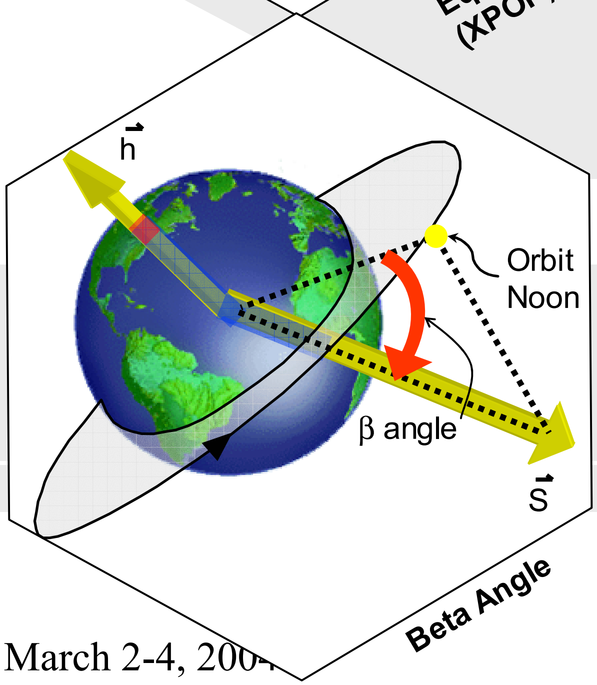
Russian [PCO] Origin at ISS center of mass

- $+X_{PCO}$ is perpendicular to the orbit plane and is opposite to the angular momentum vector of the orbit ($X_{PCO} = -h$);
- $+Z_{PCO}$ points along the normal of the plane of the angular momentum (h) and the solar vector (S) ($Z_{PCO} = S \times h$)
- $+Y_{PCO}$ points zenith at orbital noon.



US (XPOP) - Origin at ISS center of mass

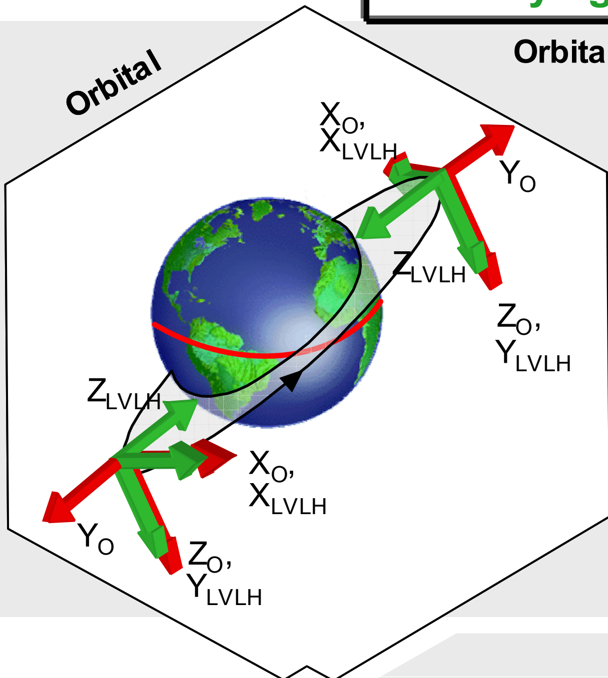
- $+X_{XPOP}$ is perpendicular to the orbit plane and coincides with the angular momentum vector ($X_{XPOP} = \mathbf{h}$);
- $+Y_{XPOP}$ points along the normal of the plane of the angular momentum (h) and the solar vector (S) lie ($Y_{XPOP} = h \times S$)
- $+Z_{XPOP}$ points nadir at orbital noon;



Beta Angle – The angle between the vector from the center of the earth to orbit noon and the vector from the center of the earth to the sun. The angle is positive when the sun is to the north of the orbit plane and negative when the sun is to the south of the orbit plane.

Orbit Noon – The point on the orbit that is closest to the sun.

Flying Attitudes: US (LVLH) vs. RS (LVLH) and TOCK



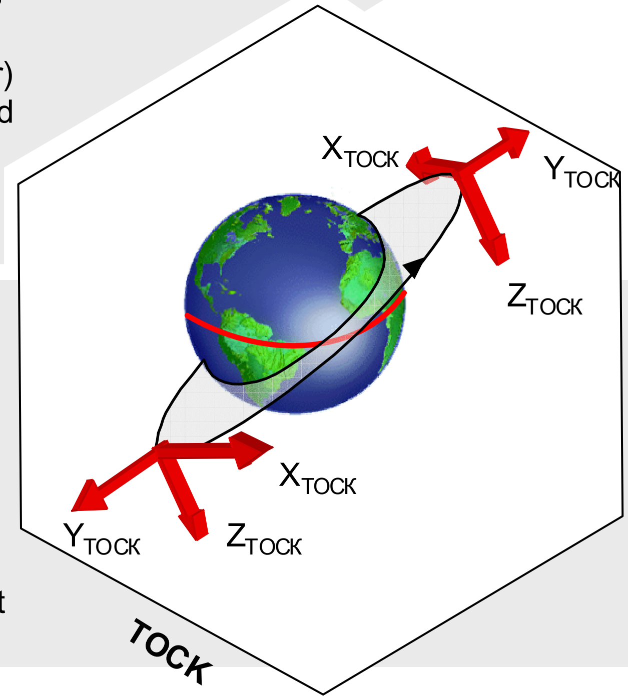
Orbital System - Attitudes at or near this reference frame are nominal attitudes for post 12A

RS [OCK] - Origin at ISS center of mass

- the $+Y_O$ axis coincides with the radius vector that connects the center of the Earth with the station center of mass (i.e. zenith);
- the $+X_O$ axis lies in the orbit plane, and points toward station orbital motion;
- the $+Z_O$ axis completes the right-handed coordinate system.

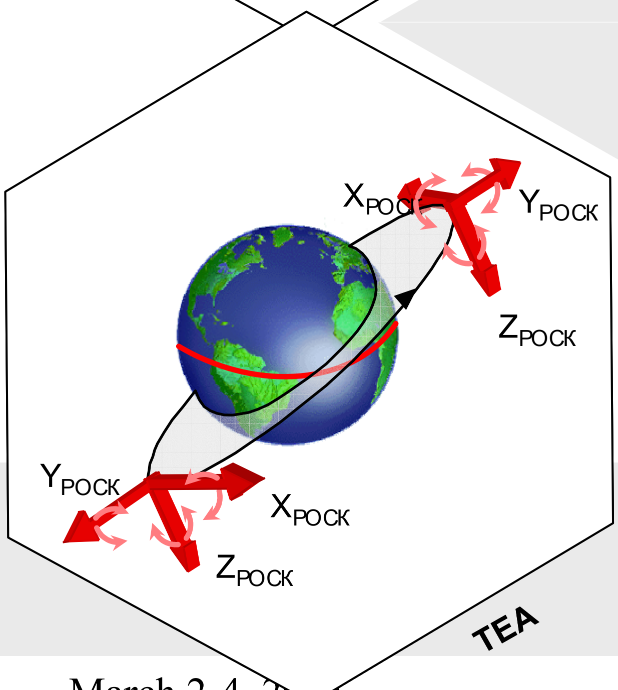
US (LVLH) - Origin at ISS center of mass

- the $+Z_{LVLH}$ axis coincides with the radius vector from the station center of mass toward the center of the Earth (i.e. nadir)
- the $+X_{LVLH}$ axis lies in the orbit plane and points with station orbital motion
- the $+Y_{LVLH}$ axis completes the right-handed coordinate system.



Current OCK [TOCK] - This is a temporary reference frame for use during handovers.

- Origin at ISS center of mass
- Coincides with the axes of the Russian body coordinate system (B-RS) at the moment of defining this reference frame (snapshot of attitude).
- This reference frame is fixed with respect to [OCK].



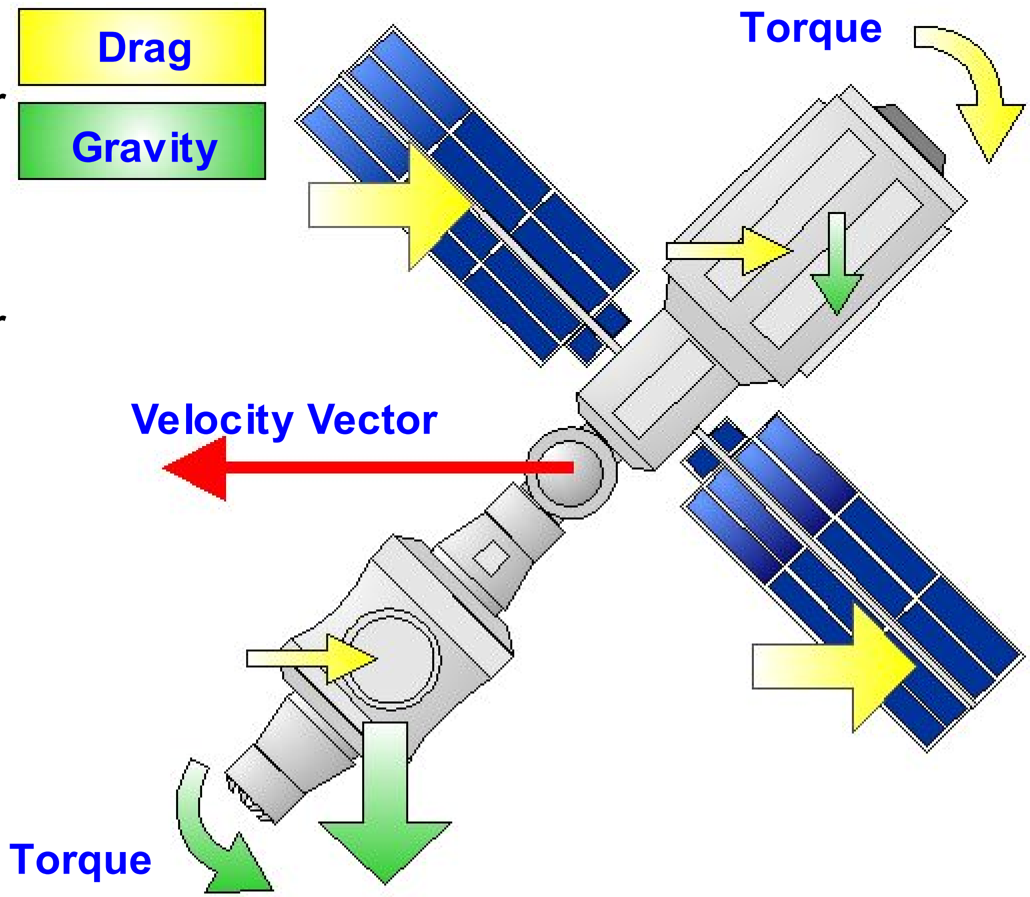
Equilibrium Orbital System [POCK] – POCK represents the instantaneous Torque Equilibrium Attitude (TEA). A TEA is an attitude for which the external torques on the station balance.

Momentum Management Properties of TEA

The imbalance of drag forces creates a rotation about the center of pressure (cp).

The imbalance of gravity forces creates a rotation about the center of gravity (cg).

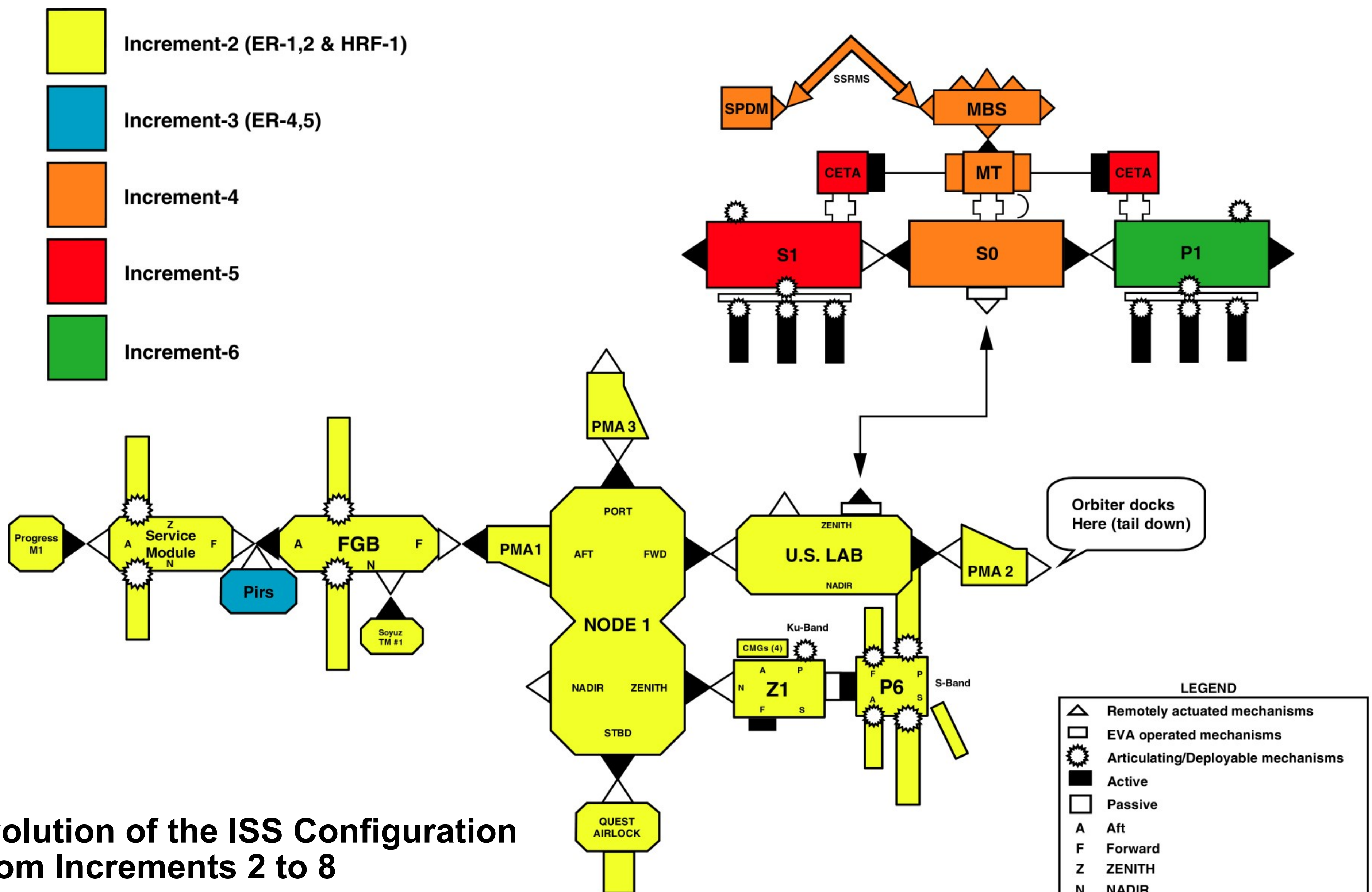
These torques exist because neither cp nor cg are at the center of mass (cm).



•What is a Torque Equilibrium Attitude?

•atmospheric torques + gravity torques + gyroscopic torques = 0

A TEA is an attitude for which the external torques on the station balance



Evolution of the ISS Configuration From Increments 2 to 8

SOME DEFINITIONS

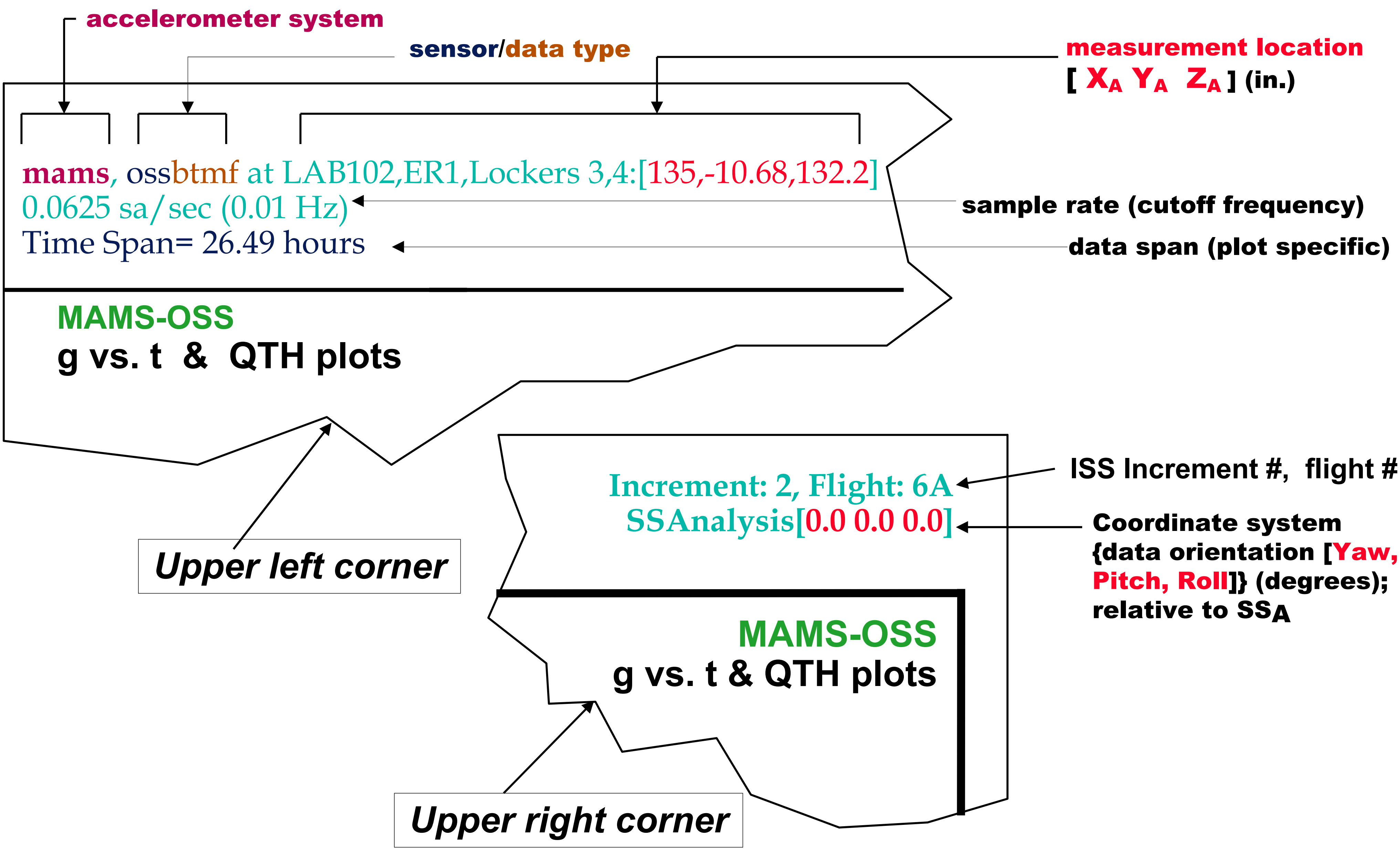
Acceleration Measurement Systems

- **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. However, PIMS analyzes and reports the data up to 0.01 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:** Space Acceleration Measurement System measures the vibratory accelerations level from 0.01 to 400 Hz aboard the ISS.

SOME 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

ISS QUASI-STEADY SAMPLE PLOTS INFORMATION



EULER SEQUENCES (Orientation)

Qualities

- Sequential rotations about axes
- ISS uses

  Z-Y-X (Yaw, Pitch, Roll)
- Shuttle uses Y-Z-X (Pitch, Yaw, Roll) but writes this as (X-Y-Z)

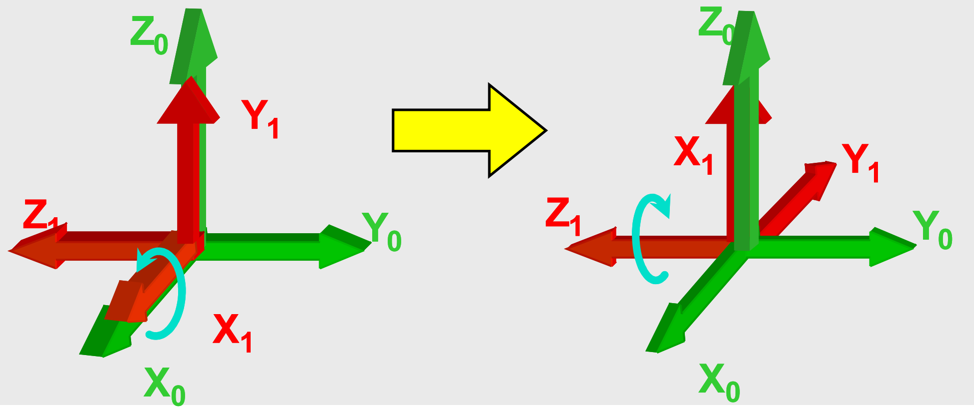
\+ Easily visualized

\- Unsuitable for computation

\- Non-unique

Euler (0, 0, 90):
90° roll about X_1

Now, add an Euler (90, 0, 0) rotation: 90° yaw about Z_1

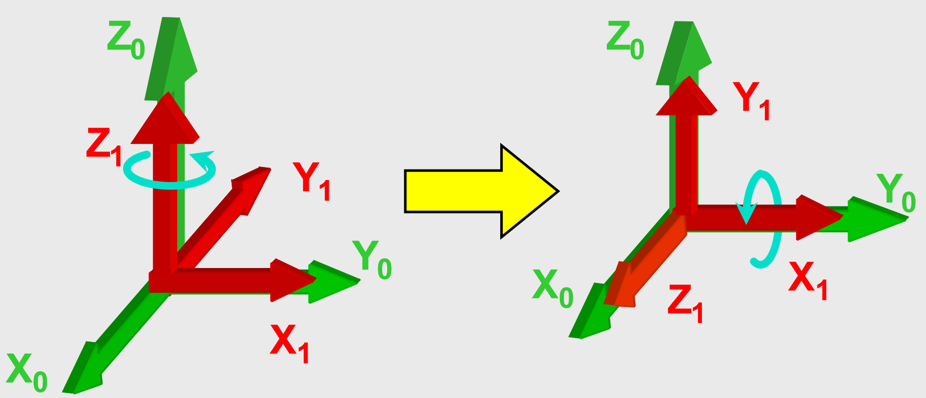


Is (0,0,90) + (90,0,0) = (90,0,90)?

Euler (90, 0, 90):

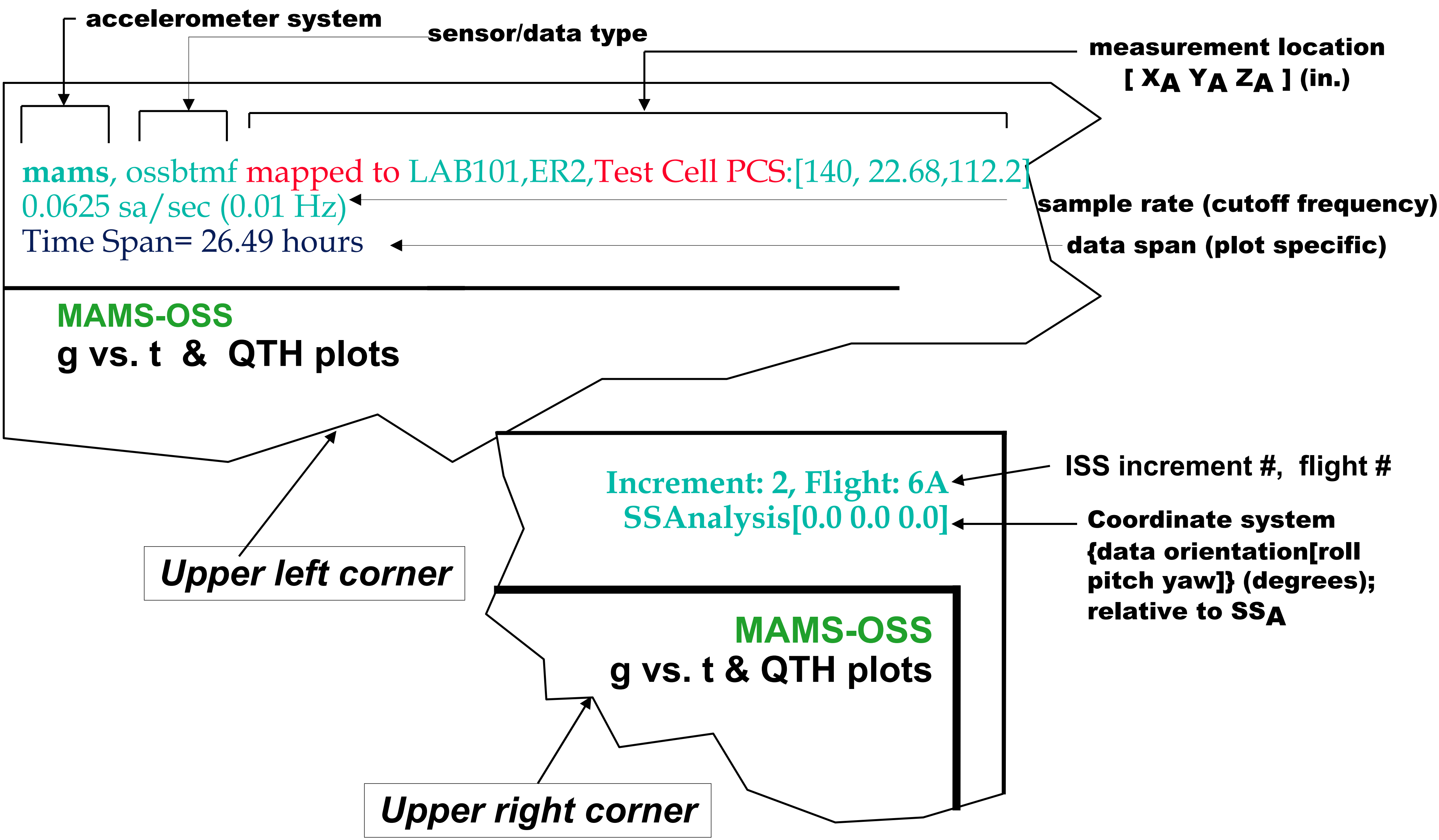
Rotation 1: 90° yaw about Z_1

Rotation 2: 90° roll about X_1



NO! Euler sequences are not additive and the order of the rotations is important! Roll then Yaw does not equal Yaw then Roll.

ISS QUASI-STEADY SAMPLE PLOTS INFORMATION



ISS VIBRATORY SAMPLE PLOTS INFORMATION

accelerometer system, sensor

measurement location
[X_A Y_A Z_A] (in.)

sams2, 121f06 at LAB101,ER2,Lower Z Panel:[191,-40.54,135.2]
500.0 sa/sec (200.00 Hz)
$\triangle$f = 0.122 Hz, Nfft = 4096
Temp. Res. = 8.192 sec, No=0

sample rate (cutoff frequency)

frequency resolution, # of points per PSD (plot specific)

temporal resolution, # of overlap points (plot specific)

SAMS
PSD & spectrogram plots

Upper left corner

Increment: 3, Flight: 7A.1
SSAnalysis[0.0 0.0 0.0]
Hanning, k=3450
Span = 8.00 hours

ISS Increment #, flight #

Coordinate system

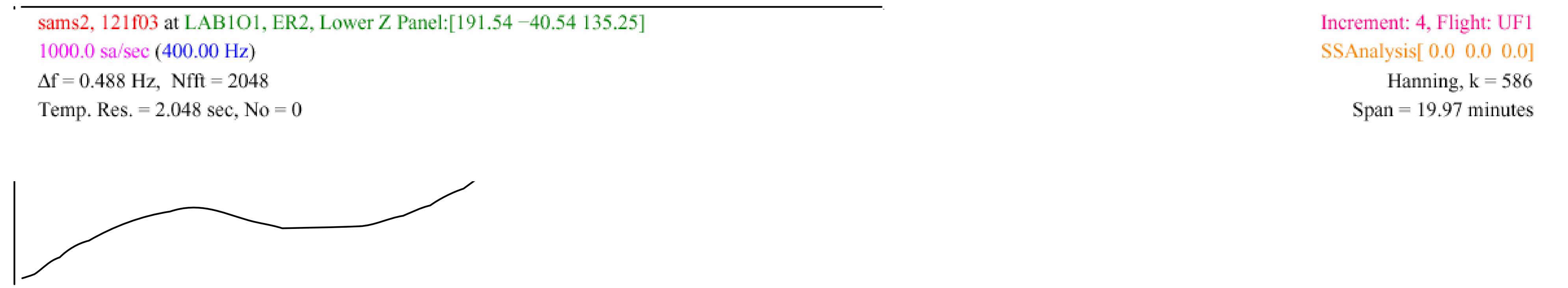
Window type, number of spectral averages

data span

SAMS
PSD & spectrogram plots

Upper right corner

SAMPLE PLOTS INFORMATION SUMMARY



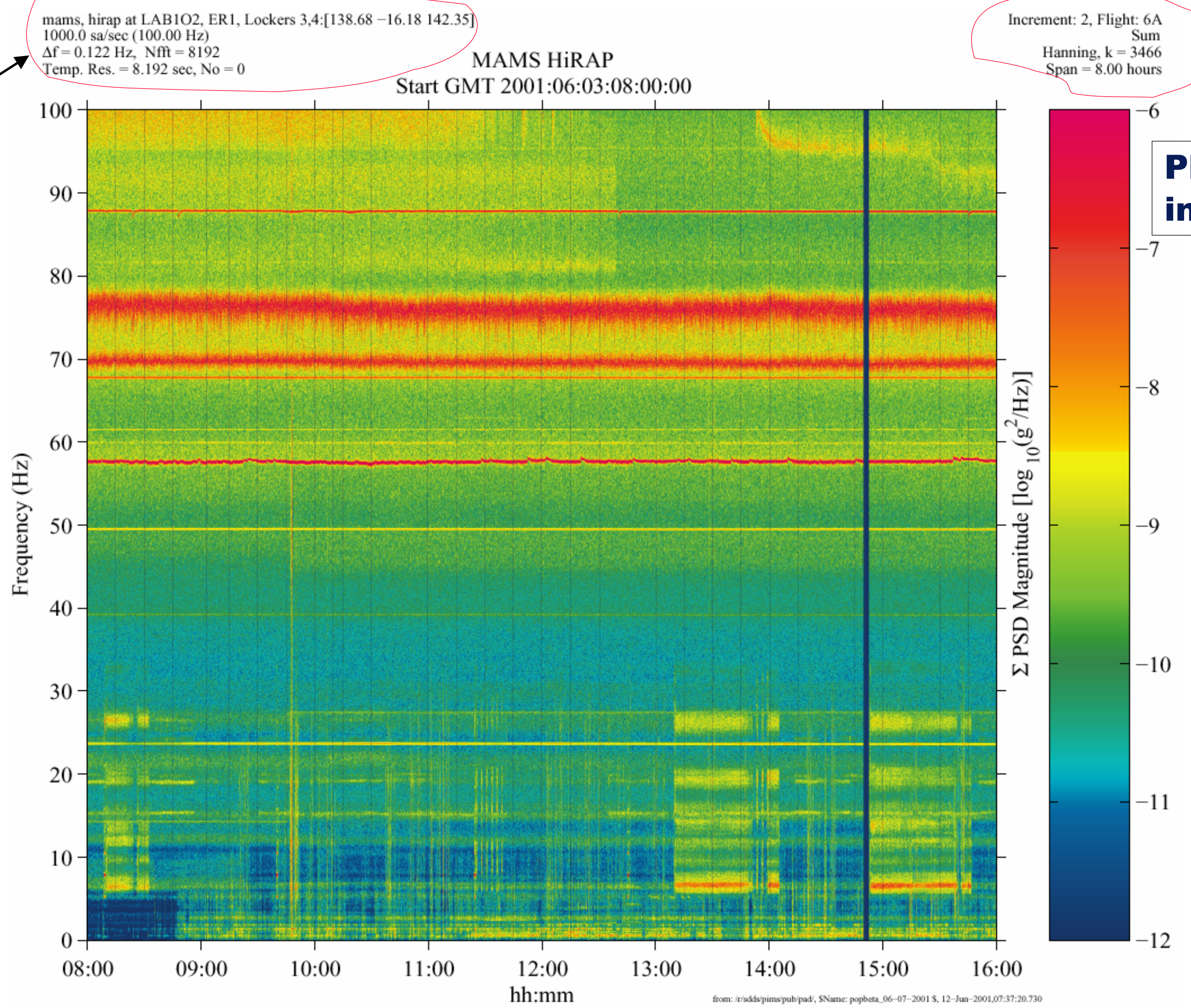
<u>Upper Left Corner:</u>

- Line 1
  - accelerometer system, sensor
  - measurement location [x_A y_A z_A] (in.)
- Line 2
  - sample rate (samples per second)
  - cutoff frequency (Hz)
- Lines ≥ 3 are plot specific
  - frequency resolution
  - temporal resolution

<u>Upper Right Corner:</u>

- Line 1
  - ISS Increment & Flight
- Line 2
  - data orientation [roll pitch yaw] (degrees); relative to SSA
- Lines ≥ 3 are plot specific
  - window type
  - number of spectral averages
  - data span

PLOTS HEADER SAMPLE

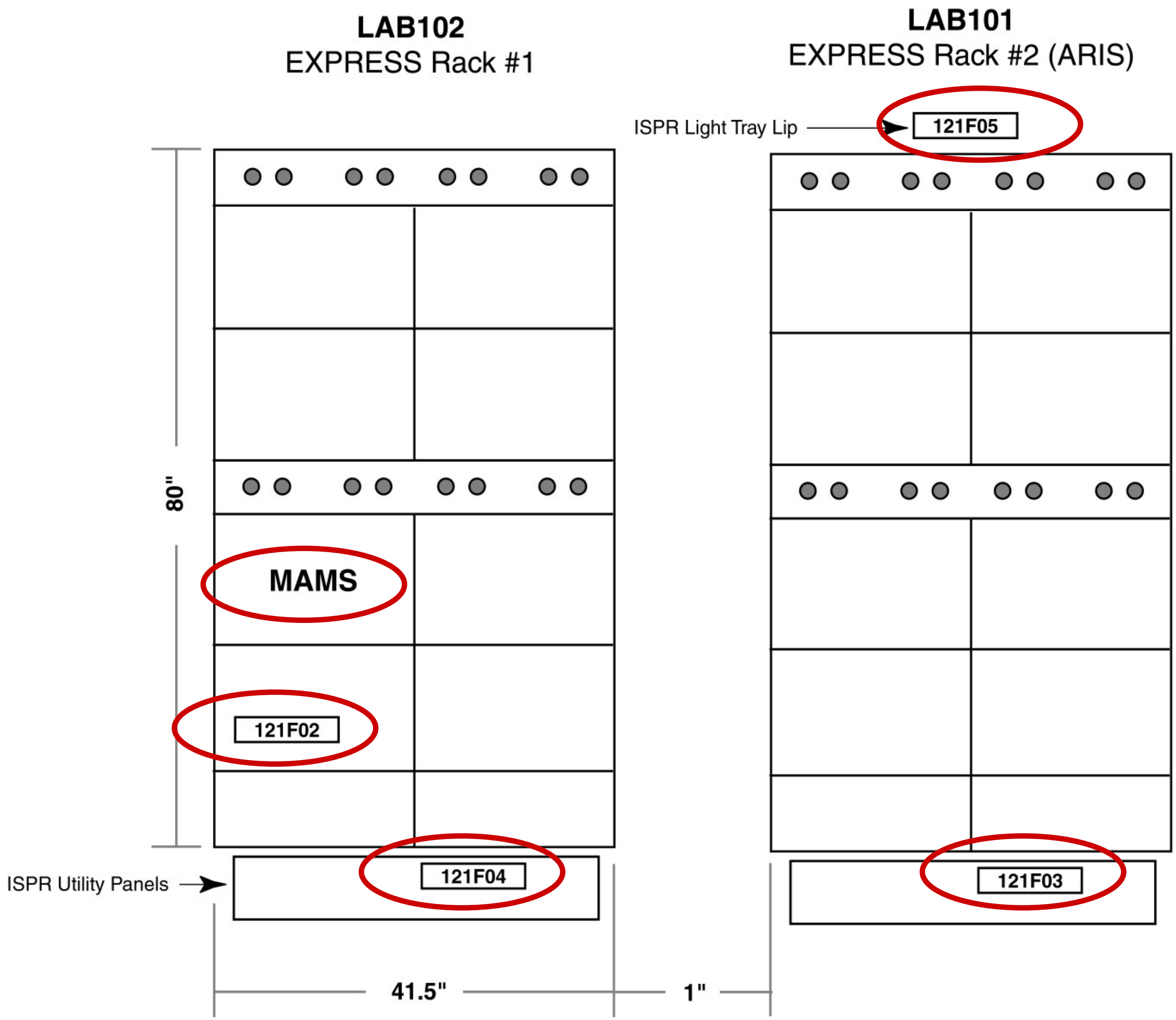


Plot header information

Plot header information

ACCELEROMETERS CURRENT LOCATIONS ON ISS

MAMS and SAMS Locations on ER 1 & 2



Available Reduced Gravity Carriers / Facilities

- STS Orbiters
- International Space Station (ISS)
- Sounding Rockets (Various Countries)
- Parabolic Flight Aircraft (KC-135)
- Free-Flyers (ESA-Russia)
- Drop Towers (USA, Europe and Asia)
- 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:

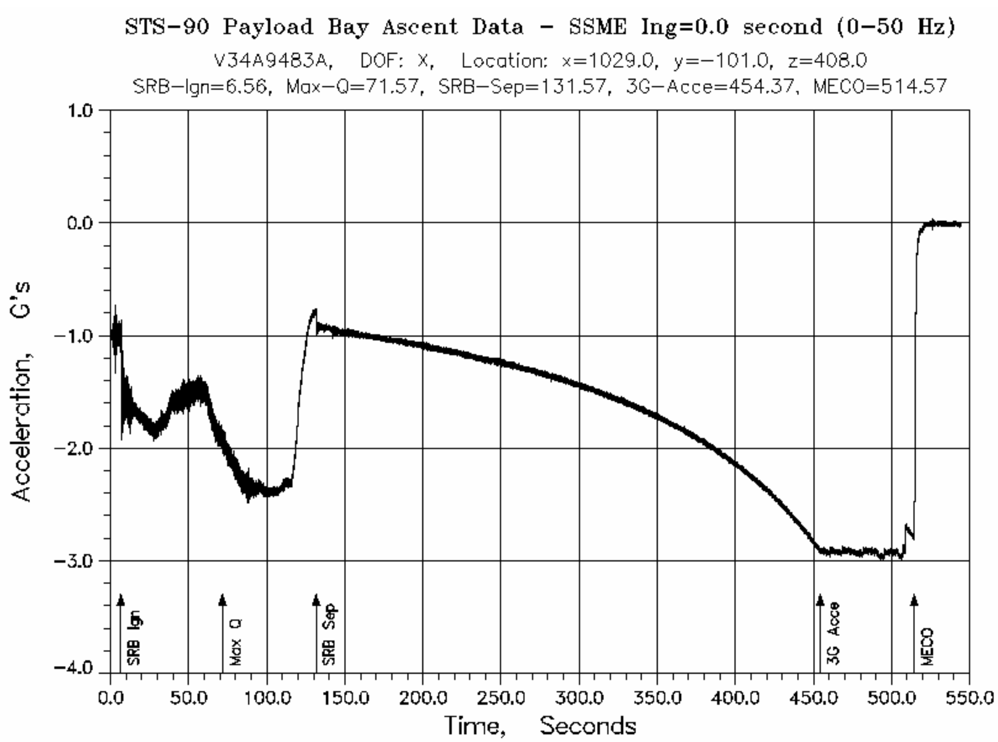
- Experiment sensitivity to acceleration sources
  - quasi-steady, vibratory and transient
  - frequency dependency and time duration
- Crew exercise
- Crew motion
- Thruster activity
- Other experiment operations
- Vehicle maneuvers
- Venting/Water dump/Waste dump
- Crew life support systems

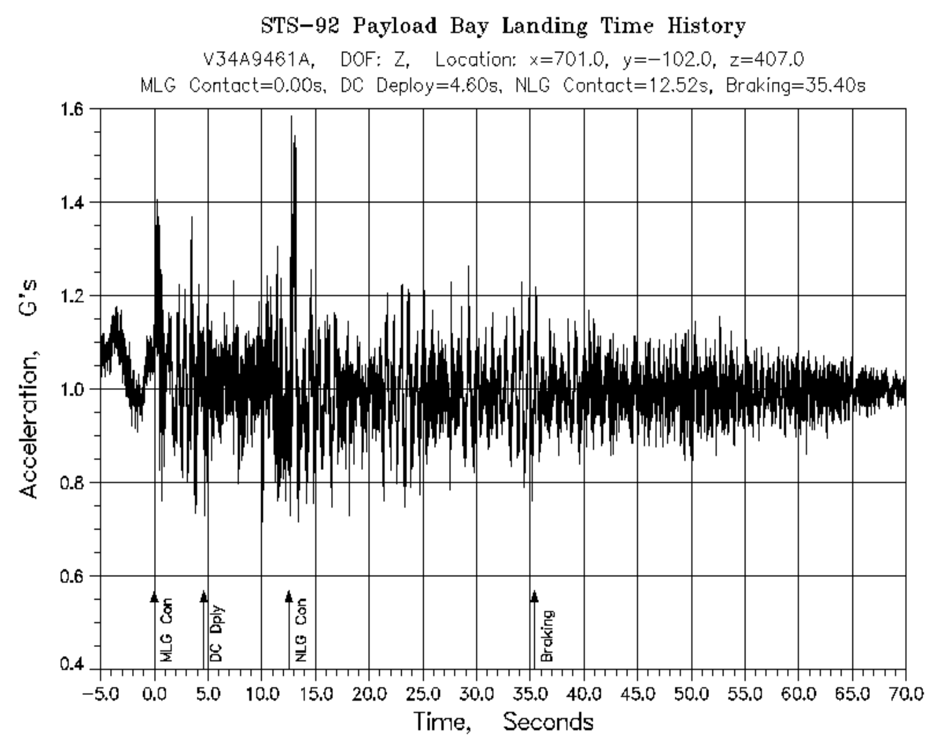
EXPERIMENT PLANNING AND EXECUTION

Keep the following points in mind during your experiment planning and execution:

- Minimize up-mass and strive to eliminate, if impossible, minimize down-mass (make use of downlink video images and science data for your experiment analysis)
- Minimize crew interaction with your science (remotely control/command) or automated system
- Number and volume of samples
- Energy available (power)
- Timeline
- Late / early access vs. preservation / viability of your samples
- Do your homework (assess acceleration impact on your samples during lift off, landing and during your science operations)

STS ASCENT & LANDING PROFILES





Shuttle ascent profile:

- effect seen primarily in x-direction
- 3g acceleration for about 1 minute
- over 2g for about 200 seconds
- about 525 secs from ground to orbit

Shuttle landing profile:

- effect seen primarily in z-direction
- 1.4g, main landing gears touch ground
- 1.6-g, noise landing gear touches ground

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)
- You 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, but do your very best to minimize crew time.

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")**

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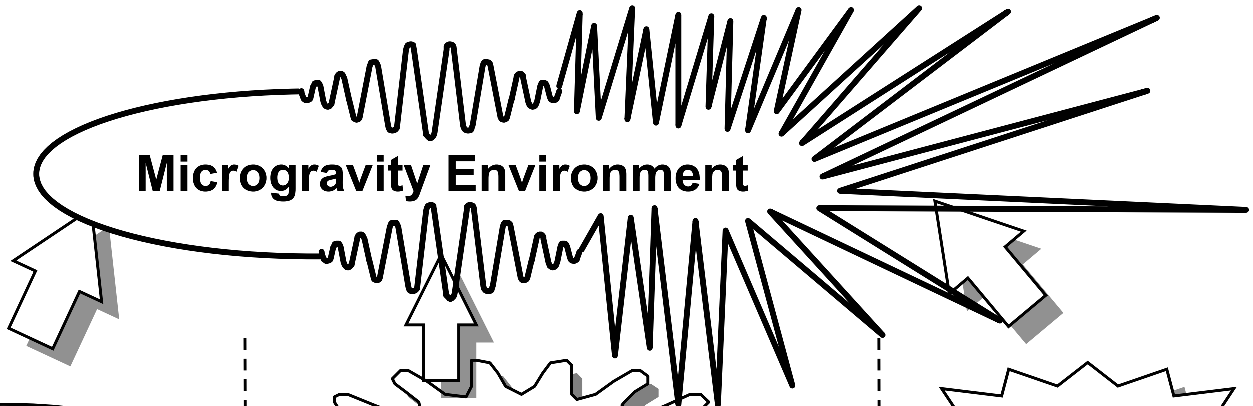
ADDITIONAL MATERIAL

Working in a Reduced Gravity Environment: A Primer

Microgravity - generic term applied to scientific investigations that exploit or explore near weightlessness; not a reference to a specific acceleration level



Component	**Quasi-Steady**	**Vibratory**	**Transient**
Instrument	***MAMS***	***SAMS & MAMS***	***SAMS & MAMS***
Frequency	$0 \leq f < 0.01$ Hz	$0.01 \leq f \leq 300$ Hz	**broadband**
Magnitude	**μg's (or less) peak**	**tens to thousands of 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
Microgravity Requirement •Periods: >/= 30 days •Yearly Total: >/= 180 days / year	**Magnitude - 1.0 μg** **(0 </= f </= 0.01 Hz.)** **Stability - 0.2 μg** perpendicular component to orbital average QS acceleration vector	**Combined Vibratory - per figure** **(0.01 </= f </=300.0 Hz.)** •100 second root mean square average •Per one-third octave band	**Individual Transient** **•1000 μg peak per axis** **•10 μg*s integrated over any 10 s interval per axis**

EXPERIMENT SENSITIVITY ASSESSMENT

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

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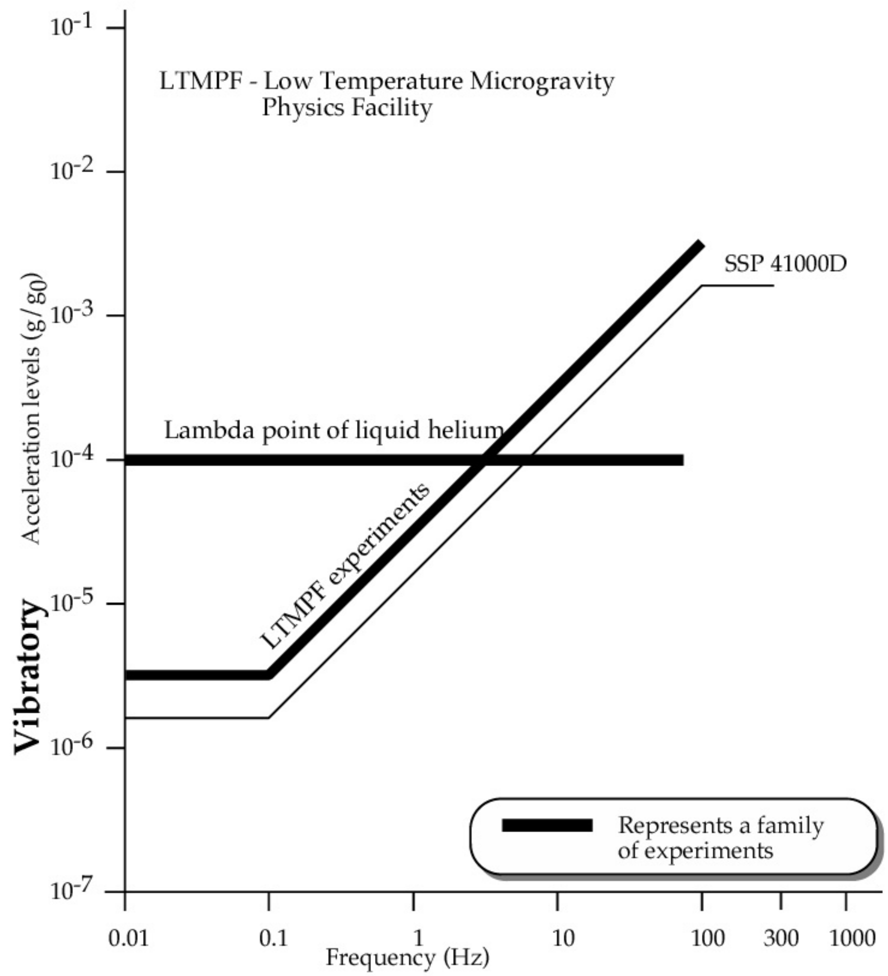
- NOTE: Many of these experiments are expected to be operated on the JEM-EF



EXPERIMENT SENSITIVITY ASSESSMENT

Biotechnology

Quasi-steady

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

Vibratory

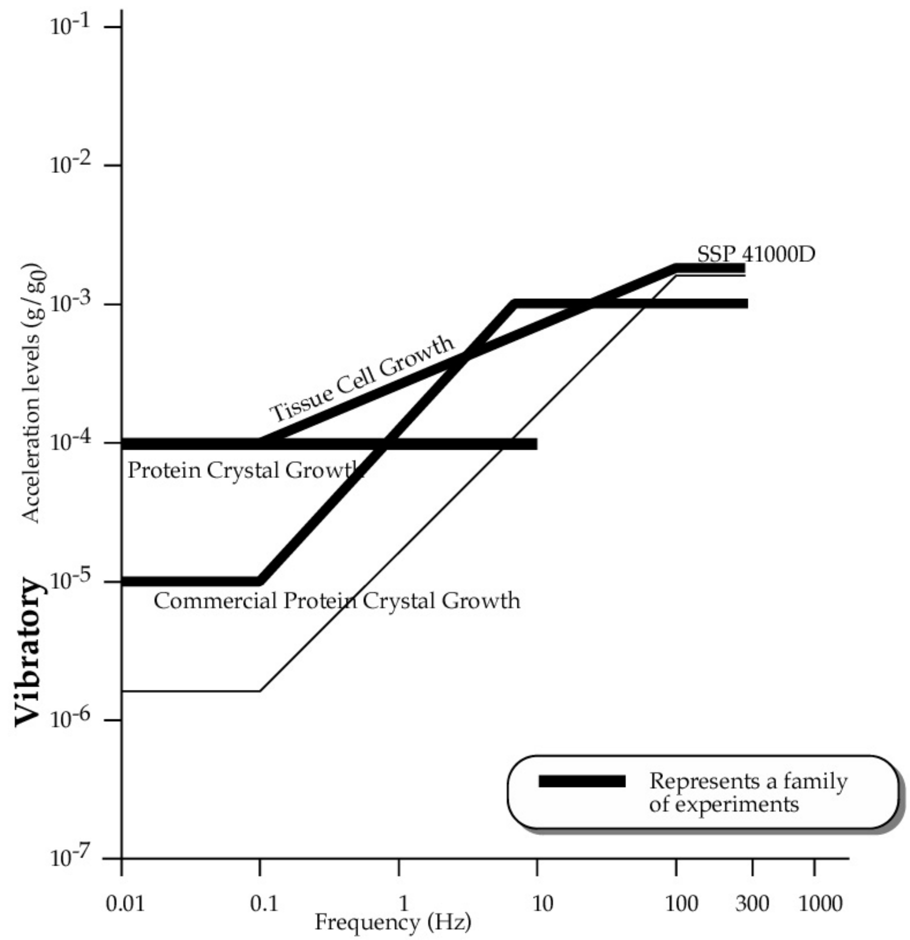
- Impact at higher frequencies of the desired operating level

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



EXPERIMENT SENSITIVITY ASSESSMENT

Fluid Physics

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

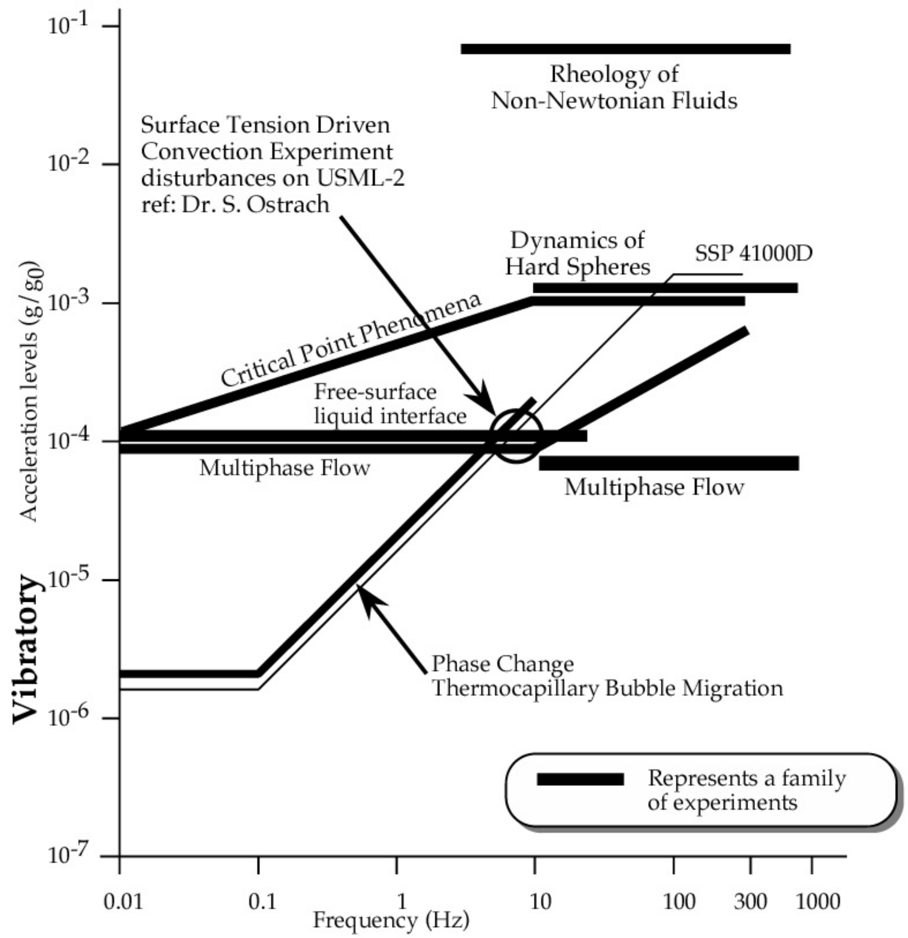
Vibratory
- Mid-range frequencies of expected environment will disturb fluid free surface experiments
- Some experiments require environment at lower levels than the ISS requirements curve

  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



EXPERIMENT SENSITIVITY ASSESSMENT

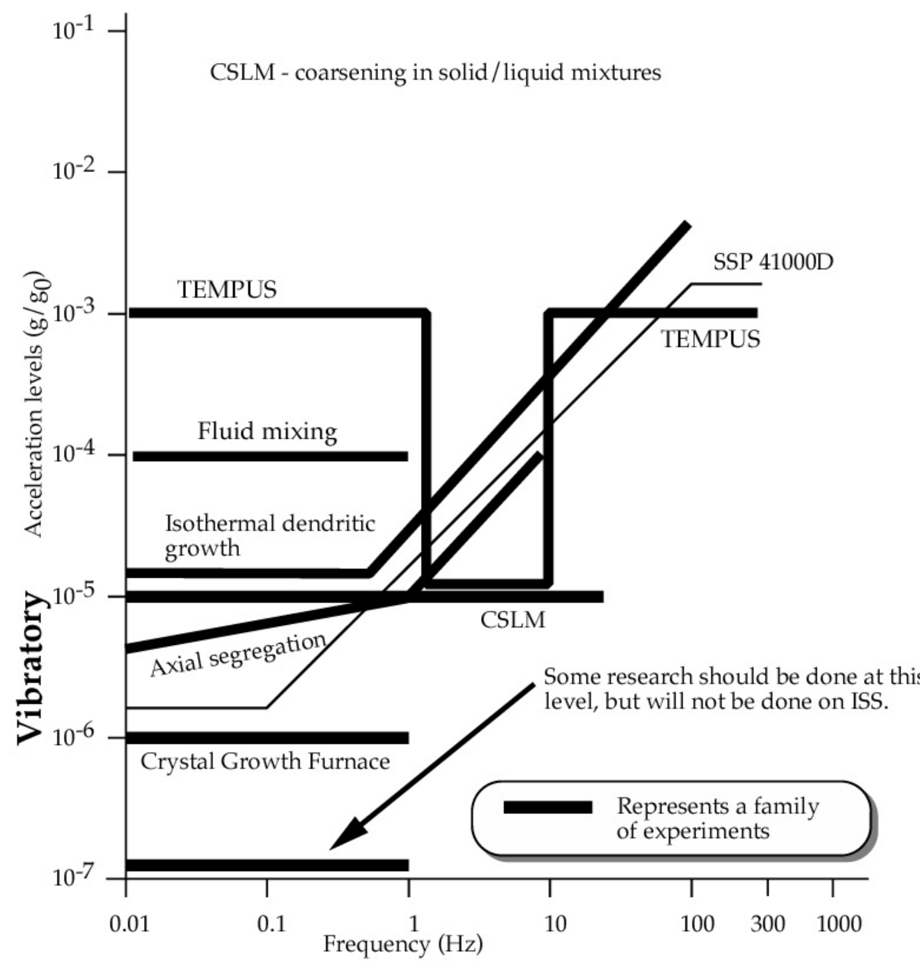
Materials Science

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

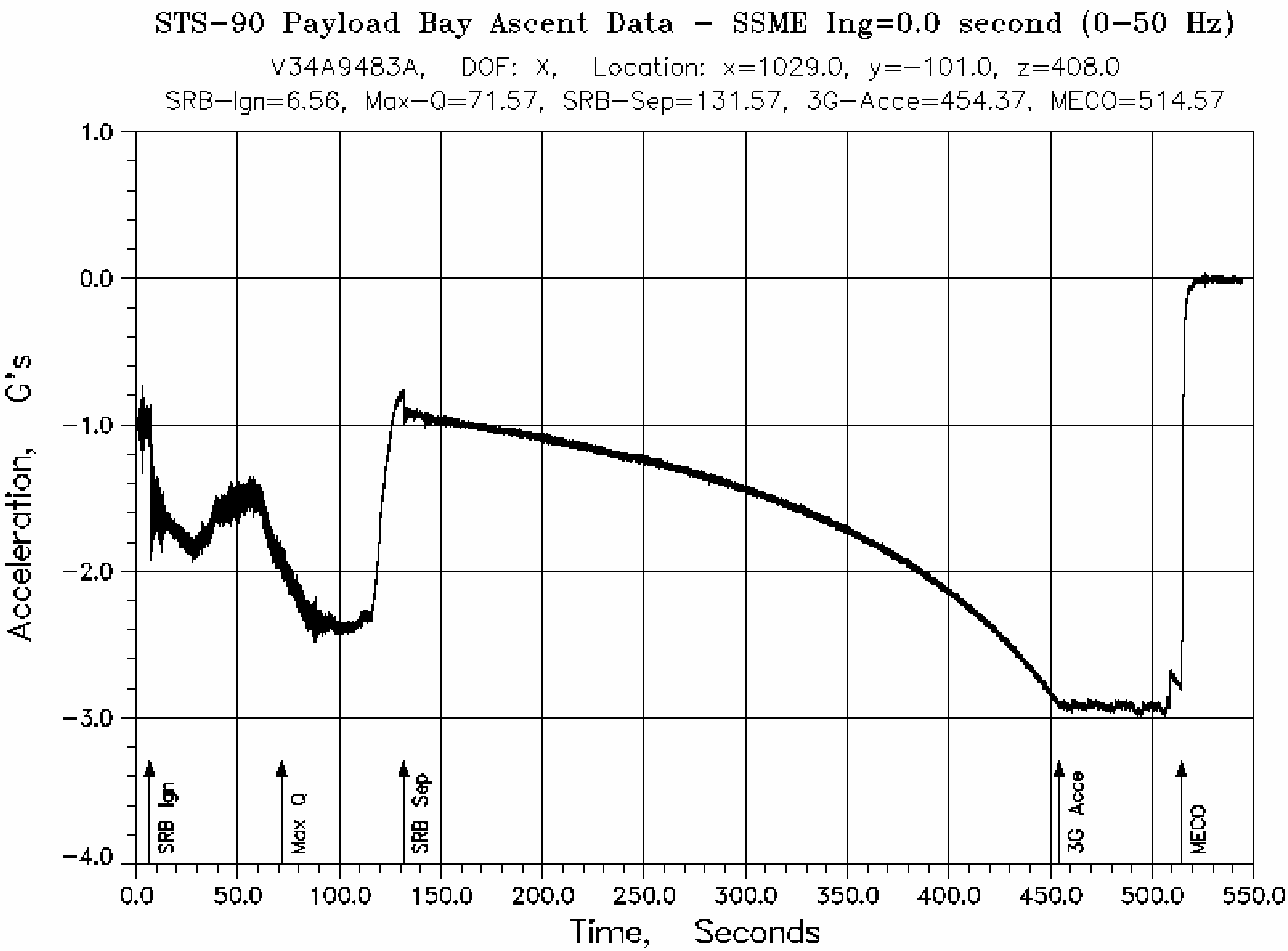
Vibratory
- Disturbances in various frequency ranges disturb experiments involving molten samples, suspended samples, etc.

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



STS ASCENT PROFILE



X-axis

STS = Columbia

SRB

SRB_{Ign}= solid rocket boosters ignition

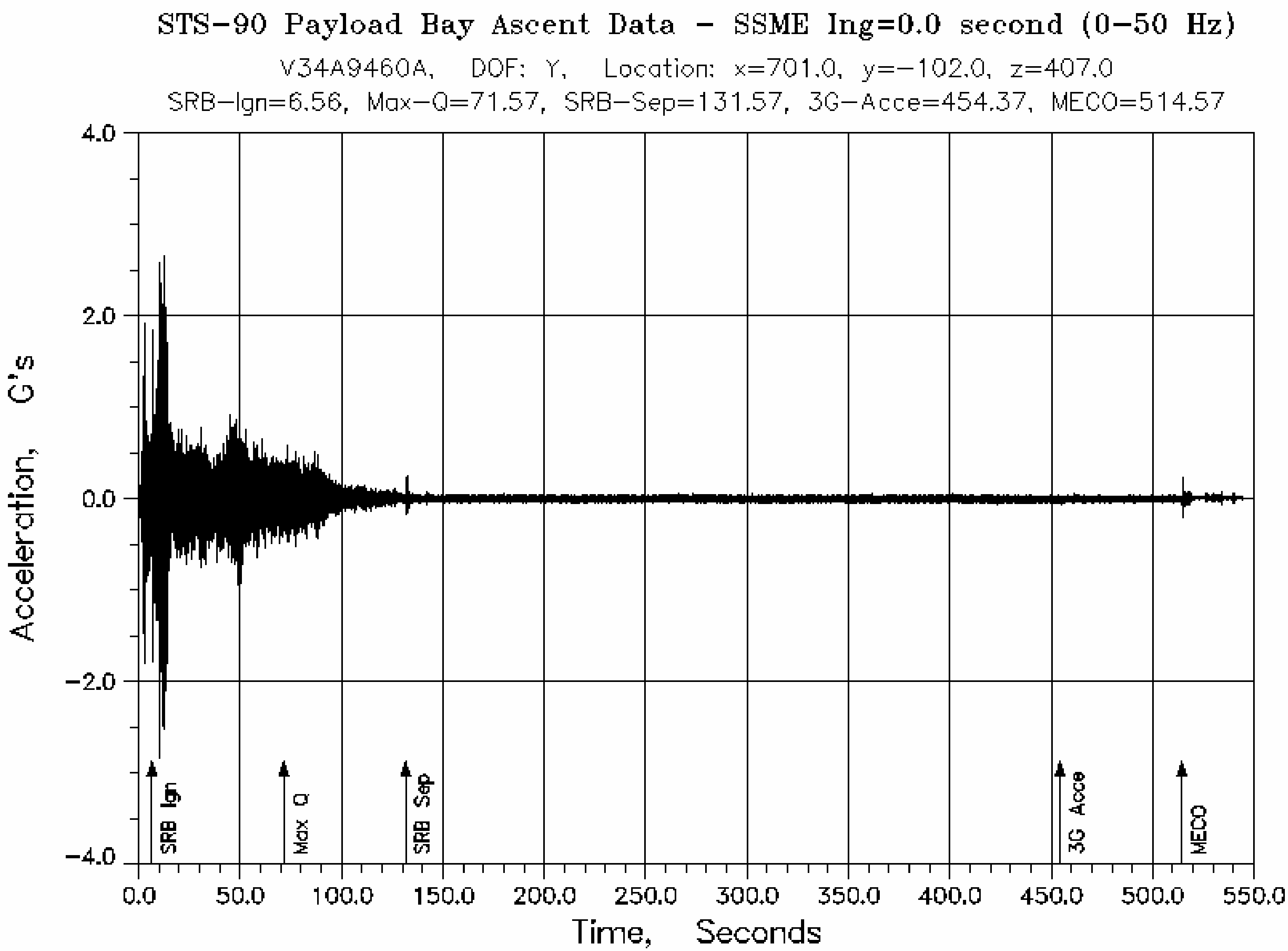
Max Q = time of maximum dynamic pressure

SRB_{Sep} = solid rocket boosters separation

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

MECO = main engine cutoff

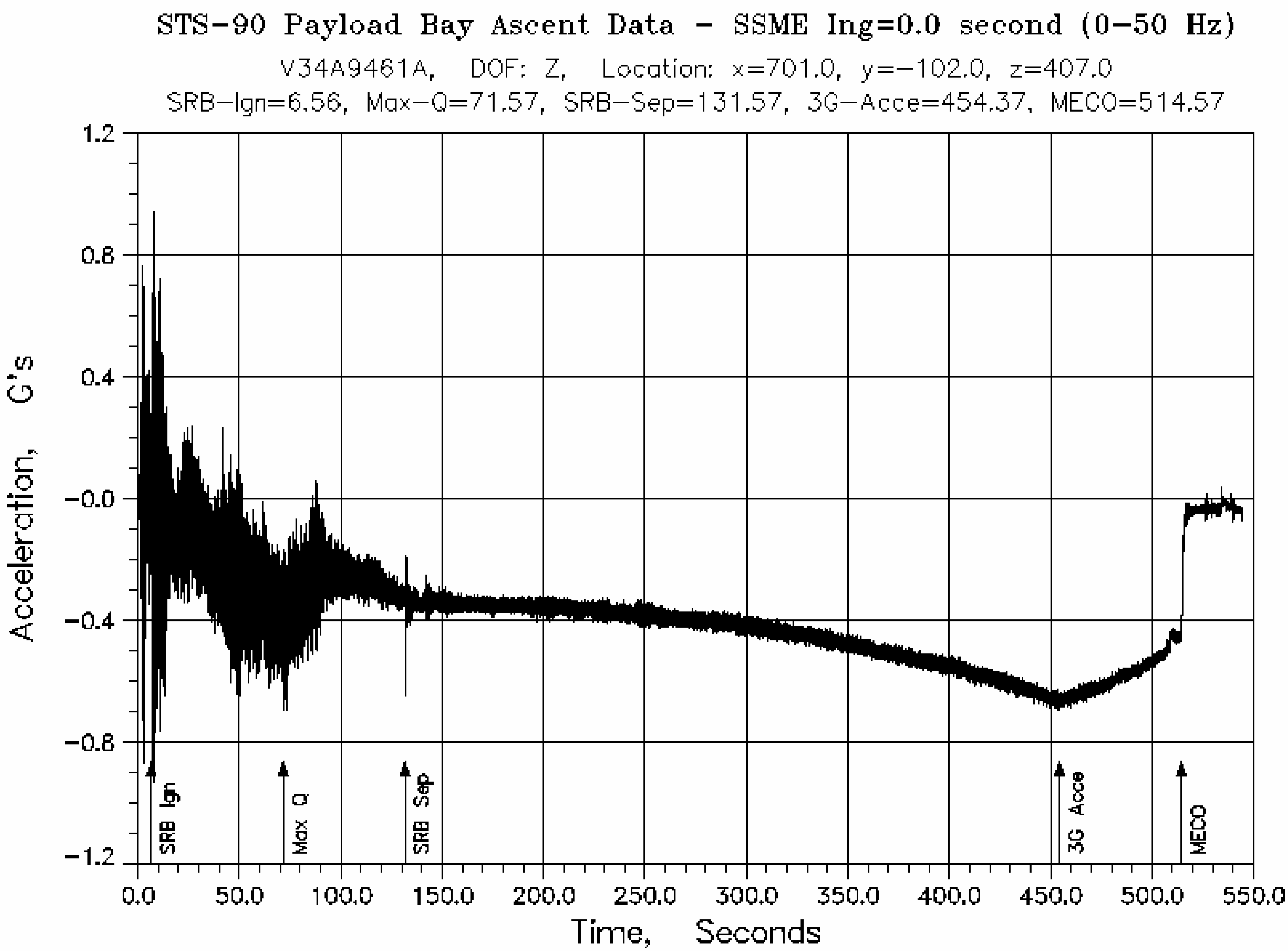
STS ASCENT PROFILE



Y-axis

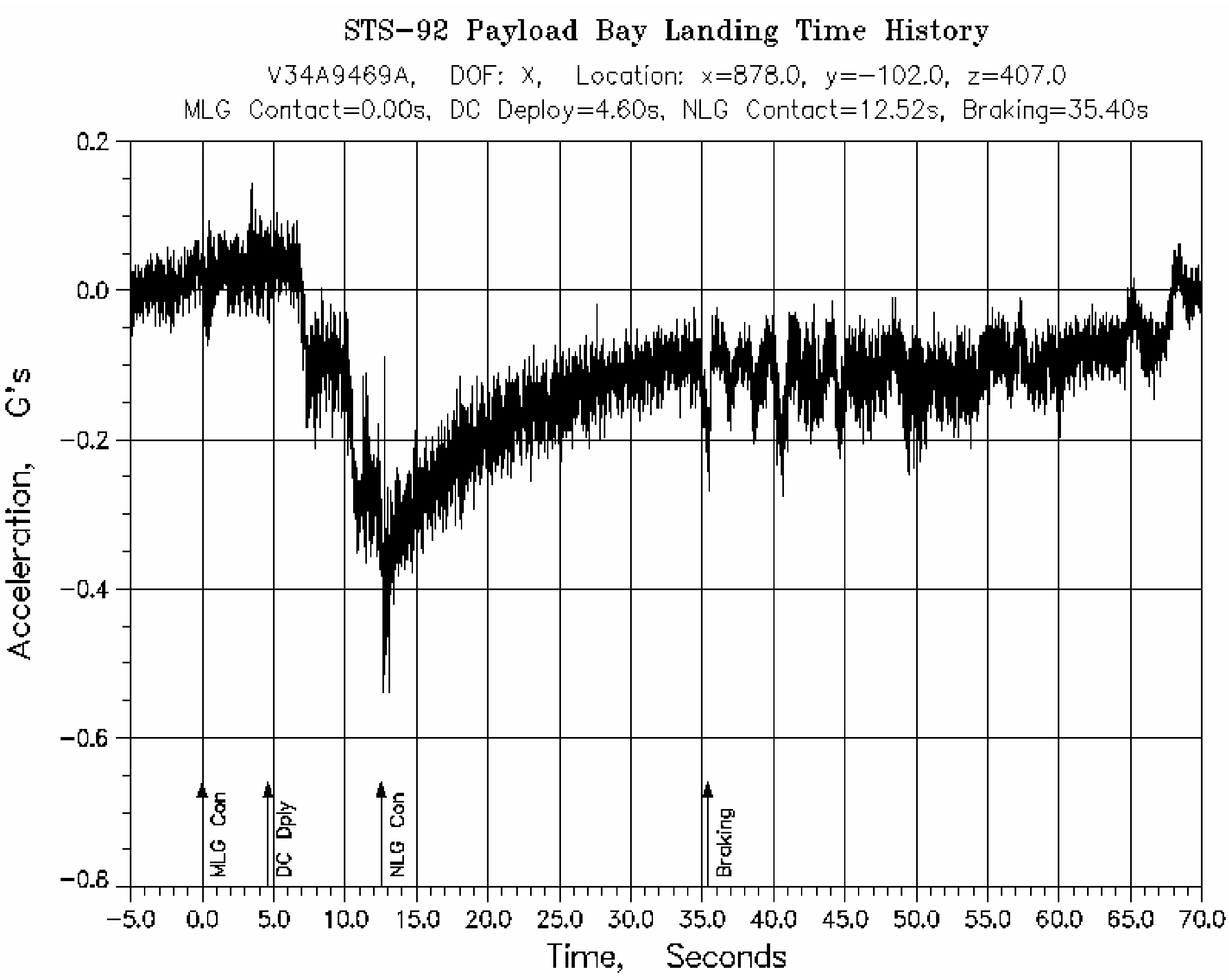
- **Sensor dynamic responses:**
  -10 to + 10 G range
- **Frequency response:**
  0 – 50 Hz
- **Sampling rate:**
  500 samples per sec.
- **Coordinate system:**
  Orbiter structural system

STS ASCENT PROFILE



Z-axis

STS LANDING PROFILE



X-axis

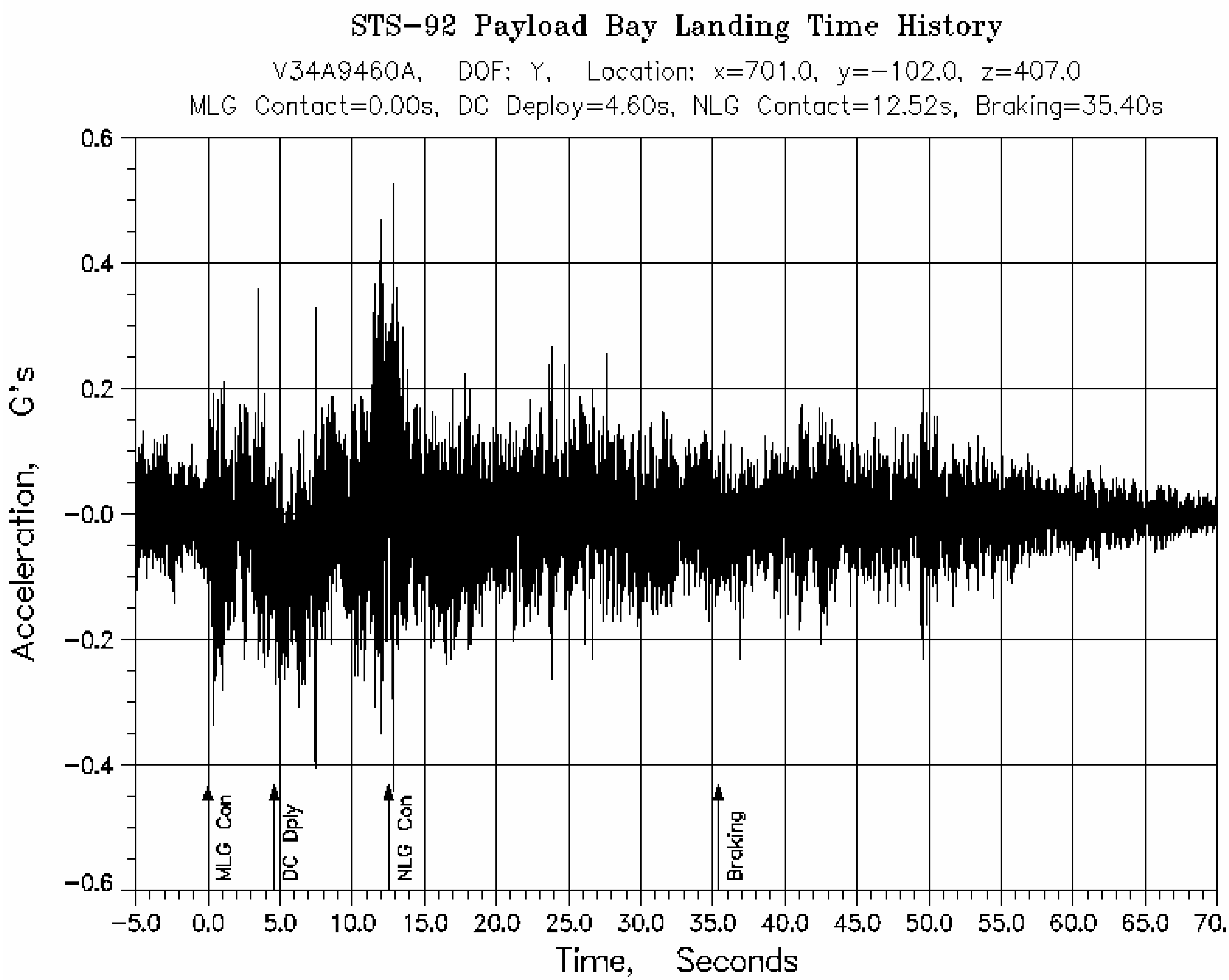
STS = Discovery

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

DC$_{deploy}$ = drag Chute deployment

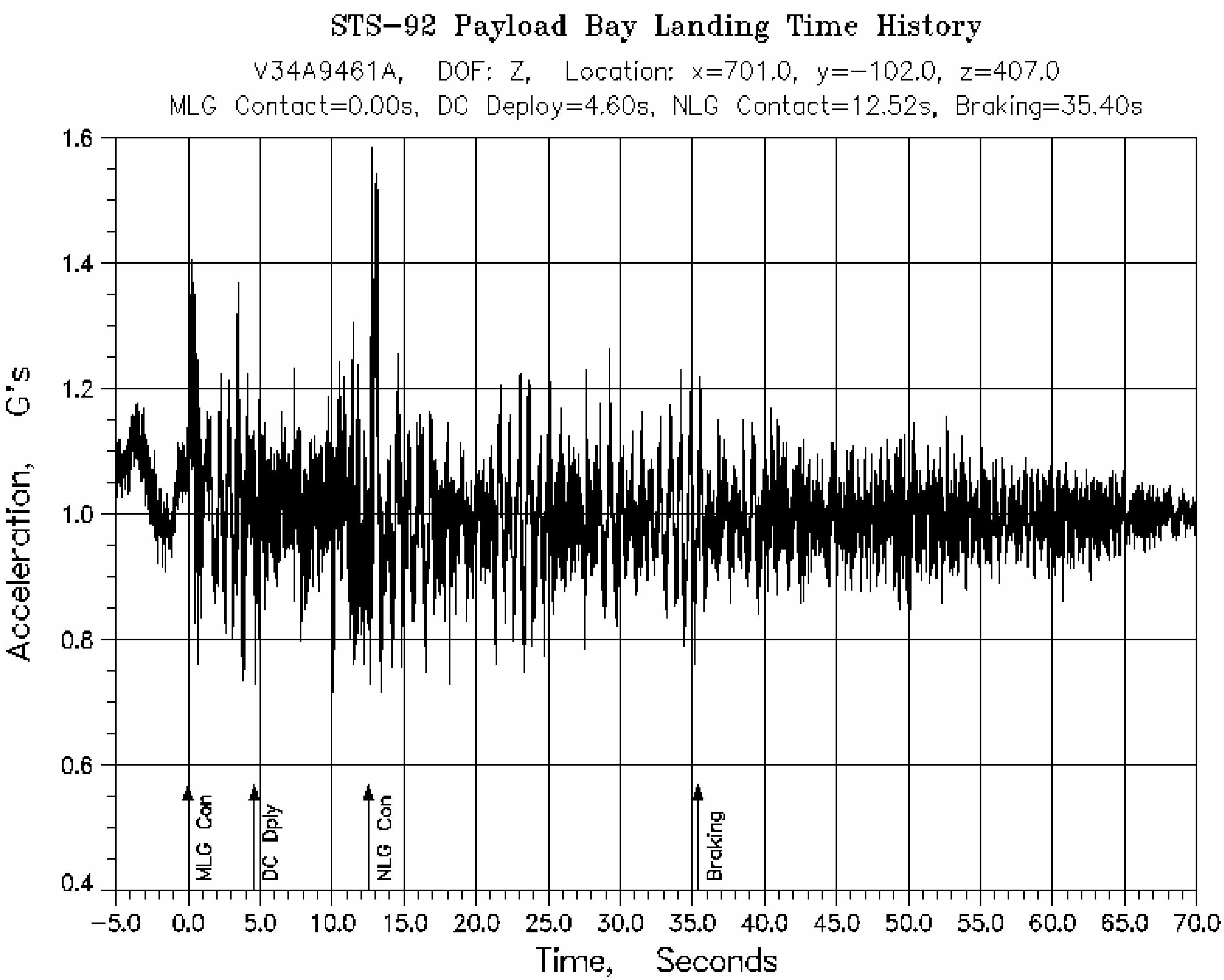
NLG$_{CONT}$ = nose landing gear ground contact

STS LANDING PROFILE



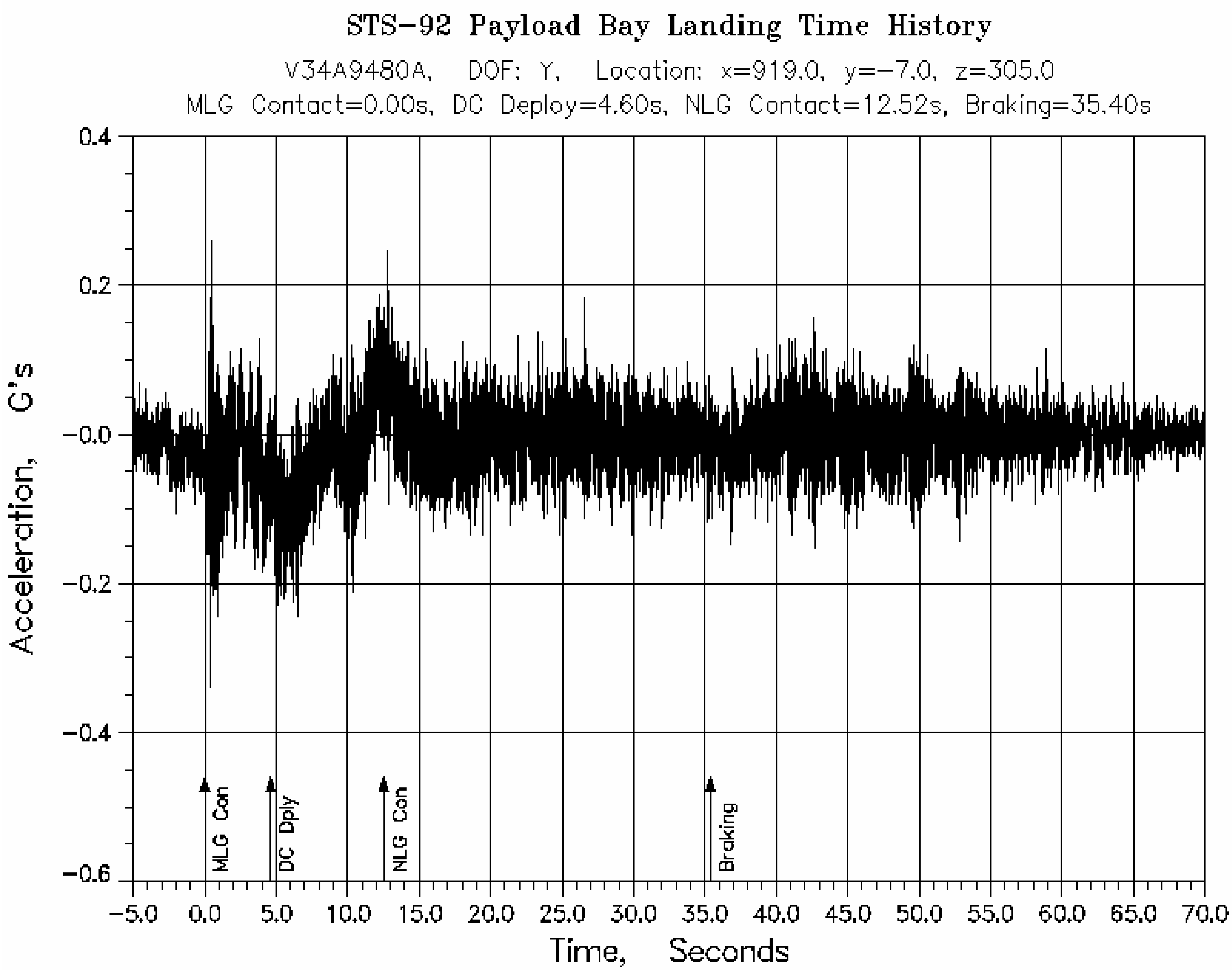
Y-axis

STS LANDING PROFILE



Z-axis

STS LANDING PROFILE



Y-axis