Microgravity Acceleration Environment of the International Space Station

Quasi-steady Regime

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Components of Quasi-steady Environment

- **Frequency content: DC to 0.01 Hz**
- **Magnitude typically 5 μg or less.**
- **Three main components of QS Vector**
  - **Aerodynamic Drag**
    - Attitude
    - Atmospheric density (time and altitude dependent)
    - ISS Configuration
  - **Rotational Effects**
    - Attitude
    - Angular velocity
    - Position relative to ISS Center of Mass
  - **Gravity Gradient**
    - 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**

Space Station Analysis Coordinate System

- **PIMS uses Space Station Analysis Coordinate System (SSA) as a reference to define all its coordinate systems and sensor locations.**
- **Quasi-steady plots for Increment Reports are generally displayed in SSA coordinates.**
- **Definition of the SSA coordinate system found in Figure 1.**
    - **Taken from SSP 30219, Rev F, “Space Station Reference Coordinate Systems”.**

Torque Equilibrium Attitude

- **Torque Equilibrium Attitude (TEA) is an “airplane like” attitude maintained relative to Local Vertical Local Horizontal (LVLH), a rotating coordinate system. (Figure 2)**
- **+XVV +ZLV, Station X-axis towards velocity vector, station Z-axis towards nadir.**
- **Actual orientation is dependent on ISS configuration.**
  - **For Increments 2 and 3 YPR ≈ (350,350,0).**

Plots of Torque Equilibrium Attitude

- **Figure 3 is a time series from a TEA period during crew sleep.**
  - **Quasi-steady acceleration magnitude about 1-2 μg**
  - **Distance from Center of Mass = [49.9 -0.8 2.7] (ft)**
  - **Z axis component primarily due to rotational effects**

- **In Figure 4 the x-axis accelerations for the MAMS location and the ISS CM are nearly identical. This lends support to the theory that in the flight direction of TEA, the gravity gradient component cancels out the rotational component.**

X-axis Perpendicular to Orbital Plane (XPOP)

- **ISS orientation is maintained relative to an inertial frame of reference. X-axis is perpendicular to orbital plane (Figure 5).**

- **Necessary for power generation and Beta Gimbal Assembly life. (BGA rotates the solar arrays)**

- **Rotational components are small compared to gravity gradient and drag.**

Plots from XPOP

- **Figure 6 is a time series during crew sleep when the ISS was in XPOP attitude. Y and Z components show cyclical variation as they are alternately subjected to the drag and gravity gradient vectors.**

- **Comparing the CM location to the MAMS OSS location in Figure 7, it can be seen that the X-direction component is almost completely due to gravity gradient effects.**
  - **X component dominates mean (~2 μg)**
  - **Y and Z vary between ± 1 μg**

Effect of Crew Activity

- **Crew activity masks the quasi-steady vector.**
  - **Crew activity causes increased variation in quasi-steady vector.**

- **Figure 8: QTH Summary Plot of Crew Active Periods for TEA**
- **Figure 9: QTH of a Compilation of Crew Sleep Periods for TEA**
- **Figure 10: QTH Summary Plot of Crew Active Periods for XPOP**
- **Figure 11: QTH of a Compilation of Crew Sleep Periods for XPOP.**
  - **Without crew effects the characteristic "ring" profile is seen in the YZ plane**

Effect of Crew Activity

•Extravehicular Activities (EVA)

- **EVAs seen to date have many disturbances yet to be characterized. These disturbances are can be seen in Figure 12 to be on the order of 10-20 μg in the Y and Z axes.**

- **Dependent on activities performed**
  - Attitude changes
  - Space Station Remote Manipulator System (SSRMBS or Canadarm)
  - Airlock depressurization
  - Crew motion

- **Prior to Russian EVA 2 During Increment 3, an SSRMBS maneuver, seen in X and Z axes of Time Series plot in Figure 13.**

- **DC-1 Airlock depressurization is evident in X axis of Figure 13.**

Venting Operations

- **10.2 Orbiter Cabin Depressurization (Figure 14)**
  - **In preparation for EVA during STS-104 Joint operations**
  - **Cabin pressure dropped from 14.7 psi to 10.2 psi**
  - **Venting in +/- Station X-axis. (Orbiter +/- Z-axis)**
  - **~4μg disturbance in X-axis, vector magnitude unchanged (Figure 15)**

- **Venting Operations sometimes accompanying by attitude maneuvers.**

- **Progress 5P fuel line purge (Figure 16)**
  - **Two stages**
    - fuel purge
    - oxygen purge
  - **Attitude hold**
  - **3-4 μg transient disturbances in Y and Z axes.**

Vehicle Dockings

- **ISS has frequent visitors**
  - **Russian Vehicles (Progress and Soyuz) and STS (Shuttle)**

- **Large disturbances during attitude maneuvers to docking attitude.**
  - **Progress and Soyuz have small Center of Mass change (1-2 ft).**
  - **Shuttle has large CM change.**

- **Grab bag of Vehicle Dockings**
  - **Soyuz TM-31 Undocking (Figure 17)**
    - Attitude change from +XVV/+ZLV to –XVV/+ZLV (180 degree yaw)
  - **Soyuz TM-33 Docking (Figure 18)**
    - Attitude change to an inertial attitude
  - **STS-104 Docking Event (Figure 19)**
    - Largest change in Z-axis, approximately ~3.4μg

Docked Operations

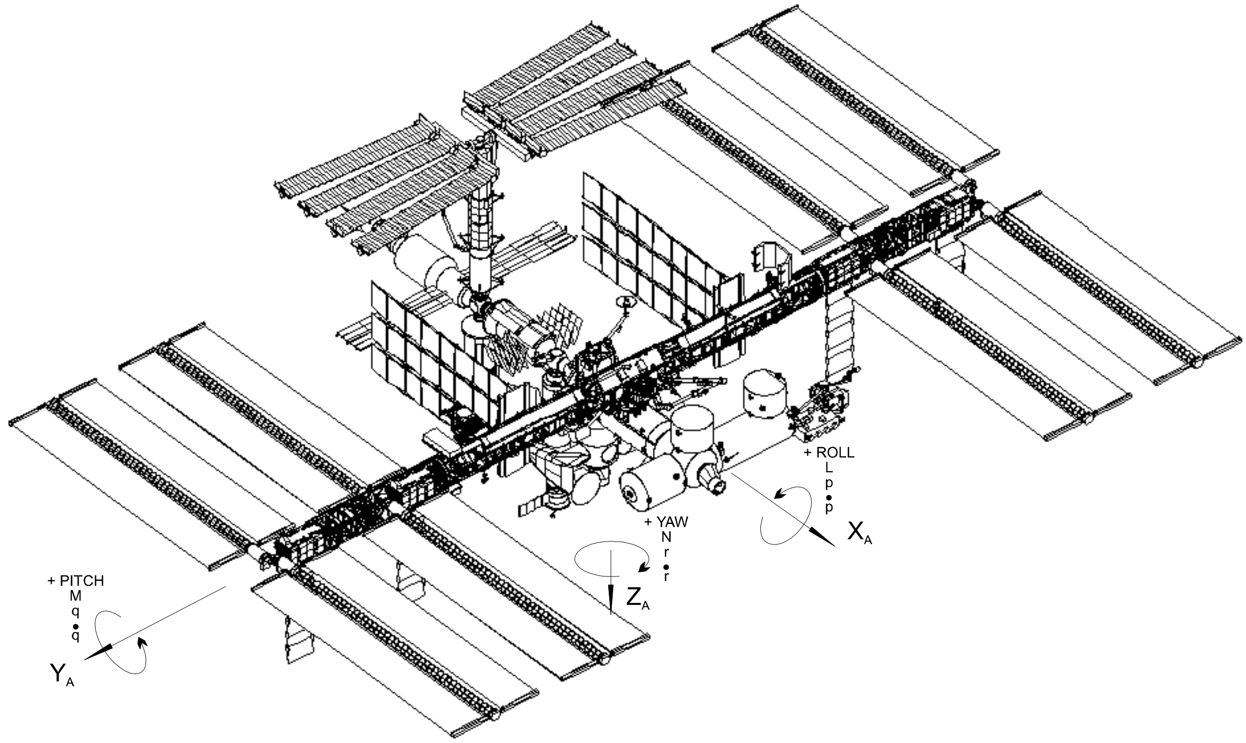
- **STS-105 Docking/Joint Operations (Figure 20)**
- **Differences in Quasi-steady vector due to increased drag, change in center of mass, new attitude.**
  - **Δ g = [-1.08 0.85 2.58] μg**
  - **Δg_{rss} = 2.87 μg.**
- **Nominal Attitude**
  - **Before docking YPR = (350,351,0).**
  - **After docking YPR = (0,23,0).**

Distance to Center of Mass	$X_{A\ (ft)}$	$Y_{A\ (ft)}$	$Z_{A\ (ft)}$
7A Configuration	53.4	-1.7	1.7
STS-105 Joint Ops	17.4	-1.3	-19.6
Net Difference	-36.0	0.4	-21.3

Center of mass information from http://sspweb.jsc.nasa.gov/vcdb. For preliminary assessments only.

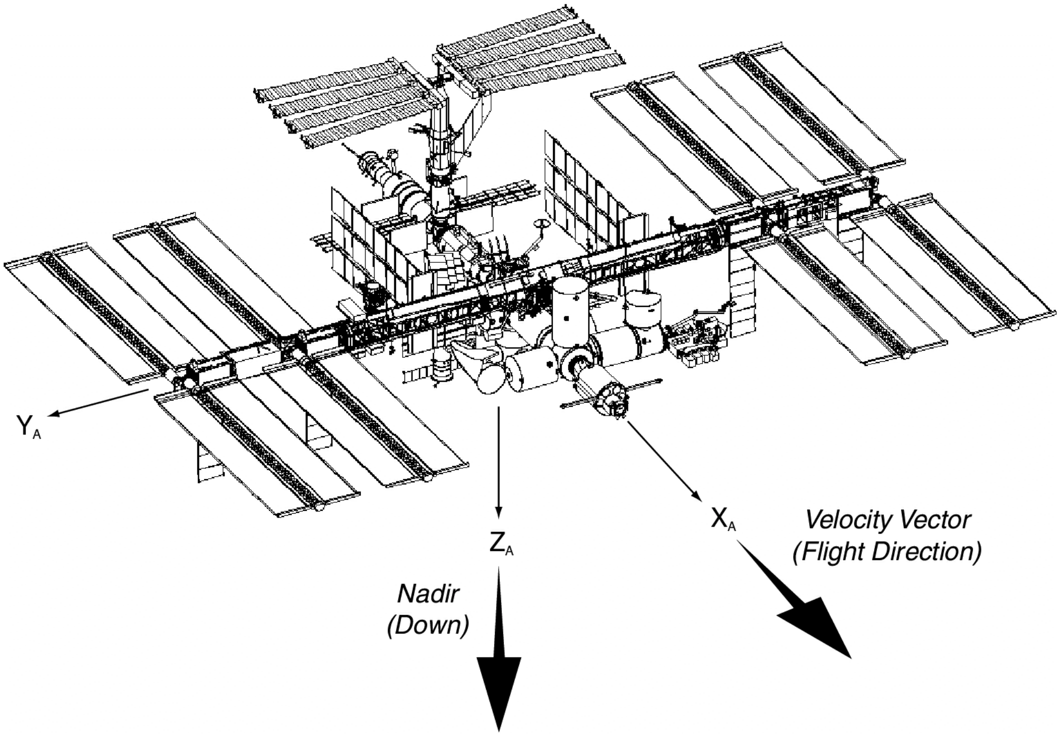
Summary of Quasi-steady Environment Findings for Increments 2 and 3.

Source	Effect	GMT
Soyuz TM-31 Undocking	12 µg peak magnitude in X-axis	06-May-200100:19:58
Progress (4P) Docking	10 µg peak magnitude in X, Y-axes	23-May-200100:24:23
STS-104 (7A)Docking	6 µg peak magnitude	14-Jul-2001, 3:21:04
STS-105 (7A.1)Docking	5 µg peak magnitude	12-Aug-2001, 19:02
STS-105 (7A.1)Undocking	6 µg peak magnitude	20-Aug-2001, 14:52
10.2 Cabin DepressuriZtion	2.5 µg peak in X axis	14-Jul-2001, 10:05:00
STS-105 Joint Ops	2.9 µg mean magnitue	12-Aug-2001, 19:02:00
Progress 4P Undocking	10-20 µg peak in - X direction	22-August-2001, 234/06:07:00
DC1 Docking	10-25 µg in - X direction	17-September-2001, 260/01:05:00
CMG 2 Testing	Increased variation on X, Y, and Z axes.	11-October-2001, 283/04:50:00
Soyuz 2 Relocation	8-10 µg peak in - X direction	19-October-2001, 291/07:58:00
EVA Activities	12-18 µg peak in -Y, and -Z directions.	08-October-2001, 281/14:23 12-November-2001, 316/21:41
SSRMBS Maneuvers	7-13 µg in the -X, and -Z directions.	08-October-2001, 281/14:23
DC1/PkhO DepressuriZtion	4 µg peak in -X direction 1.5 µg peak in -Y direction	08-October-2001, 281/14:23 12-November-2001, 316/02:35
Thrusters Inhibited Recovery	10-20 µg in -X direction for extended period	03-December-2001, 337/13:20
Progress 5P Prop Purge	3.5 -5.7 µg in Y, and -Z directions.	20-November-2001, GMT 234/19:10
TEA Attitude	-0.80 µg mean in Z axis 0.94 µg mean magnitude	Various
XPOP Attitude	1.89 µg mean in X axis 2.05 µg mean magnitude	Various

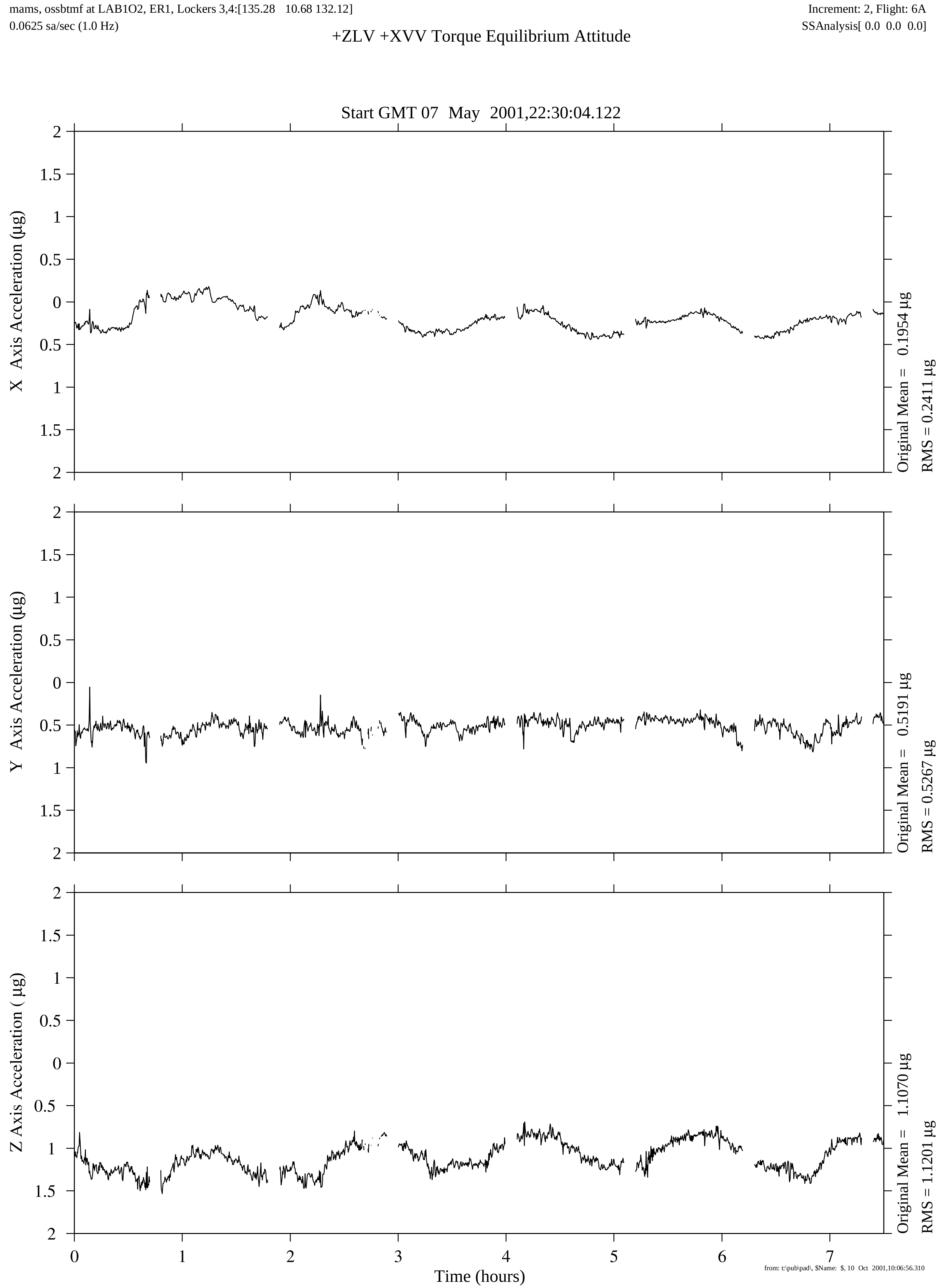


NAME:	Space Station Analysis Coordinate System
TYPE:	Right–Handed Cartesian, Body–Fixed
DESCRIPTION:	This coordinate system is derived using the Local Vertical Local Horizontal (LVLH) flight orientation. When defining the relationship between this coordinate system and another, the Euler angle sequence 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) S0 and is coincident with the S0 Coordinate frame. See figure 5.0–12, S0 coordinate frame for a more detailed description of the S0 geometric center.
ORIENTATION:	X_A The X–axis is parallel to the longitudinal axis of the module cluster. The positive X–axis is in the forward direction. Y_A The Y axis is identical with the S_O axis. The nominal alpha joint rotational axis is parallel with Y_A. 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. L, M, N: Moments about X_A, Y_A, and Z_A axes, respectively. p, q, r: Body rates about X_A, Y_A, and Z_A axes, respectively. $\dot{p}$, $\dot{q}$, $\dot{r}$: Angular body acceleration about X_A, Y_A, and Z_A axes, respectively.
SUBSCRIPT:	A

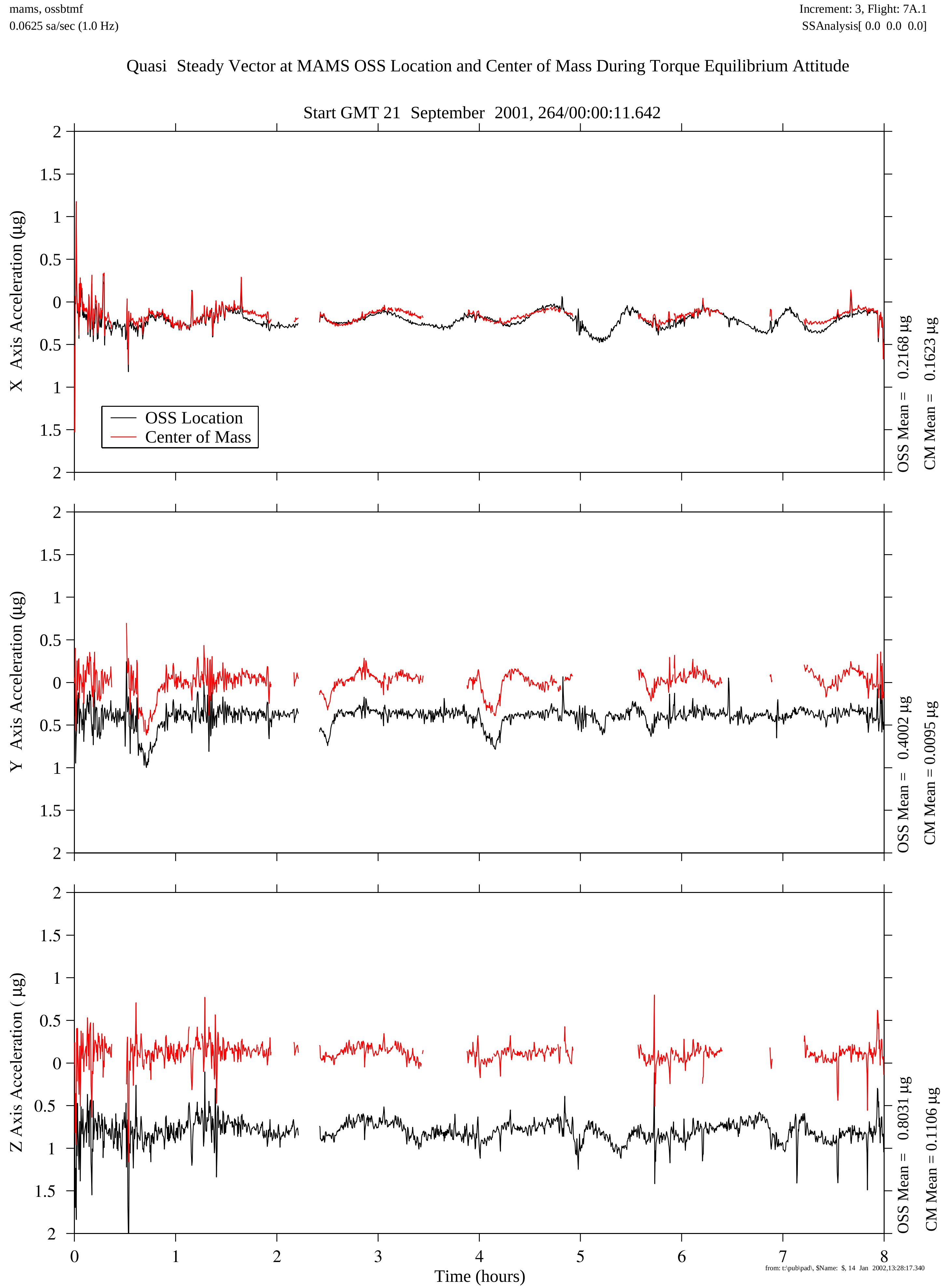
MEIT 2002 Figure19-1: Space Station Analysis Coordinate System



MEIT 2002 Figure 19-2: Local Vertical Local Horizontal (LVLH) Attitude

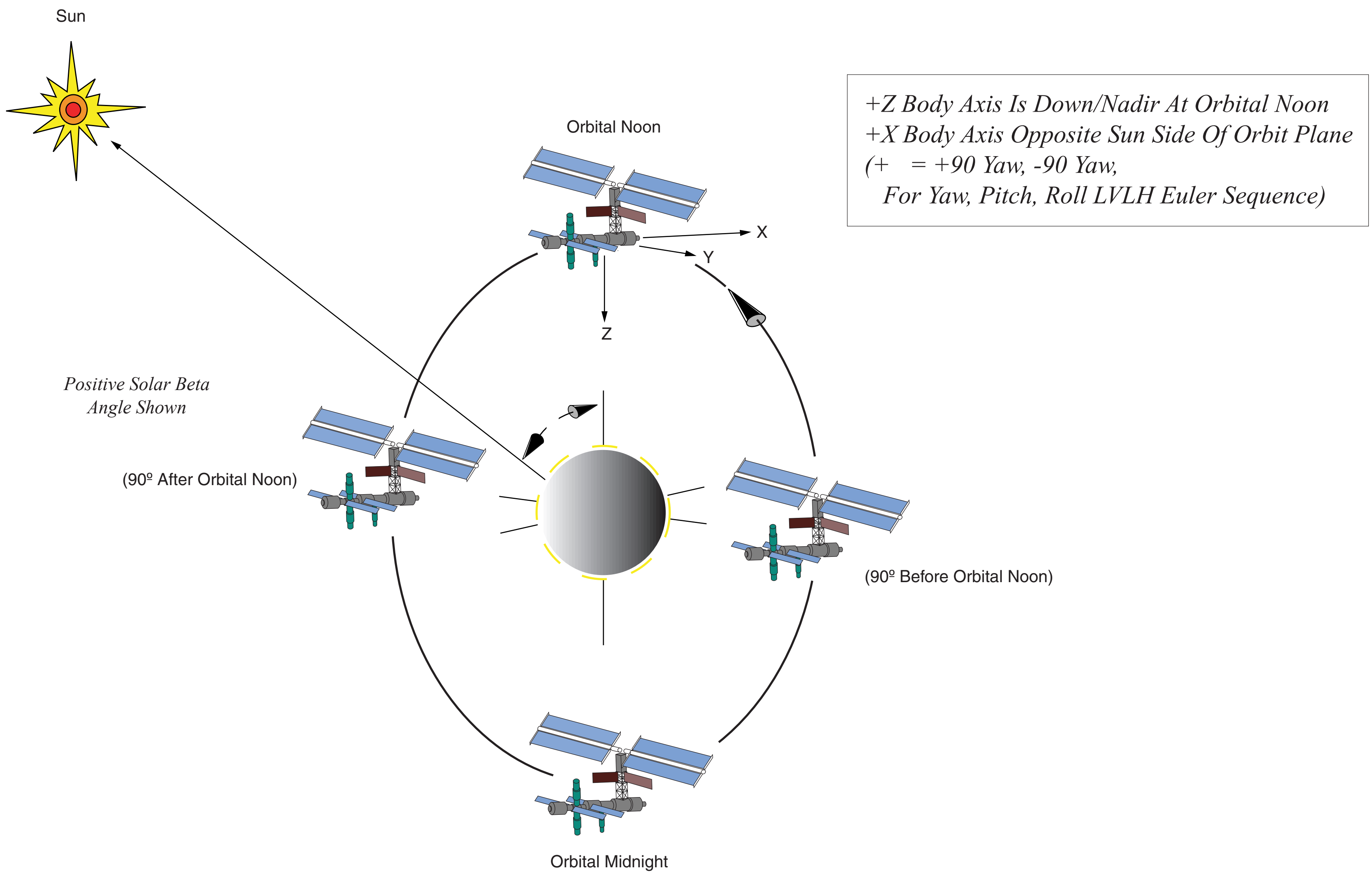


MEIT 2002 Figure 19-3: Quasi-steady Vector During TEA

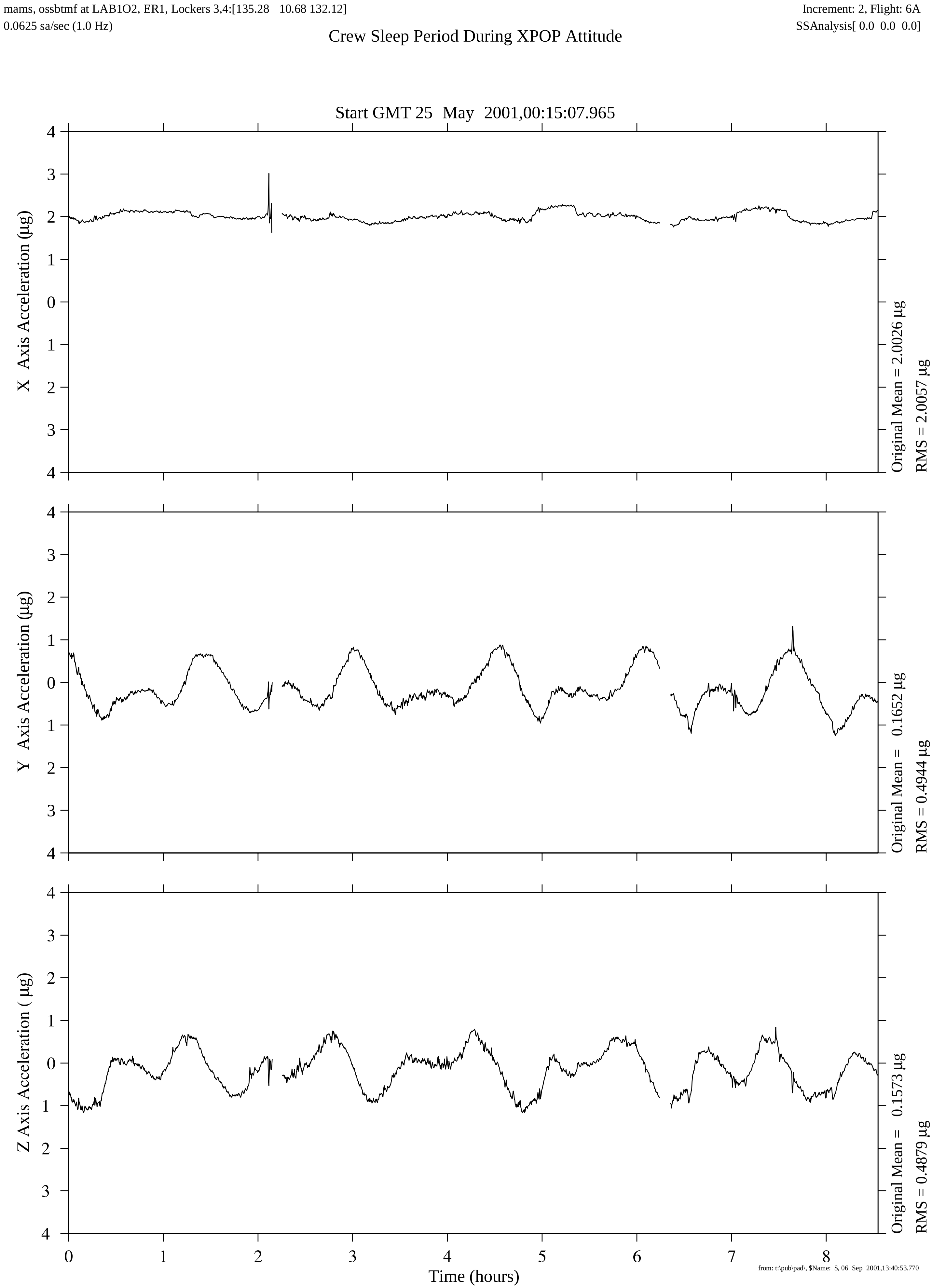


MEIT 2002 Figure 19-4: Quasi-steady Vector at MAMS OSS and Center of Mass During TEA

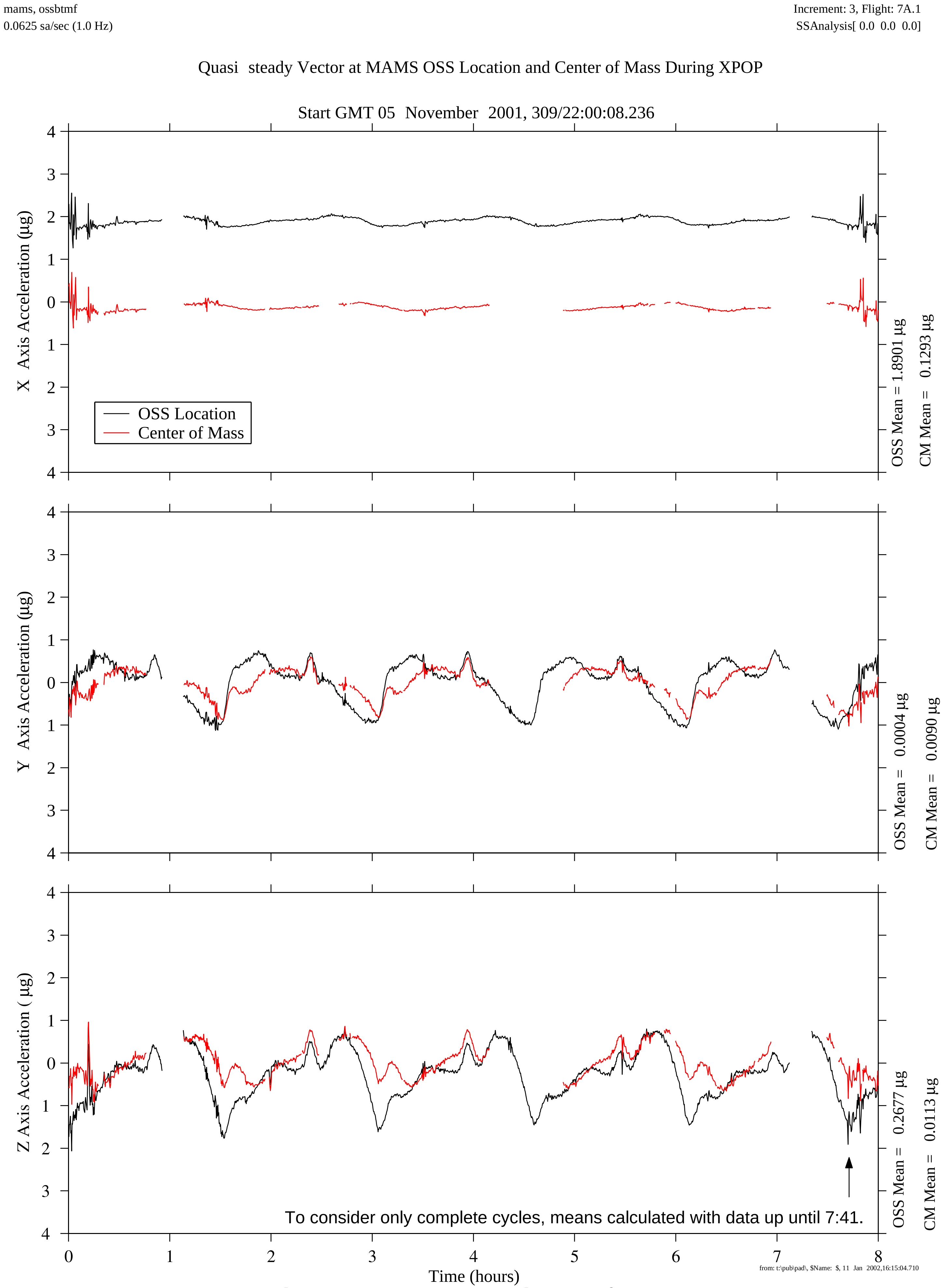
Inertial Attitude With The X Principal Axis Perpendicular to Orbit Plane, Z Nadir At Noon



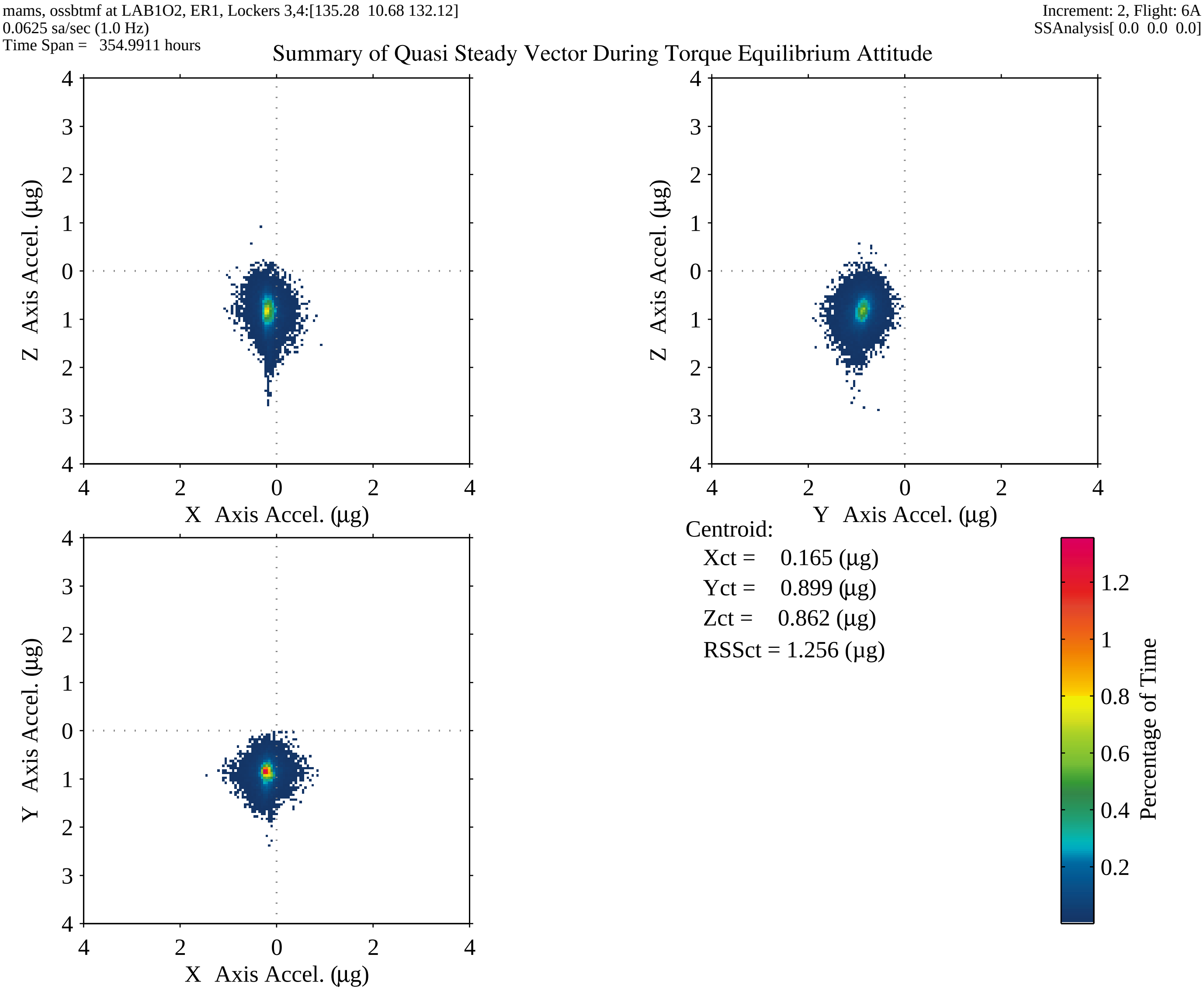
MEIT 2002 Figure 19-5: X-Axis Perpendicular to Orbital Plane (XPOP) Attitude



MEIT 2002 Figure 19-6: Quasi-steady Vector During XPOP



MEIT 2002 Figure 19-7: Quasi-steady Vector at MAMS OSS and Center of Mass During XPOP



MEIT 2002 Figure 19-8: Summary of Quasi-steady Vector During TEA

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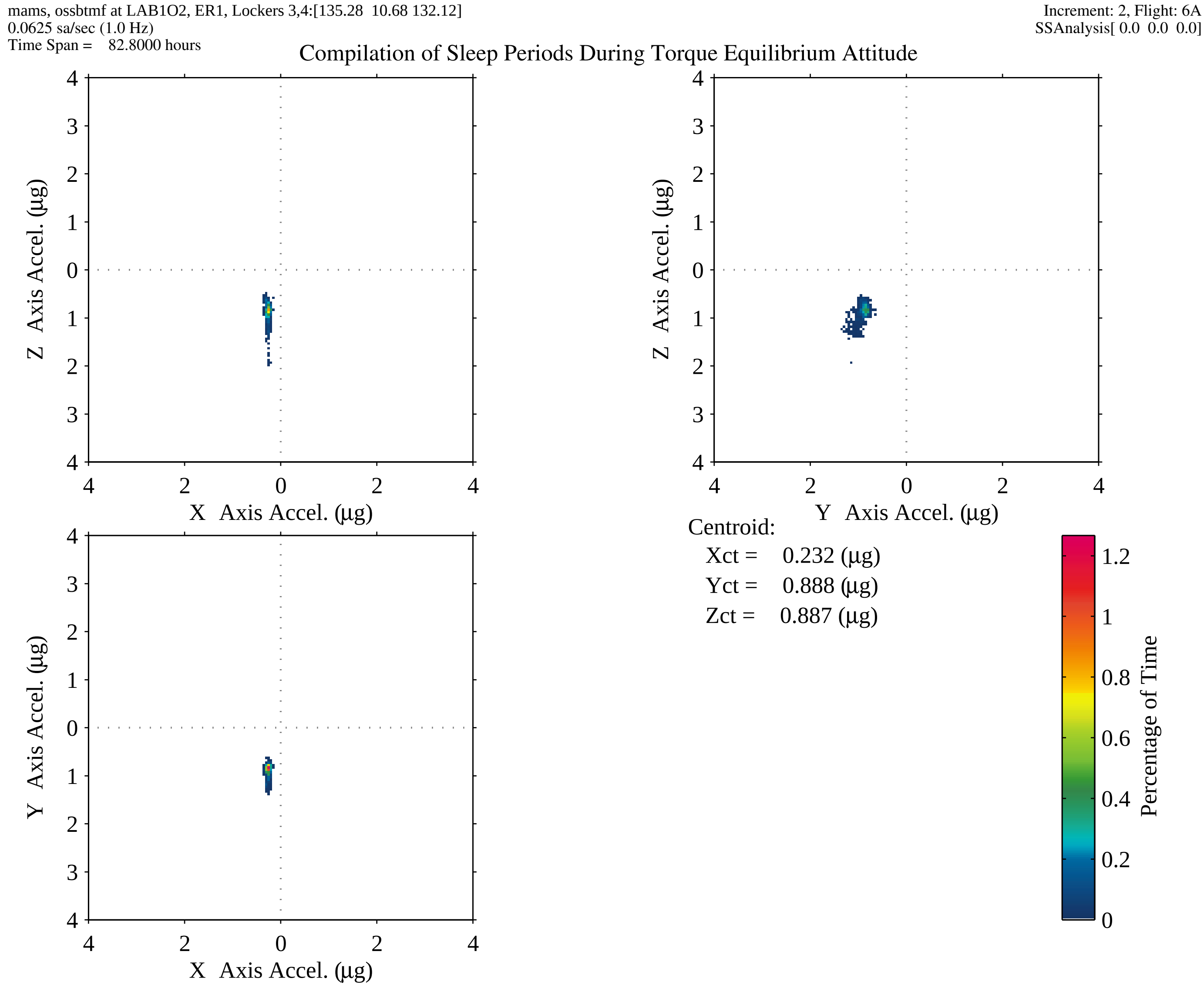

MEIT 2002 Figure 19-9: Compilation of Quasi-steady Vector During TEA for Crew Sleep Periods

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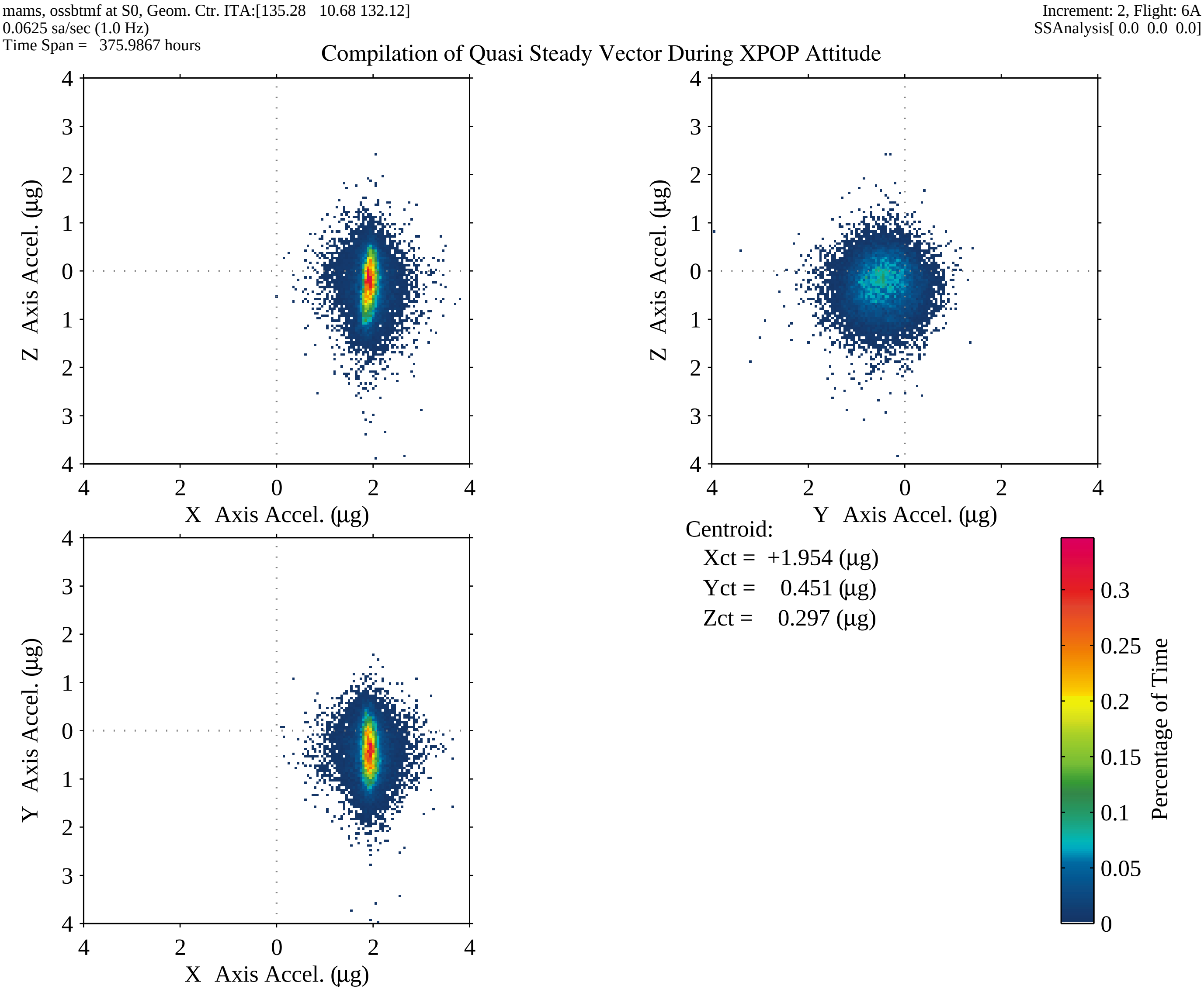

MEIT 2002 Figure 19-10: Summary of Quasi-steady Vector During TEA

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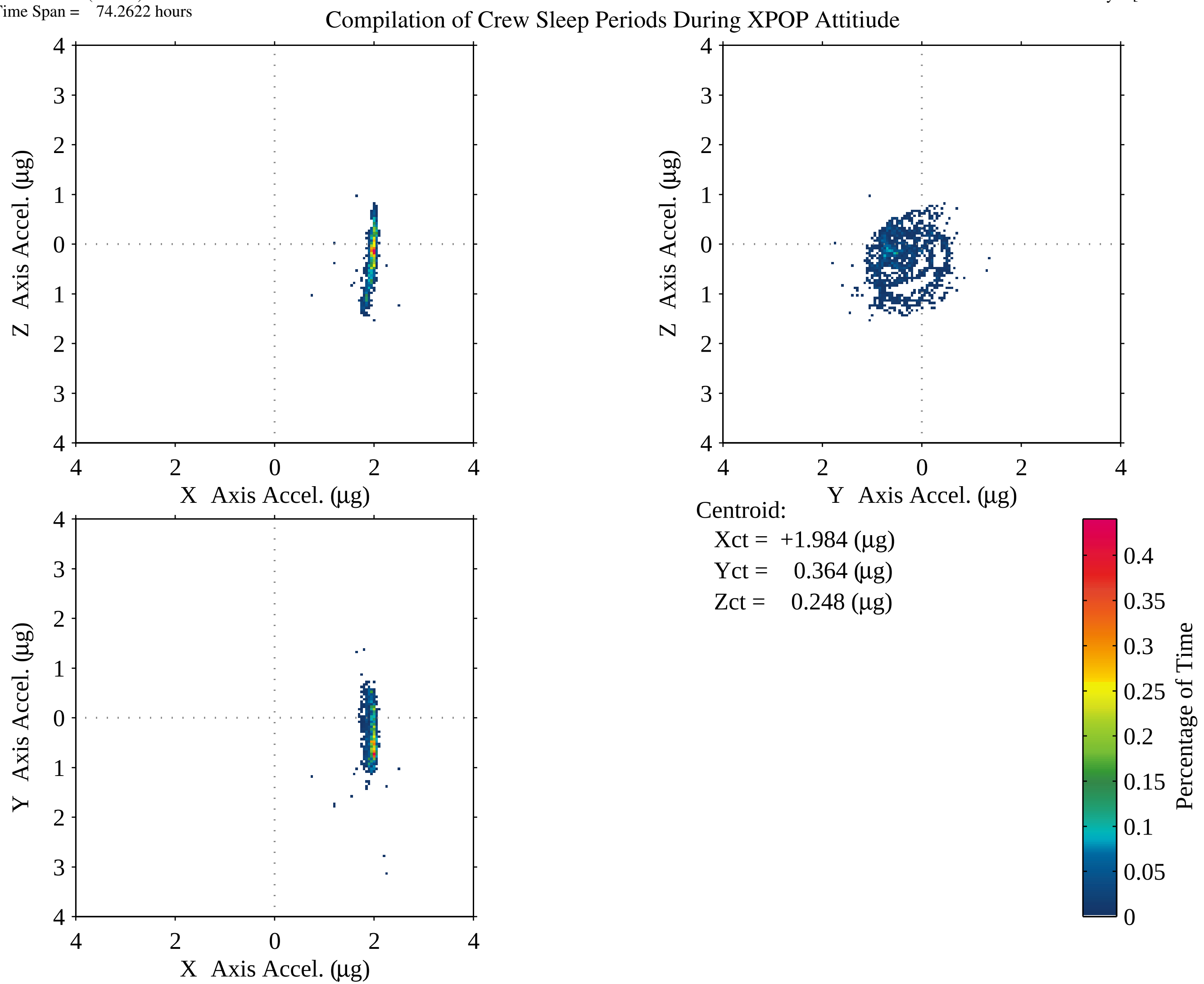
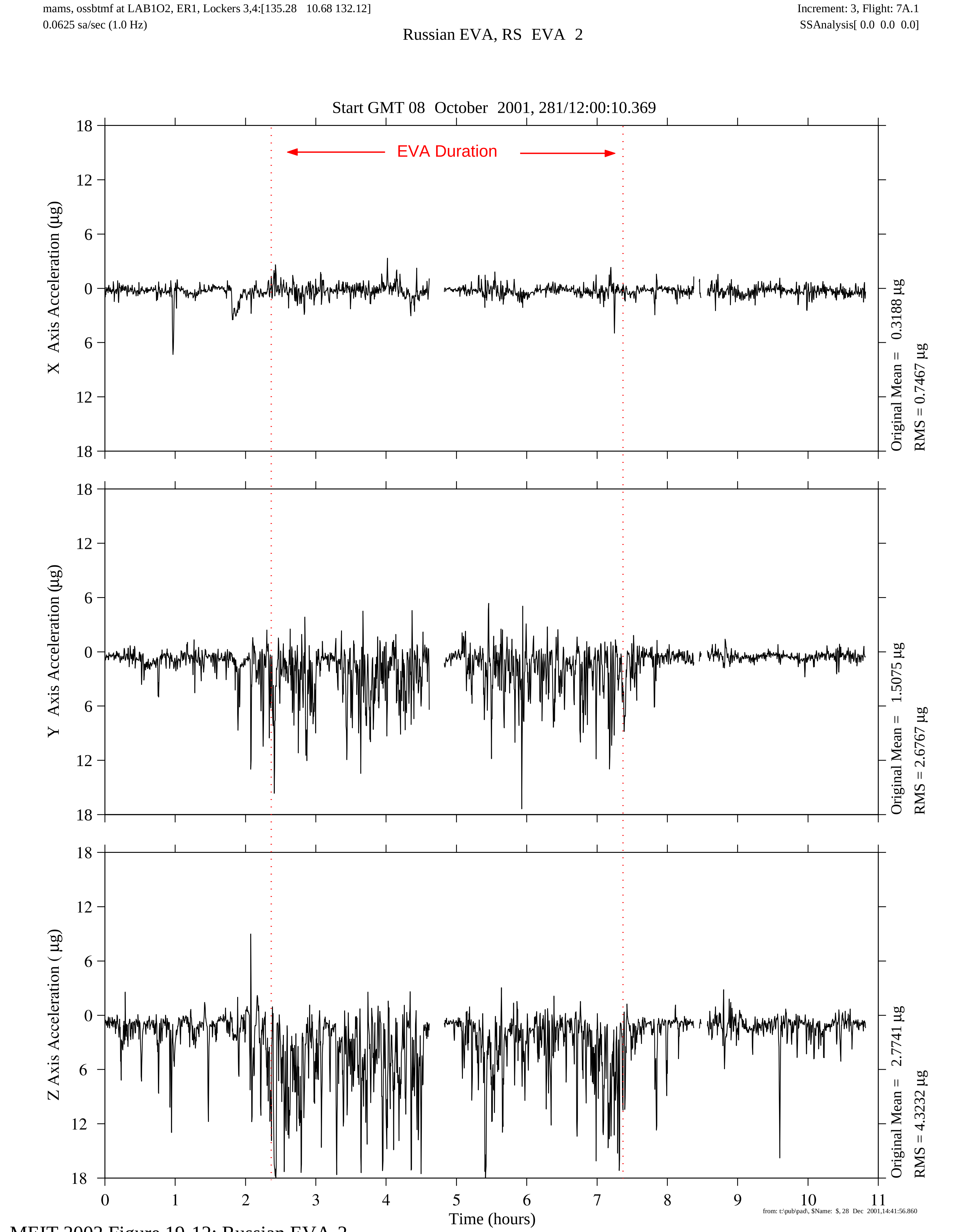
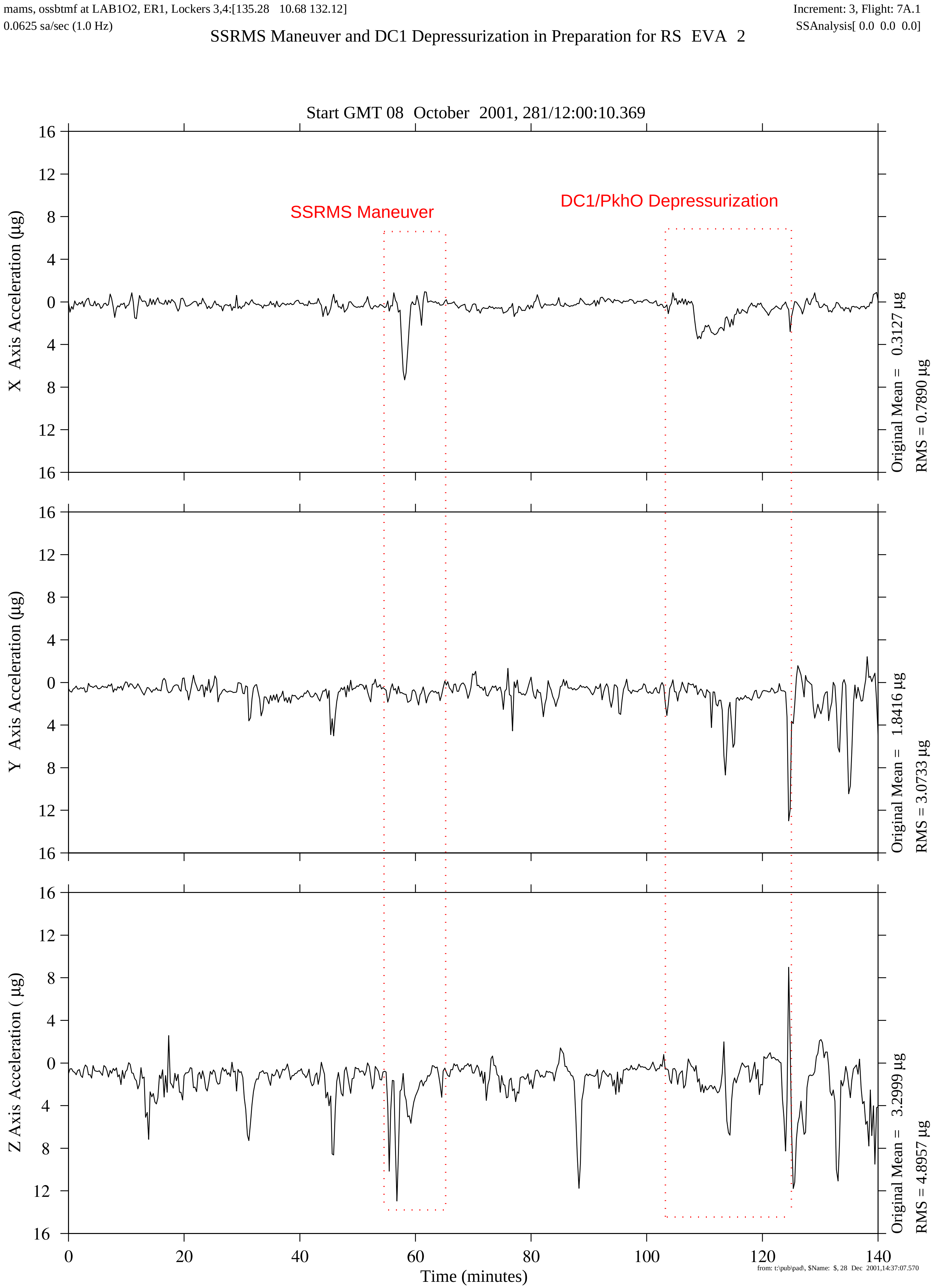


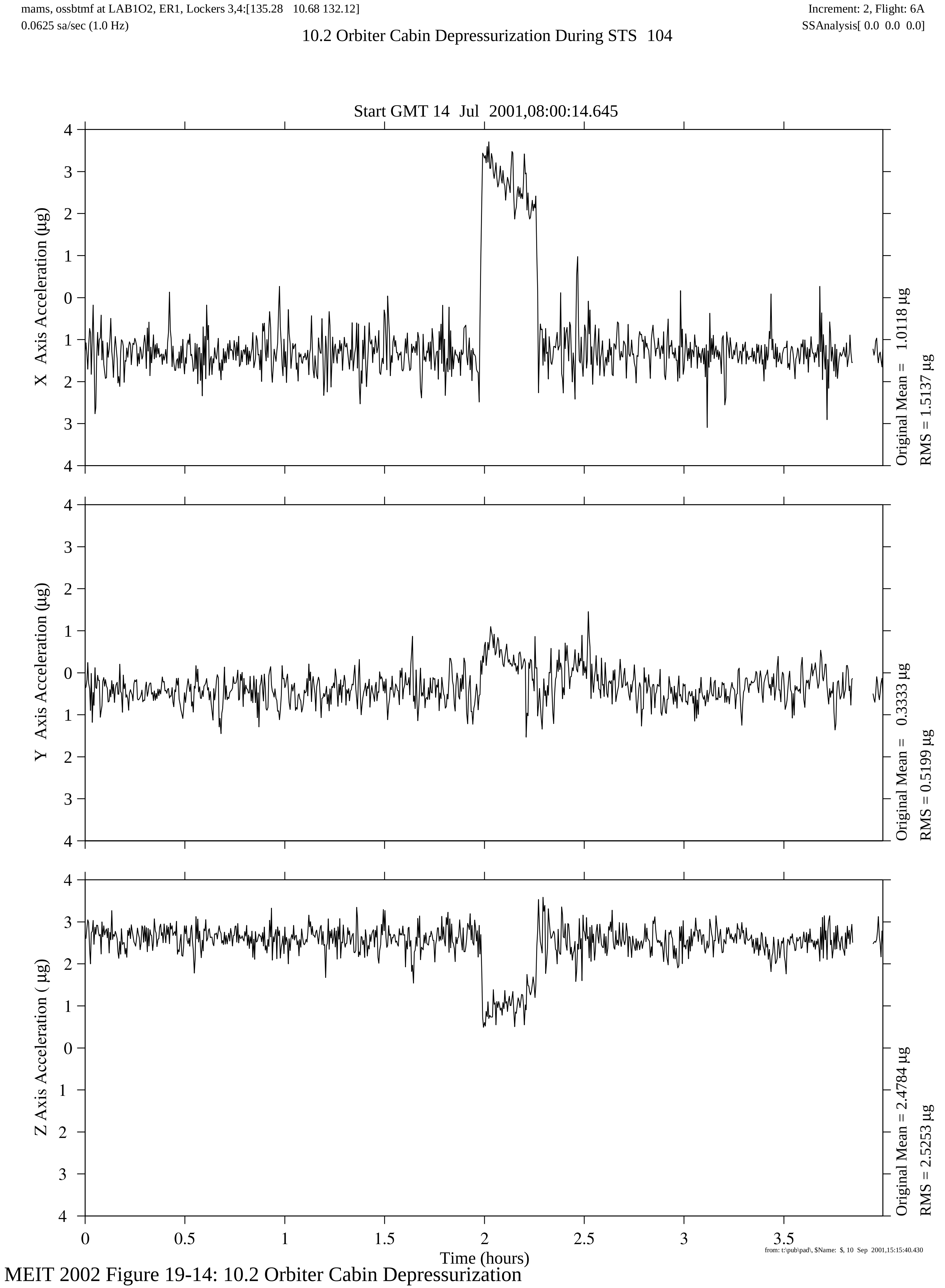
MEIT 2002 Figure 19-11: Compilation of Quasi-steady Vector During XPOP for Crew Sleep Periods



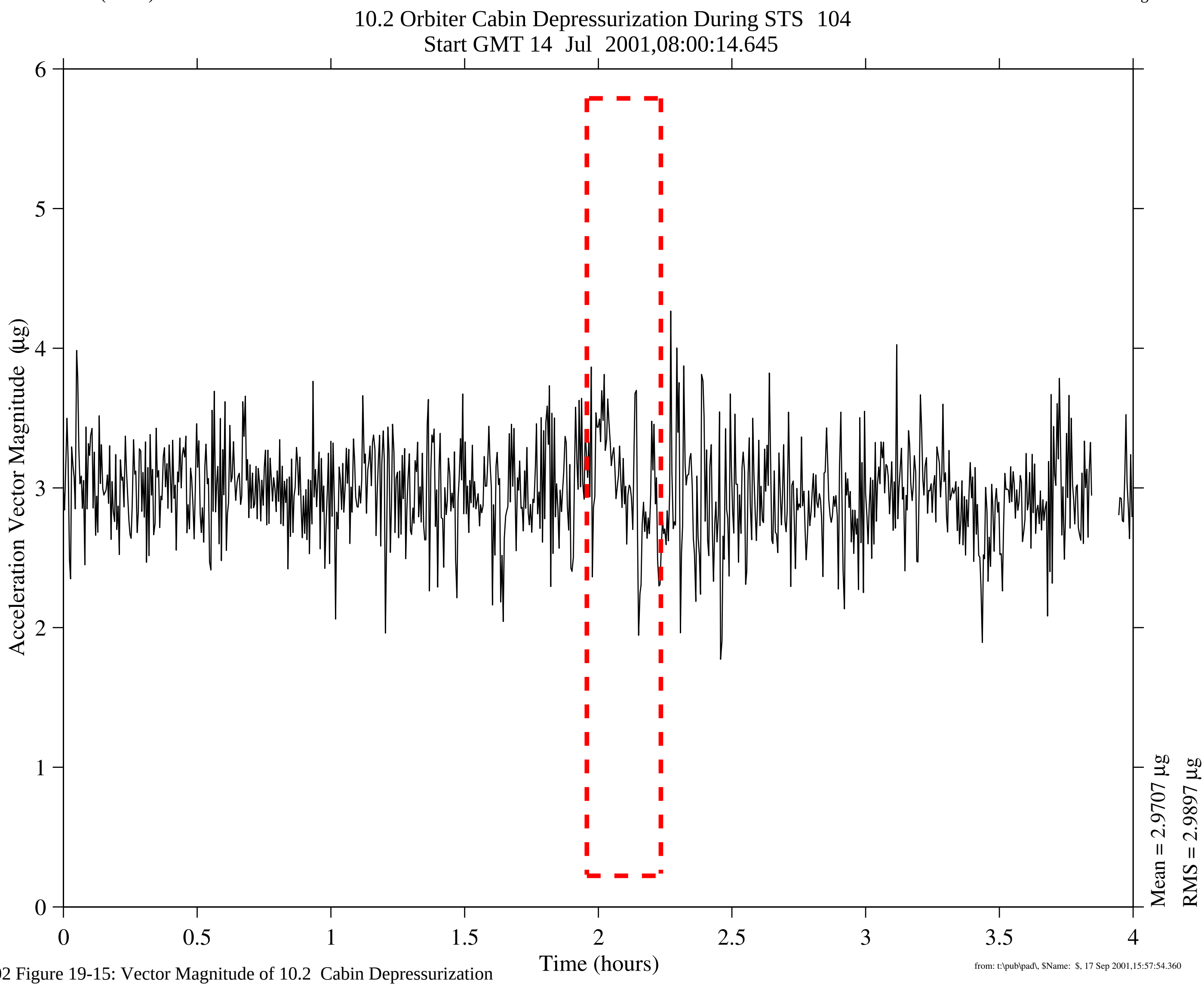
MEIT 2002 Figure 19-12: Russian EVA-2



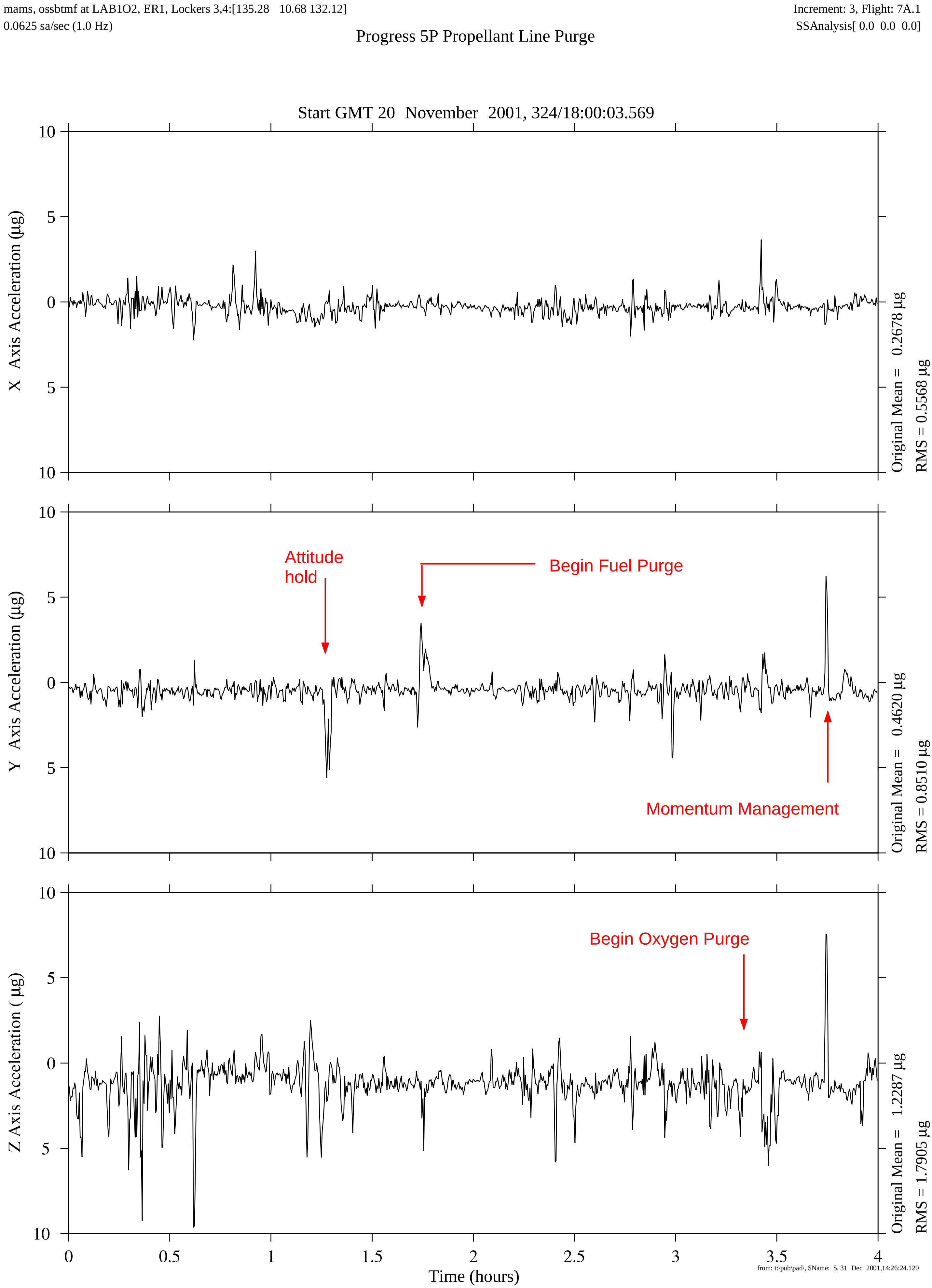
MEIT 2002 Figure 19-13: SSRMBS Maneuver and DC1 Depressurization



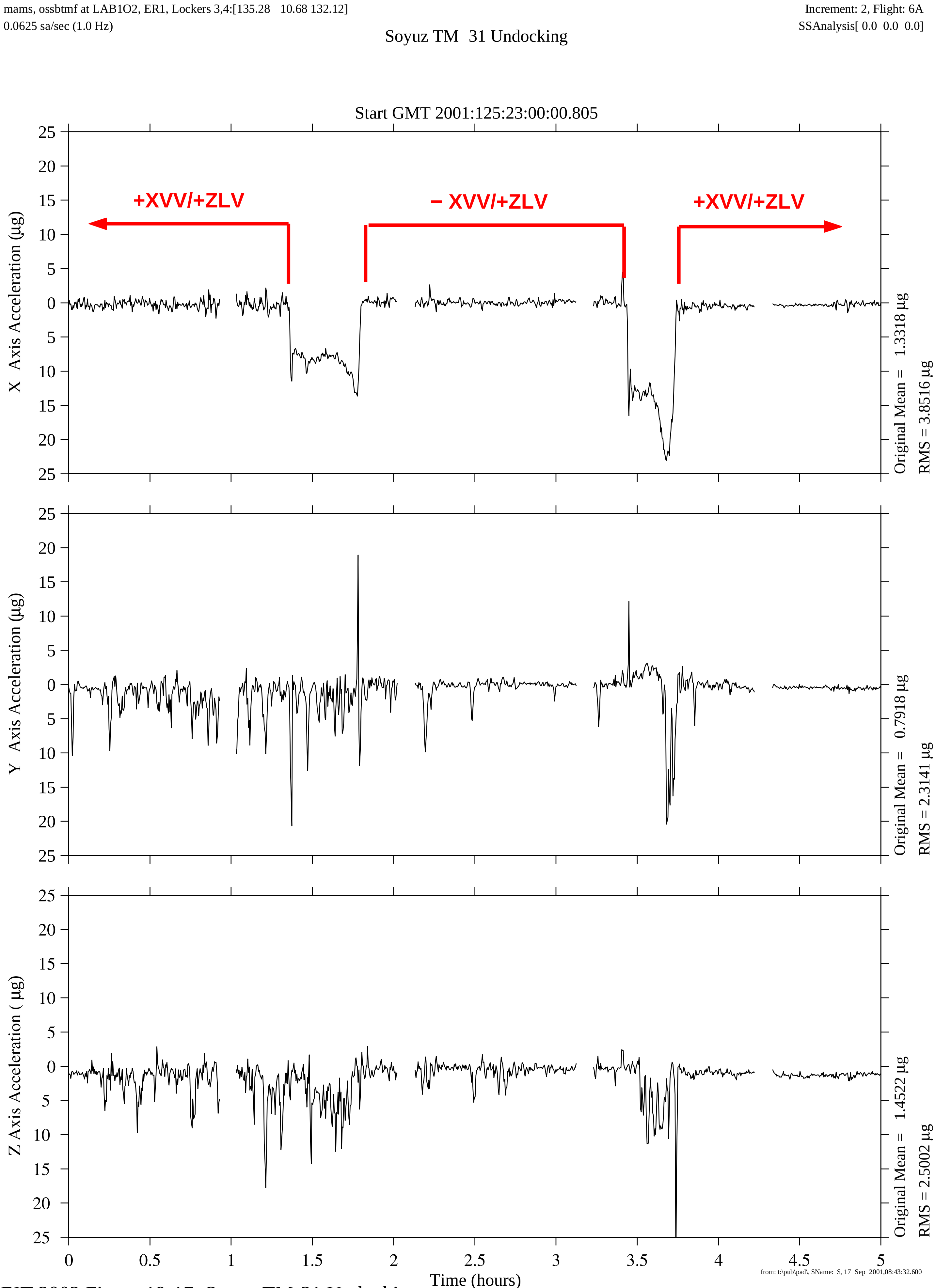
MEIT 2002 Figure 19-14: 10.2 Orbiter Cabin Depressurization



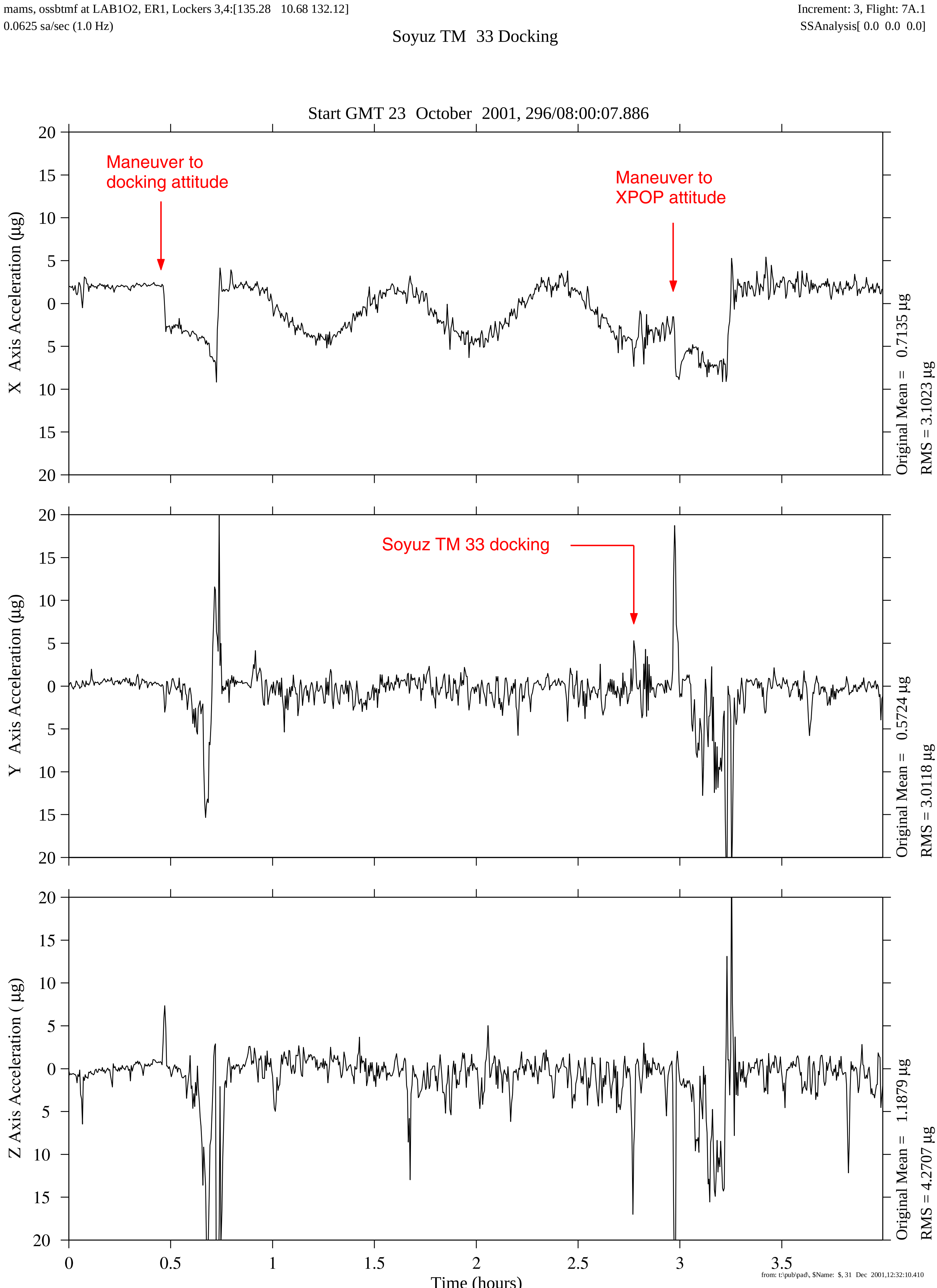
MEIT 2002 Figure 19-15: Vector Magnitude of 10.2 Cabin Depressurization



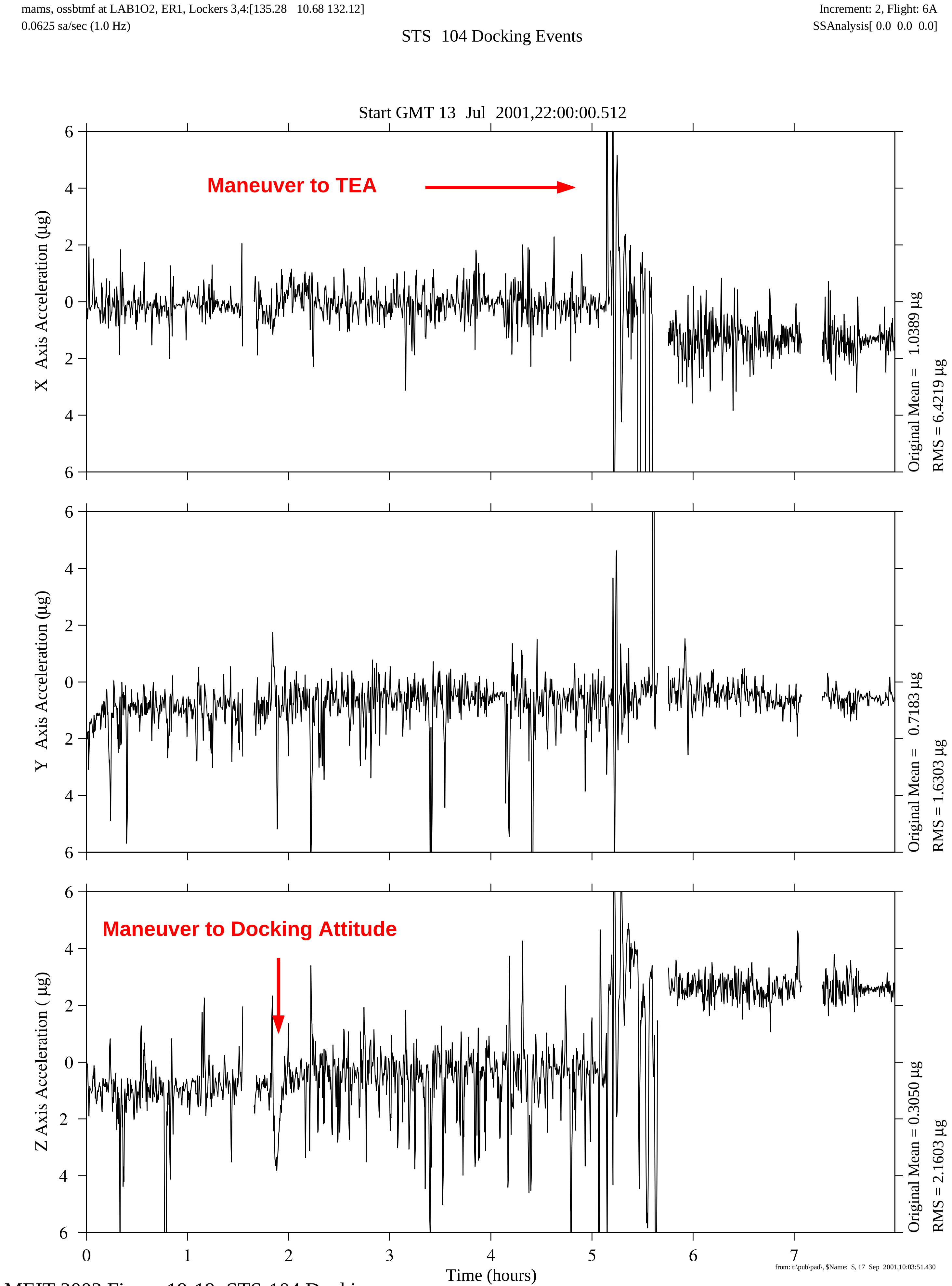
MEIT 2002 Figure 19-16: Progress 5P Prop Purge



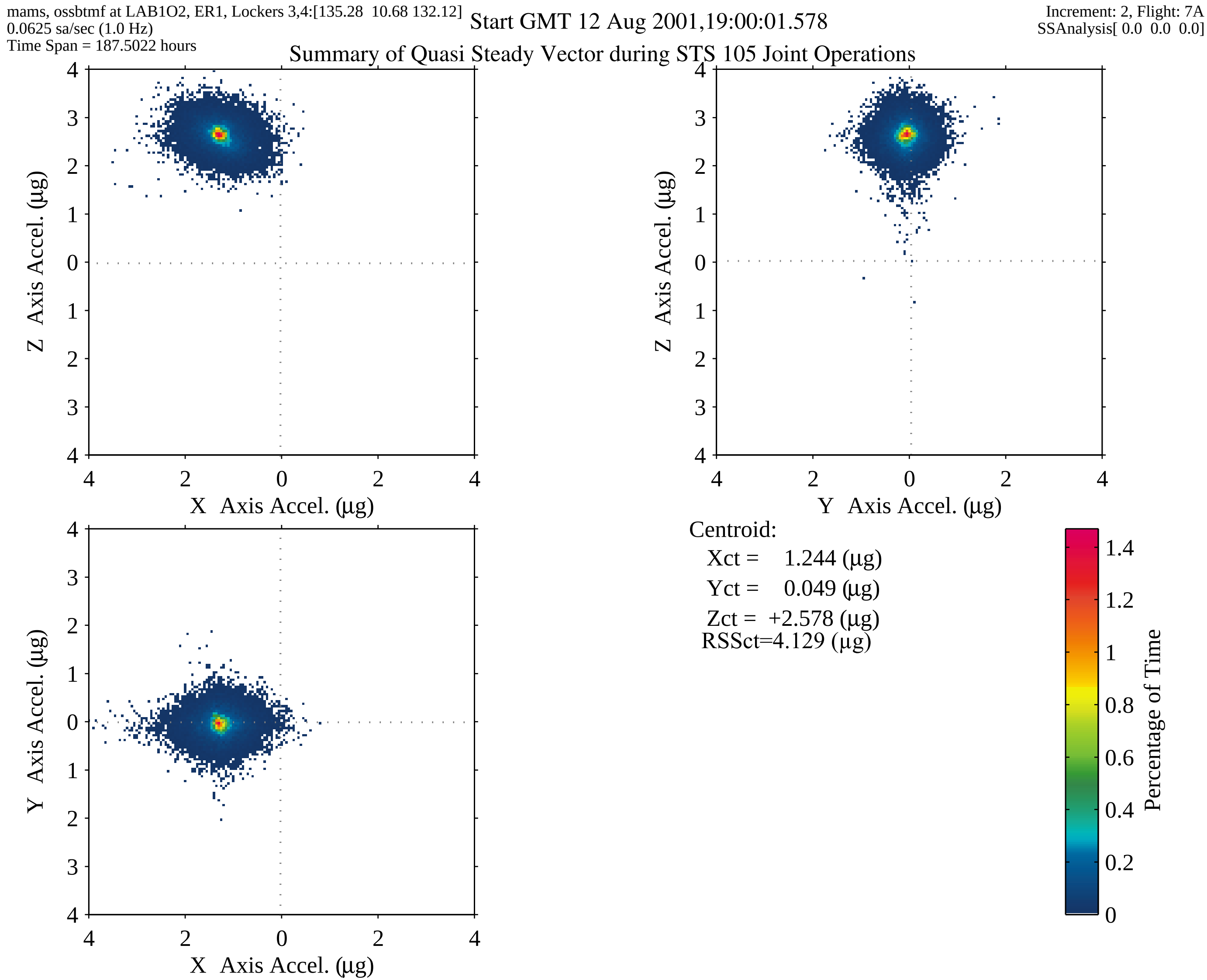
MEIT 2002 Figure 19-17: Soyuz TM-31 Undocking



MEIT 2002 Figure 19-18: Soyuz TM-33 Docking



MEIT 2002 Figure 19-19: STS-104 Docking



MEIT 2002 Figure 19-20: Summary of STS-105 Joint Operations